ON THE DERIVED CATEGORY OF 1-MOTIVES

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Abstract. We embed the derived category of Deligne 1-motives over a perfect field into the étale version of Voevodsky’s triangulated category of geometric motives, after inverting the exponential characteristic. We then show that this full embedding “almost” has a left adjoint LAlb. Applying LAlb to the motive of a variety we get a bounded complex of 1-motives, that we compute fully for smooth varieties and partly for singular varieties. Among applications, we give motivic proofs of Roitman type theorems and new cases of Deligne’s conjectures on 1-motives.

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Introduction

In this book, we compare two categories of motivic nature: the derived category of Deligne’s 1-motives and Voevodsky’s triangulated category of motives, and draw several geometric applications.

Let us recall the players in this story. Inspired by his theory of mixed Hodge structures, Deligne introduced 1-motives in [32] as an algebraic version of “Hodge theory in level $\leq 1$”: they were the first nontrivial examples of mixed motives (as opposed to Grothendieck’s pure motives [69, 36, 61, 85, 1]). They form a category that we shall denote by $\M_1(k)$ or $\M_1$.

A different step towards mixed motives was taken much later by Voevodsky, who defined in [96] a triangulated category of motives $\DM_{gm}$ that is conjectured to have a “motivic” $t$-structure whose heart should be the searched-for abelian category of mixed motives.

Since $\M_1(k)$ is expected to be contained in such a heart, it is natural to try and relate it with $\DM_{gm}(k)$. This can be done rationally. Denote by $\M_1(k) \otimes \Q$ the abelian category of 1-motives up to isogeny over $k$. When $k$ is perfect, Voevodsky asserted in [96, p. 218] (see also [94, Pretheorem 0.0.18]) that there exists a fully faithful functor

\[ \Tot^Q : D^b(\M_1(k) \otimes \Q) \hookrightarrow \DM_{gm}(k) \otimes \Q \]

whose essential image is the thick subcategory generated by motives of smooth curves. This was justified by F. Orgogozo in [78].

Our main result is that the functor $\Tot^Q$ has a left adjoint $\LA Alb^Q$. Much of this can in fact be done integrally, or more accurately $\Z[1/p]$-integrally where $p$ is the exponential characteristic of $k$. First, the embedding $\Tot^Q$ has a $\Z[1/p]$-integral version $\Tot$ provided we replace $\DM_{gm}(k)$ by its étale variant (Theorem 2.1.2). Then $\LA Alb^Q$ has an integral version $\LA Alb : \DM_{gm}(k) \rightarrow D^b(\M_1(k)[1/p])$ (§5.2). It is convenient to denote by $R\Pic$ the composition of $\LA Alb$ with the duality of $D^b(\M_1[1/p])$. These notations want to suggest: derived Albanese, derived Picard functor.

Applying $\LA Alb$ to an object $M \in \DM_{gm}(k)$ and taking 1-motivic homology, we get a series of 1-motives $L_i\Alb(M)$, $i \in \Z$. Taking for example $M = M(X)$ for $X$ a $k$-variety, we get new invariants $L_i\Alb(X)$ of $X$ with values in the category of 1-motives, as well as their duals $R^i\Pic(X)$.

In Theorem 10.2.2, we completely compute the $L_i\Alb(X)$ when $X$ is a smooth variety, justifying the notation. We partly extend this computation to singular schemes in Section 11; in many cases, we recover
for $i = 1$ the homological and cohomological Albanese and Picard 1-motives $\text{Alb}^-(X)$, $\text{Alb}^+(X)$, $\text{Pic}^-(X)$ and $\text{Pic}^+(X)$ constructed in [11] by the first author and Srinivas (Section 13).

This in turn sheds a new light on Roitman’s theorem on torsion in groups of 0-cycles modulo rational equivalence and yields many generalisations of it, as is done in Section 14.

Let us come back to Deligne’s definition of 1-motives. In [32, (10.4.1)], he conjectured that some Hodge-theoretic constructions could be described as realisations of \emph{a priori} constructed 1-motives; he also conjectured a compatibility with $l$-adic and de Rham cohomology. In [10], part of the first conjecture was proven rationally (see also [82]).

What started us on this project was the desire to use the full embedding $\text{Tot}^Q$ of (0.1) to give a natural proof of Deligne’s conjecture. In the spirit of the present work, we tackle this problem by first considering an axiomatically defined realisation functor and first get an abstract result, Theorem 15.5.5, by comparing $L\text{Alb}^Q$ with a corresponding functor on the level of categories of realisations.

To get to Deligne’s conjecture, we use Huber’s mixed realisation [49]. Using its Hodge component, we get the first part of Deligne’s conjecture in Corollary 17.3.2. Using its Hodge and $l$-adic (resp. de Rham) components, we then get the second part of Deligne’s conjecture in Theorem 18.3.1. The latter is new relatively to the existing literature.

Finally, we examine what happens in characteristic $p$, using the $l$-adic realisation functor of Ivorra [51] and Ayoub [5]. Not surprisingly, we get a version of “Deligne’s conjecture”, whose truth depends this time on the Tate conjecture in codimension 1: Theorem 19.7.1.

In the first version of this book, the proof of Proposition 4.4.1 contained a gap, which was kindly pointed out by J. Riou and J. Ayoub. One solution to save this proof was to tensor coefficients with $\mathbb{Q}$ and use Ayoub’s comparison theorem between motives with and without transfers in [4, Ann. B]. Instead, we looked at Ext groups in more detail, which added some length to Section 3 but saved Proposition 4.4.1 integrally. As a byproduct, the internal Hom we had constructed on $D^b(\mathcal{M}_1 \otimes \mathbb{Q})$ is now defined integrally (see §3.14).

\footnote{This description is not quite correct, see Remark 17.3.3. Deligne’s conjecture in [32] concerns three cases $I$, $II_n$ and $II_N$. We prove $I$ and $II_N$ but not $II_n$: to handle the latter, one would presumably have to use the generalised version of $L\text{Alb}$ developed in [7] plus a future Hodge realisation functor on the “big” DM. On the other hand, we get many cases not considered by Deligne where the obvious analogue of his conjecture is true.}
Let us stress that we have to invert the exponential characteristic $p$ of the base field $k$ everywhere. This is due to several reasons:

- Since the category $\text{DM}^{\text{eff}}_{\text{-},\text{ét}}(k)$ is $\mathbb{Z}[1/p]$-linear by [96, Prop. 3.3.3 2]), we cannot expect better comparison results.
- To be in the spirit of Voevodsky, we want to use only the étale topology and not the fppf topology which would be more natural from the viewpoint of 1-motives. Trying to prove anything meaningful without inverting $p$ in this context seems doomed to failure.

The basic reason why $p$ is inverted in $\text{DM}^{\text{eff}}_{\text{-},\text{ét}}(k)$ is homotopy invariance (the Artin-Schreier exact sequence). In parallel, if one wants to deal with non homotopy invariant phenomena, Deligne 1-motives are not sufficient and one should enlarge them to include $\mathbb{G}_a$ factors as in Laumon’s 1-motives (cf. [12], [8]). See [15] and [16] for work in this direction.

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Throughout, $k$ is a perfect field of exponential characteristic $p$. We write $\text{Sm}(k)$ for the category of smooth separated schemes of finite type and $\text{Sch}(k)$ for the category of all separated schemes of finite type. Since we ignore characteristic $p$ phenomena in this paper, we invert $p$ in the Hom groups of all categories constructed out of commutative group schemes and étale sheaves from Subsection 1.4 onwards.
Outline

We now give a detailed overview of the contents of this work.

0.1. The derived category of 1-motives, integrally. While the \( \mathbb{Z}[1/p] \)-linear category \( \mathcal{M}_{1}[1/p] \) is not an abelian category, it fully embeds into the abelian category \( t\mathcal{M}_{1}[1/p] \) of 1-motives with torsion introduced in [10], which makes it an exact category in the sense of Quillen (see §1.5). Its derived category \( D^{b}(\mathcal{M}_{1}[1/p]) \) with respect to this exact structure makes sense, and moreover the functor \( D^{b}(\mathcal{M}_{1}[1/p]) \rightarrow D^{b}(t\mathcal{M}_{1}[1/p]) \) turns out to be an equivalence (Theorem 1.6.1).

0.2. \( p \)-integral equivalence. Let \( DM_{\text{gm,\acute{e}t}}^{\text{eff}} \) be the thick subcategory of \( DM_{\text{\acute{e}t}}^{\text{eff}}(k) \) generated by the image of \( DM_{\text{gm}}^{\text{eff}}(k) \) (see Definition 2.1.1) and \( d_{\leq 1}DM_{\text{gm,\acute{e}t}}^{\text{eff}} \) the thick subcategory of \( DM_{\text{gm,\acute{e}t}}^{\text{eff}} \) generated by motives of smooth curves. In Theorem 2.1.2, we refine the full embedding (0.1) to an equivalence of categories

\[
D^{b}(\mathcal{M}_{1}(k)[1/p]) \overset{\sim}{\longrightarrow} d_{\leq 1}DM_{\text{gm,\acute{e}t}}^{\text{eff}}.
\]

0.3. Duality. Deligne’s extension of Cartier duality to 1-motives [32] provides the category of 1-motives with a natural involution \( M \mapsto M^{*} \) which extends to \( D^{b}(\mathcal{M}_{1}(k)[1/p]) \): see Proposition 1.8.4. This duality exchanges the category \( t\mathcal{M}_{1}[1/p] \) of §0.1 with a new abelian category \( t\mathcal{M}_{1}[1/p] \) of 1-motives with cotorsion (see §1.8). Rationally, the two \( t \)-structures give back the standard one, corresponding to the abelian category \( \mathcal{M}_{1} \otimes \mathbb{Q} \).

We show in Theorem 4.5.3 that, under Tot, Deligne’s Cartier duality is transformed into the involution \( M \mapsto \text{Hom}(M, \mathbb{Z}(1)) \) on \( d_{\leq 1}DM_{\text{gm,\acute{e}t}}^{\text{eff}}(k) \) given by the internal (effective) Hom. Of course, this result involves biextensions.

0.4. Left adjoint. Composing (0.2) with the inclusion into \( DM_{\text{gm,\acute{e}t}}^{\text{eff}}(k) \), we obtain a “universal realisation functor”

\[
\text{Tot} : D^{b}(\mathcal{M}_{1}(k)[1/p]) \rightarrow DM_{\text{gm,\acute{e}t}}^{\text{eff}}(k).
\]

It was conjectured by Voevodsky ([95]; this is also implicit in [94, Preth. 0.0.18]) that, rationally, Tot has a left adjoint. We prove this in Section 6.

It is shown in Remark 5.2.2 that Tot does not have a left adjoint integrally. There is nevertheless an integral statement, which involves an interplay between the étale and the Nisnevich topology.
DM_{gm}^{\text{eff}}(k) \to DM_{gm,et}^{\text{eff}}(k)$ be the change of topology functor. We find a functor

$$L_{\operatorname{Alb}} : DM_{gm}^{\text{eff}}(k) \to D^b(M_1(k)[1/p])$$

together with a (natural) motivic Albanese map

$$(0.3) \quad a_M : \alpha^* M \to \operatorname{Tot} L_{\operatorname{Alb}}(M)$$

for $M \in DM_{gm}^{\text{eff}}(k)$. Thus if $(M, N) \in DM_{gm}^{\text{eff}}(k) \times D^b(M_1[1/p])$, there is a functorial homomorphism

$$(0.4) \quad \operatorname{Hom}(L_{\operatorname{Alb}} M, N) \to \operatorname{Hom}(\alpha^* M, \operatorname{Tot}(N))$$

which is an isomorphism rationally (but not integrally in general, see Remark 5.2.2).

We give the construction of $L_{\operatorname{Alb}}$ and the motivic Albanese map in Sect. 5. This is the central result of the present work.

Experimentally, $L_{\operatorname{Alb}}$ is best adapted to the $t$-structure with heart $tM_1[1/p]$ (see above): thus we define for any $M \in DM_{gm}^{\text{eff}}(k)$ and $i \in \mathbb{Z}$

$$L_i \operatorname{Alb}(M) = t^i H_i(L_{\operatorname{Alb}}(M))$$

the homology relative to this $t$-structure.

0.5. Smooth schemes. In Theorem 10.2.2., we compute $L_{\operatorname{Alb}}(X) := L_{\operatorname{Alb}}(M(X))$ for any smooth scheme $X$: in principle this determines $L_{\operatorname{Alb}}$ on the whole of $DM_{gm}^{\text{eff}}$ since this category is generated by the $M(X)$. It is related with the “Albanese scheme” $\mathcal{A}_X/k$ of [81] (extending the Serre Albanese variety of [88]) in the following way: $L_{\operatorname{Alb}}(X)$ is a “3-extension” of $\mathcal{A}_X/k$ by the Cartier dual of the Néron-Severi group of $X$, that we define as the étale sheaf represented by cycles of codimension 1 on $X$ modulo algebraic equivalence. We deduce that $L_1 \operatorname{Alb}(X)$ is isomorphic to the 1-motive $\operatorname{Alb}^-(X)$ of [11] (corresponding to the Serre Albanese).

0.6. $L_{\operatorname{Alb}}$ and $R_{\operatorname{Pic}}$. Composing $L_{\operatorname{Alb}}$ with duality, we obtain a contravariant functor

$$R_{\operatorname{Pic}} : DM_{gm}^{\text{eff}}(k) \to D^b(M_1(k)[1/p])$$

such that

$$R^i \operatorname{Pic}(M) := t^i H^i(R_{\operatorname{Pic}}(M)) \simeq t^i H_i(L_{\operatorname{Alb}}(M))^*$$

for any $M \in DM_{gm}^{\text{eff}}(k)$. Here, $t^i H^i$ is defined with respect to the $t$-structure with heart $tM_1[1/p]$. We call $R_{\operatorname{Pic}}$ the motivic Picard functor. We define the cohomological Picard complex by $R_{\operatorname{Pic}}(X) := R_{\operatorname{Pic}}(M(X))$. 
0.7. **Singular schemes.** When $k$ is of characteristic 0 (but see beginning of Section 11), the motive and motive with compact support $M(X)$ and $M^c(X)$ are defined for any $k$-scheme of finite type $X$ as objects of $\text{DM}^\text{eff}_{\text{gm}}(k)$, so that $\text{LAlb}(X)$ and the Borel-Moore Albanese complex $\text{LAlb}^c(X) := \text{LAlb}(M^c(X))$ make sense. We further define, for an equidimensional scheme $X$ of dimension $n$, the cohomological Albanese complex $\text{LAlb}^*(X) := \text{LAlb}(M^c(X)^*n)[2n])$. Similarly with $\text{RPic}$. We give general properties of these complexes in Sect. 8.

We then give some qualitative estimates for $L^i_{\text{Alb}}(X)$ in Proposition 11.3.2 (see also Proposition 13.6.1) as well as $L^i_{\text{Alb}}^c(X) := H^i(\text{LAlb}^c(X))$ in Proposition 11.5.2. We prove that $L^1_{\text{Alb}}(X)$ is canonically isomorphic to the 1-motive $\text{Alb}^-(X)$ of [11] if $X$ is normal (Prop. 13.7.2) or proper (Cor. 13.10.2). Here, the interplay between $\text{LAlb}$ and $\text{RPic}$ (duality between Picard and Albanese) plays an essential role.

We also prove in Theorem 13.12.6 that $R^1\text{Pic}^*(X) \simeq \text{Pic}^-(X)$, hence $L^1_{\text{Alb}}^c(X) \simeq \text{Alb}^+(X)$, for any $X$.

It is striking that $L^i_{\text{Alb}}(X), L^i_{\text{Alb}}^c(X)$ and $L^i_{\text{Alb}}^*(X)$ are actually Deligne 1-motives for $i \leq 1$, but not in general for $i \geq 2$ (already for $X$ smooth projective).

0.8. **Curves.** We completely compute $L^i_{\text{Alb}}(X)$ for any curve $X$, showing that $\text{M}(X)$ has a “Chow-K"unneth decomposition” in $\text{DM}^\text{eff}_{\text{gm}, \text{et}}(k) \otimes \mathbb{Q}$ and that the $L^1_{\text{Alb}}(X)$ coincide with Deligne-Lichtenbaum motivic homology of the curve $X$ (see Theorem 12.2.1, cf. [64] and [21]). Finally, we completely compute $L^1_{\text{Alb}}^c(X)$ of a smooth curve $X$ (see Theorem 12.3.1), showing that $L^1_{\text{Alb}}^c(X) = H^1_{\text{et}}(X)(1)$ is Deligne’s motivic $H^1$ in [32]. Dually, we recover Deligne’s 1-motivic $H^1$ of any curve. With a little more effort, one should be able to identify our computations with those of Lichtenbaum in [64] and [65].

0.9. **Roitman’s theorem.** If $X$ is smooth projective, the motivic Albanese map (0.3) applied to $M = \text{M}(X)$ gives back the Albanese map from the 0-th Chow group to the rational points of the Albanese variety. This translates very classical mathematics to a motivic setting. When $X$ is only smooth, we recover a generalised Albanese map from Suslin homology

$$a_X^{\text{sing}} : H^0_{\text{sing}}(X; \mathbb{Z})[1/p] \to \mathcal{A}_{X/k}(k)[1/p]$$

which was first constructed by Ramachandran [80] and Spieß-Szamuely [91]. The map $a_X^{\text{sing}}$ is an isomorphism if $\text{dim}(X) \leq 1$ (see Proposition 14.1.2).

The observation that Suslin homology is related to 1-motives is initially due to Lichtenbaum [64].
We then get a natural proof of the theorem of Roïtman on torsion 0-cycles and its generalisation to open smooth varieties by Spieß-Szymuely [91, Th. 1.1] (removing their hypothesis on the existence of a smooth compactification): see Theorem 14.4.5.

We also deal with singular schemes when \( \text{char } k = 0 \) (but see comment at the beginning of Section 11) in Proposition 14.5.1 and its corollaries. We get a Borel-Moore version of Roïtman’s theorem as well, see Proposition 14.6.1 and its corollary. Finally, we obtain a “cohomological” Roïtman theorem, involving torsion in a motivic cohomology group: see Corollary 14.7.4.

0.10. The homotopy \( t \)-structure and 1-motivic sheaves. We already have two dual \( t \)-structures on \( D^b(\mathcal{M}_1[1/p]) \), see 0.3. The homotopy \( t \)-structure on \( \text{DM}^{\text{eff}}_{\text{-et}} \) and the equivalence of categories (0.2) induce a third \( t \)-structure (Theorem 3.10.1; see also Corollary 3.10.2). Its heart is formed of so-called 1-motivic sheaves: their consideration is central both for the duality theorem 4.5.3 and for the computation of \( \text{LAlb}(X) \) for smooth \( X \) (Th. 10.2.2). This idea was pursued by Ayoub–Barbieri-Viale in [7] and by Bertapelle in [15].

0.11. Internal Hom and tensor structure. In Corollary 3.13.5, we show that the internal Hom of \( \text{DM}^{\text{eff}}_{\text{-et}} \) restricts to an internal Hom on \( D^b(\mathcal{M}_1[1/p]) \) via the equivalence (0.2). This internal Hom \( \text{Hom}_1 \) has cohomological dimension 1 with respect to the homotopy \( t \)-structure and the two dual “motivic” \( t \)-structures; rationally, it is even exact with respect to the latter (Prop. 3.13.3 and Th. 3.14.1). In Proposition 7.1.2, we use \( \text{LAlb} \) to show that, rationally, \( \text{Hom}_1 \) has a left adjoint \( \otimes_1 \). This tensor structure on \( D^b(\mathcal{M}_1 \otimes \mathbb{Q}) \) is exact (for the standard \( t \)-structure), respects the weight filtration and may be computed explicitly.

0.12. A conceptual proof of Deligne’s conjectures. We introduce an axiomatic framework to formulate a version of Deligne’s conjectures [32, (10.4.1)] for any suitable realisation functor. This involves an abstract notion of weight filtration, which is given in Appendix E.

Assume given a triangulated category \( \mathcal{T} \) provided with a \( t \)-structure, with heart \( \mathcal{B} \) with a weight filtration \( \mathcal{B}_{\leq n} \) (see E.7.2 for the definition) and a \( t \)-exact functor \( D^b(\mathcal{B}) \to \mathcal{T} \) which is the identity on \( \mathcal{B} \). Considering “Lefschetz” objects in \( \mathcal{B} \), we define a full subcategory of level \( \leq 1 \) objects \( \mathcal{B}_{(1)} \subset \mathcal{B} \) along with a left adjoint \( \text{Alb}^\mathcal{B} \). Define \( \mathcal{T}_{(1)} \subset \mathcal{T} \) by objects with \( H^* \) in \( \mathcal{B}_{(1)} \); assuming that the \( t \)-structure is bounded, we get a left adjoint \( \text{LAlb}^\mathcal{T} \) (see 15.3.4).
Suppose now given a triangulated “realisation” functor $R : \text{DM}^{\text{eff}}_{\text{gm}} \otimes \mathbb{Q} \to \mathcal{T}$ which behaves as a usual homology theory in degrees $\leq 1$, as explained in Hypotheses 15.4.1 and 15.5.2. Let $R_1 = R^{\text{Tot}}$. We then get a “base change” natural transformation
\[(0.5) \quad L\text{Alb}^T R \Rightarrow R_1 L\text{Alb}^Q\]
and, for all $M \in \text{DM}^{\text{eff}}_{\text{gm}}(k) \otimes \mathbb{Q}$ and $i \in \mathbb{Z}$, a map
\[(0.6) \quad \text{Alb}^B H^R_i(M) \to R_1 L_i \text{Alb}^Q(M)\]
where $H^R_i(M) := H_i(R(M))$. Theorem 15.5.5 now gives an abstract version of Deligne’s conjectures: (0.5) and (0.6) are isomorphisms if, in addition, the “homological” equivalence induced by $R$ coincides with algebraic equivalence in codimension 1 and the corresponding geometric cycle class map satisfies a Lefschetz (1,1)-type theorem (or Tate conjecture in codimension 1) for smooth projective varieties. If (0.6) is an isomorphism for $M = M(X)$, $X$ smooth projective, then it is an isomorphism for any $M$ and (0.5) is an isomorphism of functors.

0.13. Hodge structures. For $X$ smooth over $\mathbb{C}$, 10.6.1 shows that the 1-motive $R^i \text{Pic}(X)$ has a Hodge realisation abstractly isomorphic to $H^i(X_{\text{an}}, \mathbb{Z}) \leq 1$, the largest 1-motivic part of the mixed Hodge structure on $H^i(X_{\text{an}}, \mathbb{Z})$ Tate-twisted by 1. The above abstract framework provides such an isomorphism in a functorial way.

Namely, if $\mathcal{B} = \text{MHS}$ is the category of (graded polarizable, $\mathbb{Q}$-linear) Deligne’s mixed Hodge structures and $\mathcal{T} = D^b(\text{MHS})$, the weight filtration provides $\mathcal{B}$ with a weight structure. Then $\mathcal{B}_{(1)} = \text{MHS}_{(1)}$ is the full subcategory of $\text{MHS}^{\text{eff}}$ given by level $\leq 1$ mixed Hodge structures. By Theorem 17.2.1, Huber’s Hodge realisation [49] restricts to an equivalence on 1-motives. The conditions of Theorem 15.5.5 are satisfied thanks to the Lefschetz (1,1)-theorem. In the isomorphism (0.6) for $M = M(X)$, $X$ a complex variety, the mixed Hodge structure $\text{Alb}^B H^R_i(X) = H_i(X, \mathbb{Q})_{\leq 1}$ is the largest quotient of level $\leq 1$ so that (0.6) yields Deligne’s conjecture on a “purely algebraic” definition of this mixed Hodge structure. Similarly, $L_i \text{Alb}^*(X)$ has Hodge realisation $\text{Alb}^B H_i(R(M(X)^*(n)[2n])) = H^{2n-i}(X, \mathbb{Q}(n))_{\leq 1}$: this provides new cases where Deligne’s conjecture holds true (up to isogeny) not included in [11], [10] or [82]. All this is Theorem 17.3.1 and its Corollary 17.3.2, see also Remark 17.3.3.

0.14. Mixed realisations. Huber’s Hodge realisation functor is only one component of her much richer mixed realisation functor [47, 49]. In Sect. 18, we show that it fits with our axiomatic approach: this yields
a reasonable interpretation of the second part of Deligne’s conjecture on comparison isomorphisms, see Corollaries 18.3.2 and 18.3.3.

0.15. **ℓ-adic.** Here we use Ayoub’s ℓ-adic realisation functor [5], which agrees with Deligne’s realisation functor from [32, (10.1.5)]. This provides, in characteristic \( p \), an ℓ-adic version of Deligne’s conjectures, which depends on the Tate conjecture in codimension 1 (Theorem 19.7.1).

0.16. **Going further.** One could explore situations like the one around the \( p \)-adic period isomorphism. We leave these developments to the motivated reader. See also [100] and [25] for further developments concerning weights.

0.17. **Caveat.** While one might hope that these results are a partial template for a future theory of mixed motives (see e.g. [3]), we should stress that some of them are definitely special to level \( \leq 1 \). Namely:

- It is succinctly pointed out in [96, §3.4 p. 215] (see [7, §2.5] for a proof) that the non finite generation of the Griffiths group prevents higher-dimensional analogues of \( \text{LAlb} \) to exist. (This goes against [94, Conj. 0.0.19].)
- Contrary to Theorem 3.10.1, the homotopy \( t \)-structure does not induce a \( t \)-structure on \( d_{\leq n} \text{DM}_{\text{gm,ét}}^{\text{eff}} \), for \( n \geq 2 \). This can already be seen on \( \mathbb{Z}(2) \), although here the homotopy sheaves are conjecturally ind-objects of \( d_{\leq 2} \text{DM}_{\text{gm,ét}}^{\text{eff}} \) (see [94, §6]).

These two issues seem related in a mysterious way! However, see [7] for a possible approach to \( n \)-motivic sheaves and a conjectural picture linking the subject to the Bloch-Beilinson motivic filtration.

**A small reading guide.** We offer some suggestions to the reader, hoping that they will be helpful.

One might start by quickly brushing through §1.1 to review the definition of Deligne’s 1-motives, look up §1.5 to read the definition of \( D^b(\mathcal{M}_1[1/p]) \) and then proceed directly to Theorem 2.1.2 (full embedding), referring to Section 1 ad libitum to read the proof of this theorem. The lengths of Sections 3 and 4 are necessary evils; they may be skipped at first reading with a look at their main results (Theorem 3.10.1: the homotopy \( t \)-structure, Corollary 3.13.5 and Theorem 3.14.1: internal Hom, and Theorem 4.5.3: agreement of the two Cartier dualities).

One may then read Section 5 on the construction of \( \text{LAlb} \) and \( \text{RPic} \) (which hopefully will be pleasant enough), glance through Section 6 (their rational versions) and have a look in passing at Section 7 for...
the tensor structure on $D^b(\mathcal{M}_1 \otimes \mathbb{Q})$. After this, the reader might fly over the mostly formal sections 8 and 9, jump to Theorem 10.2.2 which computes $\text{LAlb}(X)$ for a smooth scheme $X$, read Sections 11 and 13 on $\text{LAlb}$ of singular schemes where he or she will have a few surprises, read Section 14 on Roitman’s theorem and its generalisations, have a well-earned rest in recovering familiar objects in Section 12 (the case of curves). Then jump to Corollary 17.3.2 which gives the Hodge realisations of $\text{RPic}(X)$ and $\text{LAlb}^*(X)$ for $X$ a complex algebraic variety, look at the main results in Sect. 18 and consult Sect. 19. After which, one can backtrack to Sect. 15 and 16 to see the technical details.

And never look at the appendices.

The reader will also find an index of notations at the end.
Part 1. The universal realisation functor

1. The derived category of 1-motives

The main reference for (integral, free) 1-motives is [32, §10], see also [11, §1]. We also provide an Appendix C on 1-motives with torsion which were introduced in [10, §1]. For the derived category of 1-motives up to isogeny we refer to [96, Sect. 3.4] and [78]: here we are interested in the integral version.

1.1. Deligne 1-motives. The following terminology is handy:

1.1.1. Definition. a) An abelian sheaf $L$ on $(\text{Sm}(k))_{\text{ét}}$ is discrete if it is locally constant $\mathbb{Z}$-constructible (i.e. with finitely generated geometric fibres). The full subcategory of discrete abelian sheaves on $(\text{Sm}(k))_{\text{ét}}$ is denoted by $t\text{M}_0(k) = t\text{M}_0$.

b) A lattice is a $k$-group scheme locally constant for the étale topology, with geometric fibre(s) isomorphic to a finitely generated free abelian group, i.e. representing a torsion-free discrete sheaf. The full subcategory of lattices is denoted by $\text{M}_0(k) = \text{M}_0$.

A Deligne 1-motive over $k$ is a complex of group schemes

$$M = [L \rightarrow G]$$

where $L$ is a lattice and $G$ is a semi-abelian $k$-scheme. Thus $G$ can be represented by an extension

$$0 \rightarrow T \rightarrow G \rightarrow A \rightarrow 0$$

where $T$ is a $k$-torus and $A$ is an abelian $k$-scheme.

As a complex, we shall place $L$ in degree 0 and $G$ in degree 1. Note that this convention is only partially shared by the existing literature.

A map from $M = [L \rightarrow G]$ to $M' = [L' \rightarrow G']$ is a commutative square

$$\begin{array}{ccc}
L & \rightarrow & G \\
\downarrow f & & \downarrow g \\
L' & \rightarrow & G'
\end{array}$$

in the category of group schemes. Denote by $(f, g) : M \rightarrow M'$ such a map. The natural composition of squares makes up the category of Deligne’s 1-motives. We shall denote this category by $\text{M}_1(k)$. We shall usually write $\text{M}_1$ instead of $\text{M}_1(k)$, unless it is necessary to specify $k$.

The following lemma is immediate:

1.1.2. Lemma. $\text{M}_1$ is an idempotent complete additive category. \hfill $\square$
1.1.3. **Definition.** Let $R$ be a commutative ring. For any additive category $\mathcal{A}$, we denote by $\mathcal{A} \otimes R$ the $R$-linear category obtained from $\mathcal{A}$ by tensoring morphisms by $R$, and by $\mathcal{A} \boxtimes R$ the pseudo-abelian hull (idempotent completion) of $\mathcal{A} \otimes R$.

This distinction is useful as $\mathcal{A} \otimes R$ may not be idempotent complete even if $\mathcal{A}$ is.

We shall also use the following category, which is technically very useful:

1.1.4. **Definition.** Let $\mathcal{M}_{\text{anc}}^{\text{eff}}$ denote the category given by complexes of group schemes $[L \to G]$ where $L$ is discrete and $G$ is a commutative algebraic group whose connected component of the identity $G^0$ is semi-abelian. It contains $\mathcal{M}_1$ as a full subcategory.

This category is studied in more detail in §C.8.

1.1.5. **Proposition** (cf. [78, 3.2.2]). The inclusion $\mathcal{M}_1 \to \mathcal{M}_{\text{anc}}^{\text{eff}}$ induces an equivalence of categories

$$e : \mathcal{M}_1 \otimes \mathbb{Q} \xrightarrow{\sim} \mathcal{M}_{\text{anc}}^{\text{eff}} \otimes \mathbb{Q}. $$

In particular, the category $\mathcal{M}_1 \otimes \mathbb{Q}$ is abelian, hence $\mathcal{M}_1 \otimes \mathbb{Q} = \mathcal{M}_1 \boxtimes \mathbb{Q}$.

**Proof.** (See also Lemma B.1.3.) It is enough to show that $e$ is essentially surjective. But if $[L \to G] \in \mathcal{M}_{\text{anc}}^{\text{eff}}$, then we have a diagram

$$
\begin{array}{c}
[L^0 \to G^0] \\
\downarrow \\
[L \xrightarrow{u} G]
\end{array}
\quad \xrightarrow{\sim}
\quad
\begin{array}{c}
[L^0_{\text{fr}} \to G^0 / u(L^0_{\text{tor}})]
\end{array}
$$

where the vertical (resp. horizontal) map is a pull-back (resp. a push-out) and $L^0_{\text{fr}} := L^0 / L^0_{\text{tor}}$ where $L^0_{\text{tor}}$ is the torsion subgroup of $L^0$. Both maps are isomorphisms in $\mathcal{M}_{\text{anc}}^{\text{eff}} \otimes \mathbb{Q}$. The last assertion follows from the fact that $\mathcal{M}_{\text{anc}}^{\text{eff}} \otimes \mathbb{Q}$ is abelian (Proposition C.8.4).

1.1.6. **Remarks.** 1 (see also Def. B.1.1 c)). An *isogeny* between Deligne’s $1$-motives, from $M = [L \xrightarrow{u} G]$ to $M' = [L' \xrightarrow{u'} G']$ in $\mathcal{M}_1(k)$,
is a diagram of group schemes with exact columns

\[
\begin{array}{ccccccc}
0 & \downarrow & & & & & \downarrow \\
0 & \downarrow & F & \downarrow & \downarrow & \downarrow & \\
L & \downarrow & u & \downarrow & \downarrow & \downarrow & G \\
f & \downarrow & g & \downarrow & \downarrow & \downarrow & \\
L' & \downarrow & u' & \downarrow & \downarrow & \downarrow & G' \\
\downarrow & & & & \downarrow & \downarrow & \\
E & 0 & \downarrow & \downarrow & \downarrow & \downarrow & \\
\downarrow & & & & & & \\
0 & & & & & & \\
\end{array}
\]

where \( F \) and \( E \) are finite. Isogenies become invertible in \( \mathcal{M}_1 \otimes \mathbb{Q} \).

2. The category \( \mathcal{M}_1 \) of Deligne’s 1-motives has kernels and cokernels (see Proposition C.1.3) but it is not abelian. This easily follows from the diagram hereabove: an isogeny has vanishing kernel and cokernel but it is not an isomorphism in \( \mathcal{M}_1 \).

1.2. Weights and cohomological dimension. Recall that \( M = [L \to G] \in \mathcal{M}_1 \) has an increasing filtration by sub-1-motives as follows:

\[
W_i(M) = \begin{cases} 
M & i \geq 0 \\
G & i = -1 \\
T & i = -2 \\
0 & i \leq -3 
\end{cases}
\]

We then have \( \text{gr}_{-2}^W(M) = T[-1], \text{gr}_{-1}^W(M) = A[-1] \) and \( \text{gr}_0^W(M) = L \) (according to our convention of placing \( L \) in degree zero). We say that \( M \) is pure of weight \( i \) if \( \text{gr}_j^W M = 0 \) for all \( j \neq i \). Note that for two pure 1-motives \( M, M' \), \( \text{Hom}(M, M') \neq 0 \) only if they have the same weight.

1.2.1. Proposition ([78, 3.2.4]). The category \( \mathcal{M}_1 \otimes \mathbb{Q} \) is of cohomological dimension \( \leq 1 \), i.e. if \( \text{Ext}^i(M, M') \neq 0 \), for \( M, M' \in \mathcal{M}_1 \otimes \mathbb{Q} \), then \( i = 0 \) or 1.

Recall a sketch of the proof in [78]. (For a generalisation and a different proof, see Proposition C.12.3.) One first checks that \( \text{Ext}^1(M, M') \)
= 0 if \( M, M' \) are pure of weights \( i, i' \) and \( i \leq i' \). This formally reduces the issue to checking that if \( M, M', M'' \) are pure respectively of weights \( 0, -1, -2 \), then the Yoneda product of two classes \( (e_1, e_2) \in \text{Ext}^1(M, M') \times \text{Ext}^1(M', M'') \) is 0. Of course we may assume \( e_1 \) and \( e_2 \) integral. By a transfer argument, one may further reduce to algebraically closed. Then the point is that \( e_1 \) and \( e_2 \) "glue" into a 1-motive, so are induced by a 3 step filtration on a complex of length 1; after that, it is formal to deduce that \( e_2 \cdot e_1 = 0 \) (cf. [SGA7, IX, Prop. 9.3.8 c]).

1.2.2. Remark. We observe that Proposition 1.2.1 can be regarded as an algebraic version of a well-known property of \( \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q} \). Namely, \( \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q} \) can be realised as a thick abelian sub-category of \( \mathbb{Q} \)-mixed Hodge structures, see [32]. Since the latter is of cohomological dimension \( \leq 1 \), so is \( \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q} \) (use [67, Ch. III, Th. 9.1]).

1.3. Group schemes and sheaves with transfers.

1.3.1. Definition (cf. Def. D.1.2). We denote by \( \text{HI}_{\text{ét}} = \text{HI}_{\text{ét}}(k) \) the category of homotopy invariant étale sheaves with transfers over \( \text{Sm}(k) \): this is the full subcategory of the category \( \text{EST}(k) = \text{Shv}_{\text{ét}}(\text{SmCor}(k)) \) from [96, §3.3] consisting of those étale sheaves with transfers that are homotopy invariant.

Let \( G \) be a commutative \( k \)-group scheme. We shall denote by \( \overline{G} \) the associated étale sheaf of abelian groups. In fact, under a minor assumption, \( \overline{G} \) is an étale sheaf with transfers, as explained by Spieß-Szamuely [91, Proof of Lemma 3.2], cf. also Orgogozo [78, 3.1.2]. Both references use symmetric powers, hence deal only with smooth quasi-projective varieties. Here is a cheap way to extend their construction to arbitrary smooth varieties: this avoids to have to prove that \( \text{DM}_{\text{eff}}^{\text{gm}}(k) \) may be presented in terms of smooth quasi-projective varieties, cf. [78, beg. of §1].

1.3.2. Lemma. Suppose that the neutral component \( G^0 \) is quasi-projective. Then the étale sheaf \( \overline{G} \) is provided with a canonical structure of presheaf with transfers. Moreover, if \( G^0 \) is a semi-abelian variety, then \( \overline{G} \) is homotopy invariant.

Proof. For two smooth \( k \)-varieties \( X, Y \), we have to provide a pairing

\[
c(X, Y) \otimes \overline{G}(X) \to \overline{G}(Y)
\]

with the obvious compatibilities. As in [70, Ex. 2.4], it is enough to construct a good transfer \( f_* : \overline{G}(W) \to \overline{G}(X) \) for any finite surjective
map \( f : W \to X \) with \( X \) a normal \( k \)-variety. For \( X \) and \( W \) quasi-projective, this is done in [91] or [78]4. In general, cover \( X \) by affine opens \( U_i \) and let \( V_i = f^{-1}(U_i) \). Since \( f \) is finite, \( V_i \) is also affine, hence transfers \( G(V_i) \to G(U_i) \) and \( G(V_i \cap V_j) \to G(V_i \cap V_j) \) are defined; the commutative diagram

\[
\begin{array}{cccc}
0 & \to & G(W) & \longrightarrow & \prod G(V_i) \longrightarrow & \prod G(V_i \cap V_j) \\
& & f_* \downarrow & & f_* \downarrow & \\
0 & \to & G(X) & \longrightarrow & \prod G(U_i) \longrightarrow & \prod G(U_i \cap U_j)
\end{array}
\]

uniquely defines the desired \( f_* \).

The second statement of the lemma is well-known (e.g. [78, 3.3.1]).

\[ \square \]

Actually, the proof of [91, Lemma 3.2] defines a homomorphism in \( \text{HI}_{\text{ét}} \)

\[ \sigma : L(G) \to G \]

which is split by the obvious morphism of sheaves

\[ \gamma : G \to L(G) \]

given by the graph of a morphism. (In this book we use the old notation \( L(X) \) from [96] for the \( \text{étale sheaf with transfers represented by a scheme } X \): it was replaced by \( Z_{\text{tr}}(X) \) in [70].) Therefore \( \sigma \) is an epimorphism of sheaves. (One should be careful, however, that \( \gamma \) is not additive.) When \( G \) is homotopy invariant, one deduces from it as in [91, Remark 3.3] a morphism in \( \text{DM}^{\text{eff}}_{\text{ét}}(k) \)

\[ (1.1) \quad M_{\text{et}}(G) = C_*(L(G)) \to G. \]

Let \( \text{HI}_{\text{ét}}^{[0,1]} \) be the category of complexes of length 1 of objects of \( \text{HI}_{\text{ét}} \) (concentrated in degrees 0 and 1): this is an abelian category. Lemma 1.3.2 gives us a functor

\[ M^{\text{eff}} \to \text{HI}_{\text{ét}}^{[0,1]} \]

\[ M \mapsto M \]

hence, by composing with the embedding \( \mathcal{M}_1 \to \mathcal{M}_{\text{anc}}^{\text{eff}} \) of Proposition 1.1.5, another functor

\[ (1.2) \quad \mathcal{M}_1 \to \text{HI}_{\text{ét}}^{[0,1]} . \]

\[ \text{For the symmetric powers of } G \text{ to exist as schemes, it suffices that } G^0 \text{ be quasi-projective.} \]
1.4. 1-motives with torsion and an exact structure on $\mathcal{M}_1[1/p]$.

Recall that, from now on, we invert the exponential characteristic $p$ in the Hom groups of all categories constructed out of commutative $k$-group schemes or étale $k$-sheaves. This does nothing in characteristic 0.

The reader can check that most of the statements below become false if $p > 1$ is not inverted. We hope that statements integral at $p$ may be recovered in the future by considering some kind of non-homotopy invariant motives and cohomology theories.

We start with:

1.4.1. **Proposition.** Let $M^\cdot$ be a complex of objects of $\mathcal{M}_{\text{anc}}[1/p]$. The following conditions are equivalent:

(i) The total complex $\text{Tot}(M^\cdot)$ in $C(H\text{I}_{\text{ét}})[1/p]$ (see Definition 1.3.1 and Lemma 1.3.2) is acyclic.

(ii) For any $q \in \mathbb{Z}$, $H^q(M^\cdot)$ is of the form $[F^q = F^q]$, where $F^q$ is finite.

**Proof.** (ii) $\Rightarrow$ (i) is obvious. For the converse, let $M^q = [L^q \to G^q]$ for all $q$. Let $L^\cdot$ and $G^\cdot$ be the two corresponding “column” complexes of sheaves. Then we have a long exact sequence in $H\text{I}_{\text{ét}}$:

$$\cdots \to H^q(L^\cdot) \to H^q(G^\cdot) \to H^q(\text{Tot}(M^\cdot)) \to H^{q+1}(L^\cdot) \to \cdots$$

The assumption implies that $H^q(L^\cdot) \sim H^q(G^\cdot)$ for all $q$. Since $H^q(L^\cdot)$ is discrete and $H^q(G^\cdot)$ is representable by a commutative algebraic group, both must be finite. $\square$

We now restrict to complexes of $\mathcal{M}_1[1/p]$.

1.4.2. **Definition.** A complex of $\mathcal{M}_1[1/p]$ is acyclic if it satisfies the equivalent conditions of Proposition 1.4.1. An acyclic complex of the form $0 \to N' \to N \to N'' \to 0$ is called a short exact sequence.

Recall that in [10] a category of 1-motives with torsion was introduced. We shall denote it here by $^t\mathcal{M}_1$ in order to distinguish it from $\mathcal{M}_1$. Denote by $^t\mathcal{M}_1^{\text{eff}}$ the effective 1-motives with torsion: $^t\mathcal{M}_1^{\text{eff}}$ is the full subcategory of the category $\mathcal{M}_{\text{anc}}$ of Definition 1.1.4 consisting of the objects $[L \to G]$ where $G$ is connected. Then $^t\mathcal{M}_1$ is the localisation of $^t\mathcal{M}_1^{\text{eff}}$ with respect to quasi-isomorphisms.

The main properties of $^t\mathcal{M}_1$ are recalled in Appendix C. In particular, the category $^t\mathcal{M}_1[1/p]$ is abelian (Theorem C.5.3) and by Proposition C.7.1 we have a full embedding

$$\mathcal{M}_1[1/p] \hookrightarrow ^t\mathcal{M}_1[1/p]$$
which makes $\mathcal{M}_1[1/p]$ an exact subcategory of $\mathcal{M}_1[1/p]$. The following lemma is clear:

1.4.3. **Lemma.** A complex $0 \to N' \xrightarrow{j} N \xrightarrow{\jmath} N'' \to 0$ in $\mathcal{M}_1[1/p]$ is a short exact sequence in the sense of Definition 1.4.2 if and only if it is a short exact sequence for the exact structure given by (1.3).

1.4.4. **Remarks.** 1) There is another, much stronger, exact structure on $\mathcal{M}_1[1/p]$, induced by its full embedding in $\mathcal{M}_{\text{eff anc}}[1/p]$: it amounts to require a complex $[L \to G]$ to be exact if and only if both complexes $L$ and $G$ are acyclic. We shall not use this exact structure in the sequel. (See also Remark 1.8.5.)

2) Clearly, the complexes of Definition 1.4.2 do not provide $\mathcal{M}_{\text{eff anc}}[1/p]$ with an exact structure. It is conceivable, however, that they define an exact structure on the localisation of $\mathcal{M}_{\text{eff anc}}[1/p]$/homotopies with respect to morphisms with acyclic kernel and cokernel.

1.5. **The derived category of 1-motives.**

1.5.1. **Lemma.** A complex in $C(\mathcal{M}_1[1/p])$ is acyclic in the sense of Definition 1.4.2 if and only if it is acyclic with respect to the exact structure of $\mathcal{M}_1[1/p]$ provided by Lemma 1.4.3 in the sense of [14, 1.1.4] or [77, §1].

**Proof.** Let $X^\cdot \in C(\mathcal{M}_1[1/p])$. Viewing $X^\cdot$ as a complex of objects of $\mathcal{M}_{\text{eff anc}}[1/p]$, we define $D^n = \text{Im}(d^n : X^n \to X^{n+1})$. Note that the $D^n$ are Deligne 1-motives. Let $e_n : X^n \to D^n$ be the projection and $m_n : D^n \to X^{n+1}$ be the inclusion. We have half-exact sequences

\begin{equation}
0 \to D^{n-1} \xrightarrow{m_{n-1}} X^n \xrightarrow{e_n} D^n \to 0
\end{equation}

with middle cohomology equal to $H^n(X^\cdot)$. Thus, if $X^\cdot$ is acyclic in the sense of Definition 1.4.2, the sequences (1.4) are short exact which means that $X^\cdot$ is acyclic with respect to the exact structure of $\mathcal{M}_1[1/p]$. Conversely, suppose that $X^\cdot$ is acyclic in the latter sense. Then, by definition, we may find $D^n$, $e'_n$, $m'_n$ such that $d^n = m'_ne'_n$ and that the sequences analogous to (1.4) are short exact. Since $\mathcal{M}_{\text{eff anc}}[1/p]$ is abelian (Proposition C.8.4), $D^n = D^n$ and we are done. \qed

From now on, we shall only say “acyclic” without further precision.

Let $K(\mathcal{M}_1[1/p])$ be the homotopy category of $C(\mathcal{M}_1[1/p])$. By [77, Lemmas 1.1 and 1.2], the full subcategory of $K(\mathcal{M}_1[1/p])$ consisting of acyclic complexes is triangulated and thick (the latter uses the fact that $\mathcal{M}_1[1/p]$ is idempotent-complete, cf. Lemma 1.1.2). Thus one may define the derived category of $\mathcal{M}_1[1/p]$ in the usual way:
1.5.2. **Definition.** a) The derived category of 1-motives is the localisation $D(M_1[1/p])$ of the homotopy category $K(M_1[1/p])$ with respect to the thick subcategory $A(M_1[1/p])$ consisting of acyclic complexes. Similarly for $D^+(M_1[1/p])$ and $D^b(M_1[1/p])$.
b) A morphism in $C(M_1[1/p])$ is a quasi-isomorphism if its cone is acyclic.

1.6. **Torsion objects in the derived category of 1-motives.** Let $M_1$ be the category of lattices (see Definition 1.1.1): the inclusion functor $M_0[1/p] \hookrightarrow M_1[1/p]$ provides it with the structure of an exact subcategory of $M_1[1/p]$. Moreover, the embedding

\[ \mathcal{M}_0[1/p] \xrightarrow{B} \mathcal{M}_0[1/p] \]

is clearly exact, where $\mathcal{M}_0$ is the abelian category of discrete étale sheaves (see Definition 1.1.1 again). In fact, we also have an exact functor

\[ \mathcal{M}_0[1/p] \xrightarrow{C} \mathcal{M}_1[1/p] \]

\[ L \mapsto [L \rightarrow 0]. \]

Hence an induced diagram of triangulated categories:

\[
\begin{array}{ccc}
D^b(M_0[1/p]) & \xrightarrow{B} & D^b(\mathcal{M}_0[1/p]) \\
\downarrow A & & \downarrow C \\
D^b(M_1[1/p]) & \xrightarrow{D} & D^b(\mathcal{M}_1[1/p]).
\end{array}
\]

1.6.1. **Theorem.** In the above diagram

a) $B$ and $D$ are equivalence of categories.
b) $A$ and $C$ are fully faithful; restricted to torsion objects they are equivalences of categories.

(For the notion of torsion objects, see Proposition B.2.1.)

**Proof.** a) For $B$, this follows from Proposition A.1.2 provided we check that any object $M$ in $\mathcal{M}_0[1/p]$ has a finite left resolution by objects in $M_0[1/p]$. In fact $M$ has a length 1 resolution: let $E/k$ be a finite Galois extension of group $\Gamma$ such that the Galois action on $M$ factors through $\Gamma$. Since $M$ is finitely generated, it is a quotient of some power of $\mathbb{Z}[\Gamma]$, and the kernel is a lattice. Exactly the same argument works for $D$.

b) By a) it is sufficient to prove that $C$ is fully faithful. It suffices to verify that the criterion of Proposition A.1.4 is verified by the full embedding $\mathcal{M}_0[1/p] \rightarrow \mathcal{M}_1[1/p]$. 
Let \([L \to 0] \hookrightarrow [L' \to G']\) be a monomorphism in \(\mathcal{M}_1[1/p]\). We may assume that it is given by an effective map. The assumption implies that \(L \to L'\) is mono: it then suffices to compose with the projection \([L' \to G'] \to [L' \to 0]\).

It remains to show that \(A\) is essentially surjective on torsion objects. Let \(X = [C \cdot \to G \cdot] \in D^b(M_{\text{anc}}[1/p])\), and let \(n > 0\) be such that \(nX = 0\). Arguing as in the proof of Proposition 1.4.1, this implies that the cohomology sheaves of both \(C\) and \(G\) are killed by some possibly larger integer \(m\). We have an exact triangle

\[
[0 \to G ] \to X \to [C \to 0] \xrightarrow{+1}
\]

which leaves us to show that \([0 \to G']\) is in the essential image of \(C\). Let \(q\) be the smallest integer such that \(G^q \neq 0\): we have an exact triangle

\[
\{G^q \to \text{Im } d^q\} \to G' \to \{0 \to G^{q+1}/\text{Im } d^q \to \ldots \} \xrightarrow{+1}
\]

(here we use curly braces in order to avoid confusion with the square braces used for 1-motives). By descending induction on \(q\), the right term is in the essential image of \(C\).

1.6.2. Corollary. Let \(A\) be a subring of \(\mathbb{Q}\) containing \(1/p\). Then the natural functor

\[
D^b(M_{\text{anc}}[1/p]) \otimes A \to D^b(M_1 \otimes A)
\]

is an equivalence of categories. These categories are idempotent-complete for any \(A\).

Proof. By Proposition 1.4.1, this is true by replacing the category \(M_1[1/p]\) by \(\mathcal{M}_1[1/p]\). On the other hand, the same argument as above shows that the functor \(D^b(M_1 \otimes A) \to D^b(\mathcal{M}_1 \otimes A)\) is an equivalence. This shows the first statement; the second one follows from the fact that \(D^b\) of an abelian category is idempotent-complete.

\(^5\)Note that this is true even if \(m\) is divisible by the characteristic of \(k\), since we only consider sheaves over smooth \(k\)-schemes.
1.7. Discrete sheaves and permutation modules. The following proposition will be used in §2.6.a.

1.7.1. Proposition. Let $G$ be a profinite group. Denote by $D^b_c(G)$ the derived category of finitely generated (topological discrete) $G$-modules. Then $D^b_c(G)$ is thickly generated by $\mathbb{Z}$-free permutation modules.

Proof. The statement says that the smallest thick subcategory $\mathcal{T}$ of $D^b_c(G)$ which contains permutation modules is equal to $D^b_c(G)$. Let $M$ be a finitely generated $G$-module: to prove that $M \in \mathcal{T}$, we immediately reduce to the case where $G$ is finite. Let $M = M/M_{\text{tors}}$. Realise $M \otimes \mathbb{Q}$ as a direct summand of $\mathbb{Q}[G]^n$ for $n$ large enough. Up to scaling, we may assume that the image of $M$ in $\mathbb{Q}[G]^n$ is contained in $\mathbb{Z}[G]^n$ and that there exists a submodule $N$ of $\mathbb{Z}[G]^n$ such that $M \cap N = 0$ and $M \oplus N$ is of finite index in $\mathbb{Z}[G]^n$. This reduces us to the case where $M$ is finite. Moreover, we may assume that $M$ is $\ell$-primary for some prime $\ell$.

Let $S$ be a Sylow $\ell$-subgroup of $G$. Recall that there exist two inverse isomorphisms

$$
\varphi : \mathbb{Z}[G] \otimes_{\mathbb{Z}[S]} M \xrightarrow{\sim} \text{Hom}_{\mathbb{Z}[S]}(\mathbb{Z}[G], M)
$$

$$
\varphi(g \otimes m)(\gamma) = \begin{cases} 
\gamma gm & \text{if } \gamma g \in S \\
0 & \text{if } \gamma g \notin S.
\end{cases}
$$

$$
\psi : \text{Hom}_{\mathbb{Z}[S]}(\mathbb{Z}[G], M) \xrightarrow{\sim} \mathbb{Z}[G] \otimes_{\mathbb{Z}[S]} M
$$

$$
\psi(f) = \sum_{g \in S \setminus G} g^{-1} \otimes f(g).
$$

On the other hand, we have the obvious unit and counit homomorphisms

$$
\eta : M \to \text{Hom}_{\mathbb{Z}[S]}(\mathbb{Z}[G], M)
$$

$$
\eta(m)(g) = gm
$$

$$
\varepsilon : \mathbb{Z}[G] \otimes_{\mathbb{Z}[S]} M \to M
$$

$$
\varepsilon(g \otimes m) = gm.
$$

It is immediate that

$$
\varepsilon \circ \psi \circ \eta = (G : S).
$$

Since $(G : S)$ is prime to $\ell$, this shows that $M$ is a direct summand of the induced module $\mathbb{Z}[G] \otimes_{\mathbb{Z}[S]} M \simeq \text{Hom}_{\mathbb{Z}[S]}(\mathbb{Z}[G], M)$. But it is well-known (see e.g. [90, §8.3, cor. to Prop. 26]) that $M$, as an $S$-module, is a successive extension of trivial $S$-modules. Any trivial
torsion $S$-module has a length 1 resolution by trivial torsion-free $S$-modules. Since the “induced module” functor is exact, this concludes the proof.

1.8. Cartier duality and 1-motives with cotorsion. We now introduce a new category ${\mathcal{M}}_1$:

1.8.1. Definition. We denote by ${\mathcal{M}}_1^{\text{eff}}$ the full subcategory of ${\mathcal{M}}^{\text{eff}}$ consisting of those $[L \to G]$ such that $L$ is a lattice and $G$ is an extension of an abelian variety by a group of multiplicative type, and by ${\mathcal{M}}_1$ its localisation with respect to quasi-isomorphisms. An object of ${\mathcal{M}}_1$ is called a 1-motive with cotorsion.

Recall that Deligne [32, §10.2.11-13] (cf. [11, 1.5]) defined a self-duality on the category ${\mathcal{M}}_1$, that he called Cartier duality. The following facts elucidate the introduction of the category ${\mathcal{M}}_1$.

1.8.2. Lemma. Let $\Gamma$ be a group of multiplicative type, $L$ its Cartier dual and $A$ an abelian variety (over $k = \overline{k}$). We have an isomorphism

$$\tau : \text{Ext}(A, \Gamma) \xrightarrow{\cong} \text{Hom}(L, \text{Pic}^0(A))$$

given by the canonical “pushout” mapping.

Proof. Displaying $L$ as an extension of $L_{\text{fr}}$ by $L_{\text{tor}}$ denote the corresponding torus by $T := \text{Hom}(L_{\text{fr}}, \mathbb{G}_m)$ and let $F := \text{Hom}(L_{\text{tor}}, \mathbb{G}_m)$ be the dual finite group. We obtain a map of short exact sequences

$$0 \to \text{Ext}(A, T) \to \text{Ext}(A, \Gamma) \to \text{Ext}(A, F) \to 0$$

$$\tau_{\text{fr}} \downarrow \quad \tau \downarrow \quad \tau_{\text{tor}} \downarrow$$

$$0 \to \text{Hom}(L_{\text{fr}}, \text{Pic}^0(A)) \to \text{Hom}(L, \text{Pic}^0(A)) \to \text{Hom}(L_{\text{tor}}, \text{Pic}^0(A)) \to 0.$$

Now $\tau_{\text{fr}}$ is an isomorphism by the classical Weil-Barsotti formula, i.e. $\text{Ext}(A, \mathbb{G}_m) \cong \text{Pic}^0(A)$, and $\tau_{\text{tor}}$ is an isomorphism since the Néron-Severi group of $A$ is free: $\text{Hom}(L_{\text{tor}}, \text{Pic}^0(A)) = \text{Hom}(L_{\text{tor}}, \text{Pic}(A)) = H^1(A, F) = \text{Ext}(A, F)$ (cf. [71, 4.20]).

1.8.3. Lemma. Cartier duality on ${\mathcal{M}}_1$ extends to a contravariant additive functor

$$(\ )^* : {\mathcal{M}}_1^{\text{eff}} \to {\mathcal{M}}_1^{\text{eff}}$$

which sends a q.i. to a q.i.

Proof. The key point is that $\text{Ext}(\_, \mathbb{G}_m)$ vanishes on discrete sheaves (cf. [71, 4.17]), hence Cartier duality extends to an exact duality between discrete sheaves and groups of multiplicative type.

To define the functor, we proceed as usual (see [11, 1.5]): starting with $M = [L \to A] \in {\mathcal{M}}_1^{\text{eff}}$, let $G^u$ be the extension of the dual abelian
variety $A^*$ by the Cartier dual $L^*$ of $L$ given by Lemma 1.8.2 (note that $G^u$ may be described as the group scheme which represents the functor associated to $\text{Ext}(M, \mathbb{G}_m)$). We define $M^* = [0 \to G^u] \in \mathcal{M}_1^{\text{eff}}$. For a general $M = [L \to G] \in \mathcal{M}_1^{\text{eff}}$, with $G$ an extension of $A$ by $T$, the extension $M$ of $[L \to A]$ by the toric part $[0 \to T]$ provides the corresponding extension $G^\pi$ of $A'$ by $L^*$ and a boundary map

$$u^* : \text{Hom}(T, \mathbb{G}_m) \to \text{Ext}([L \to A], \mathbb{G}_m) = G^\pi(k)$$

which defines $M^* \in \mathcal{M}_1^{\text{eff}}$.

For a quasi-isomorphism $M \to M'$ with kernel $[F \to F]$ for a finite group $F$, cf. (C.2), the quotient $[L \to A] \mapsto [L' \to A']$ has kernel $[F \to F_A]$ where $F_A := \text{Ker}(A \to A')$ and the following is a pushout

$$
\begin{array}{c}
0 \to \text{Hom}(T', \mathbb{G}_m) \to \text{Hom}(T, \mathbb{G}_m) \to \text{Hom}(F_T, \mathbb{G}_m) \to 0 \\
\downarrow{\text{(u')}^*} \quad \downarrow{u^*} \quad \downarrow{\text{}} \\
0 \to \text{Ext}([L' \to A'], \mathbb{G}_m) \to \text{Ext}([L \to A], \mathbb{G}_m) \to \text{Ext}([F \to F_A], \mathbb{G}_m) \to 0
\end{array}
$$

where $F_T := \text{Ker}(T \to T')$. $\square$

1.8.4. Proposition. a) The functor of Lemma 1.8.3 induces an anti-equivalence of categories

$$(\ )^* : \mathcal{M}_1[1/p] \xrightarrow{\sim} \mathcal{M}_1[1/p].$$

b) The category $\mathcal{M}_1[1/p]$ is abelian and the two functors of a) are exact.

c) Cartier duality on $\mathcal{M}_1[1/p]$ is an exact functor, hence induces a triangulated self-duality on $D^b(\mathcal{M}_1[1/p])$.

Proof. a) The said functor exists by Lemma 1.8.3, and it is clearly additive. Let us prove that it is i) essentially surjective, ii) faithful and iii) full.

i) We proceed exactly as in the proof of Lemma 1.8.3, taking an $[L' \to G'] \in \mathcal{M}_1[1/p]$, and writing $G'$ explicitly as an extension of an abelian variety by a group of multiplicative type.

ii) We reduce to show that the functor of Lemma 1.8.3 is faithful by using that Lemma C.2.3 is also true in $\mathcal{M}_1^{\text{eff}}[1/p]$ (dual proof). By additivity, we need to prove that if $f : M_0 \to M_1$ is mapped to 0, then $f = 0$. But, by construction, $f^*$ sends the mutiplicative type part of $M_1^*$ to that of $M_0^*$. 

iii) Let $M_0 = [L_0 \to G_0]$, $M_1 = [L_1 \to G_1]$ in $\mathcal{M}_{1}^{\text{eff}}[1/p]$, and let $f : M_1^* \to M_0^*$ be (for a start) an effective map. We have a diagram

$$
\begin{array}{cccccc}
0 & \longrightarrow & \Gamma_1 & \longrightarrow & G_1' & \longrightarrow & A_1' & \longrightarrow & 0 \\
& & \uparrow f_G & & \downarrow & & & \\
0 & \longrightarrow & \Gamma_0 & \longrightarrow & G_0' & \longrightarrow & A_0' & \longrightarrow & 0 \\
\end{array}
$$

where $M_i^* = [L_i' \to G_i']$, $A_i'$ is the dual of the abelian part of $M_i$ and $\Gamma_i$ is the dual of $L_i$. If $f_G$ maps $\Gamma_1$ to $\Gamma_2$, there is no difficulty to get an (effective) map $g : M_0 \to M_1$ such that $g^* = f$. In general we reduce to this case: let $\mu$ be the image of $f_G(\Gamma_1)$ in $A_0'$; this is a finite group. Let now $A_2' = A_0'/\mu$, so that we have a commutative diagram

$$
\begin{array}{cccccc}
0 & \longrightarrow & \Gamma_0 & \longrightarrow & G_0' & \longrightarrow & A_0' & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \\
0 & \longrightarrow & \Gamma_2 & \longrightarrow & G_0' & \longrightarrow & A_2' & \longrightarrow & 0 \\
\end{array}
$$

where $\mu = \text{Ker}(A_0' \to A_2') = \text{Coker}(\Gamma_0 \to \Gamma_2)$. By construction, $f_G$ induces maps $f_L : \Gamma_1 \to \Gamma_2$ and $f_A : A_1' \to A_2'$.

Consider the object $M_2 = [L_2 \to G_2] \in \mathcal{M}_{1}^{\text{eff}}[1/p]$ obtained from $(L_0', \Gamma_2, A_2')$ and the other data by the same procedure as in the proof of Lemma 1.8.3. We then have a q.i.s. $M_2 \to M_0$ with kernel $[\mu = \mu]$ and a map $g : M_2 \to M_1$ induced by $(f_L, f_L, f_A)$, and $(gs^{-1})^* = f$.

If $f$ is a q.i., clearly $g$ is a q.i.; this concludes the proof of fullness.

b) Since $\mathcal{M}_{1}^{1/p}$ is abelian, $\mathcal{M}_{1}^{1/p}$ is abelian by a). Equivalences of abelian categories are automatically exact.

c) One checks as for $\mathcal{M}_{1}^{1/p}$ that the inclusion of $\mathcal{M}_{1}^{1/p}$ into $\mathcal{M}_{1}^{1/p}$ induces the exact structure of $\mathcal{M}_{1}^{1/p}$. Then, thanks to b), Cartier duality preserves exact sequences of $\mathcal{M}_{1}^{1/p}$, which means that it is exact on $\mathcal{M}_{1}^{1/p}$.

1.8.5. Remarks. 1) Cartier duality does not preserve the strong exact structure of Remark 1.4.4 1). For example, let $A$ be an abelian variety, $a \in A(k)$ a point of order $m > 1$ and $B = A/\langle a \rangle$. Then the sequence

$$
0 \to [\mathbb{Z} \to 0] \overset{m}{\longrightarrow} [\mathbb{Z} \overset{f}{\longrightarrow} A] \to [0 \to B] \to 0,
$$

with $f(1) = a$, is exact in the sense of Definition 1.4.2 but not in the sense of Remark 1.4.4. However, its dual

$$
0 \to [0 \to B^*] \to [0 \to G] \to [0 \to \mathbb{G}_m] \to 0
$$

is exact in the strong sense. Taking the Cartier dual of the latter sequence, we come back to the former.
2) One way to better understand what happens in Lemma 1.8.3 and Proposition 1.8.4 would be to introduce a category $\tilde{\mathcal{M}}^{\text{eff}}_1$, whose objects are quintuples $(L,u,G,A,\Gamma)$ with $L$ a lattice, $\Gamma$ a group of multiplicative type, $A$ an abelian variety, $G$ an extension of $A$ by $\Gamma$ and $u$ a morphism from $L$ to $G$. Morphisms in $\tilde{\mathcal{M}}^{\text{eff}}_1$ are additive and respect all these structures. There is an obvious functor $(L,u,G,A,\Gamma) \mapsto [L \xrightarrow{u} G]$ from $\tilde{\mathcal{M}}^{\text{eff}}_1$ to $\mathcal{M}^{\text{eff}}_1$, the functor of Lemma 1.8.3 lifts to an anti-isomorphism of categories $\tilde{\mathcal{M}}^{\text{eff}}_1 \xrightarrow{\sim} \mathcal{M}^{\text{eff}}_1$ and the localisation of $\tilde{\mathcal{M}}^{\text{eff}}_1[1/p]$ with respect to the images of q.i. of $\mathcal{M}^{\text{eff}}_1[1/p]$ is equivalent to $\mathcal{M}_1[1/p]$. We leave details to the interested reader.

Dually to Theorem 1.6.1, we now have:

1.8.6. **Theorem.** The natural functor $\mathcal{M}_1[1/p] \to \mathcal{M}^{\text{eff}}_1[1/p]$ is fully faithful and induces an equivalence of categories $D^b(\mathcal{M}_1[1/p]) \xrightarrow{\sim} D^b(\mathcal{M}^{\text{eff}}_1[1/p])$.

Moreover, Cartier duality exchanges $\mathcal{M}^{\text{eff}}_1[1/p]$ and $\mathcal{M}_1[1/p]$ inside the derived category $D^b(\mathcal{M}_1[1/p])$.

**Proof.** This follows from Theorem 1.6.1 and Proposition 1.8.4. □

1.8.7. **Notation.** For $C \in D^b(\mathcal{M}_1[1/p])$, we write $^tH^n(C)$ (resp. $^tH^n(C)$) for its cohomology objects relative to the $t$-structure with heart $\mathcal{M}^{\text{eff}}_1[1/p]$ (resp. $\mathcal{M}_1[1/p]$). We also write $^tH_n$ for $^tH^{-n}$ and $^tH_n$ for $^tH^{-n}$.

Thus we have two $t$-structures on $D^b(\mathcal{M}_1[1/p])$ which are exchanged by Cartier duality; naturally, these two $t$-structures coincide after tensoring with $\mathbb{Q}$. In Section 3, we shall introduce a third $t$-structure, of a completely different kind: see Corollary 3.10.2.

We shall also come back to Cartier duality in Section 4.

1.9. **How not to invert $p$.** This has been done by Alessandra Bertapelle [15]. She defines a larger variant of $\mathcal{M}_1$ by allowing finite connected $k$-group schemes in the component of degree 0. Computing in the fppf topology, she checks that the arguments provided in Appendix C carry over in this context and yield in particular an integral analogue to Theorem C.5.3. Also, the analogue of (1.3) is fully faithful integrally, hence an exact structure on $\mathcal{M}_1$; she also checks that the analogue of Theorem 1.6.1 holds integrally.

In particular, her work provides an exact structure on $\mathcal{M}_1$, hence an integral definition of $D^b(\mathcal{M}_1)$. One could check that this exact structure can be described a priori using Proposition 1.4.1 and Lemma 1.4.3, and working with the fppf topology.
It is likely that the duality results of §1.8 also extend to Bertapelle’s context.

2. Universal realisation

2.1. Statement of the theorem. The derived category of 1-motives up to isogeny can be realised in Voevodsky’s triangulated category of motives. With rational coefficients, this is part of Voevodsky’s Pretheorem 0.0.18 in [94] and claimed in [96, Sect. 3.4, on page 218]. Details of this fact appear in Orgogozo [78]. In this section we shall give a $p$-integral version of this theorem, where $p$ is the exponential characteristic of $k$, using the étale version of Voevodsky’s category.

By Lemma 1.3.2, any 1-motive $M = [L \to G]$ may be regarded as a complex of homotopy invariant étale sheaves with transfers. By Lemma D.1.3, $M[1/p] := M \otimes \mathbb{Z}[1/p]$ is a complex of strictly homotopy invariant étale sheaves with transfers; this defines a functor

$$M \mapsto M[1/p].$$

(see [96, Sect. 3] for motivic complexes).

From now on, we will usually drop the mention of $k$ from the notation for the various categories of motives encountered.

2.1.1. Definition. We denote by $\text{DM}^{\text{eff}}_{\text{gm, ét}}$ the thick subcategory of $\text{DM}^{\text{eff}}_{\text{ét}}$ generated by the image of $\text{DM}^{\text{eff}}_{\text{gm}}$ under the “change of topology” functor

$$\alpha^* : \text{DM}^{\text{eff}}_{\text{gm}} \to \text{DM}^{\text{eff}}_{\text{ét}}$$

of [96, §3.3]. We set $M_{\text{ét}}(X) := \alpha^* M(X)$.

2.1.2. Theorem. Let $p$ be the exponential characteristic of $k$. The functor (2.1) extends to a fully faithful triangulated functor

$$T : D^b(M_1[1/p]) \to \text{DM}^{\text{eff}}_{\text{gm, ét}}$$

where the left hand side was defined in §1.4. Its essential image is the thick subcategory $d_{\leq 1} \text{DM}^{\text{eff}}_{\text{gm, ét}}$ of $\text{DM}^{\text{eff}}_{\text{gm, ét}}$ generated by motives of smooth curves.

The proof is in several steps.

2.2. Construction of $T$. We follow Orgogozo. Clearly, the embedding (1.2) extends to a functor

$$C^b(M_1) \to C^b(H^1_{\text{ét}}[0,1]).$$
By Lemma A.2.1, we have a canonical functor $C^b(HI_{\text{et}}^{[0,1]}) \xrightarrow{\text{Tot}} D^b(HI_{\text{et}})$, and there is a canonical composite functor

$$D^b(HI_{\text{et}}) \xrightarrow{\otimes \mathbb{Z}[1/p]} D^b(HI_{\text{et}}^s) \rightarrow DM_{\text{eff}}^-,$$

where $HI_{\text{et}}^s$ is the category of strictly homotopy invariant étale sheaves with transfers (see Def. D.1.2 and Proposition D.1.4). To get $T$, we are therefore left to prove

2.2.1. **Lemma.** The composite functor

$$C^b(M_1) \rightarrow C^b(HI_{\text{et}}^{[0,1]}) \xrightarrow{\text{Tot}} D^b(HI_{\text{et}})$$

factors through $D^b(M_1[1/p])$.

**Proof.** It is a general fact that a homotopy in $C^b(M_1)$ is mapped to a homotopy in $C^b(HI_{\text{et}}^{[0,1]})$, and therefore goes to 0 in $D^b(HI_{\text{et}})$, so that the functor already factors through $K^b(M_1)$. The lemma now follows from Lemma 1.5.1. □

2.3. **Full faithfulness.** It is sufficient by Proposition B.2.4 to show that $T \otimes \mathbb{Q}$ and $T_{\text{tors}}$ are fully faithful.

For the first fact, we reduce to [78, 3.3.3 ff]. We have to be a little careful since Orgogozo’s functor is not quite the same as our functor: Orgogozo sends $C$ to $\text{Tot}(C)$ while we send it to $\text{Tot}(C)[1/p]$, but the map $\text{Tot}(C) \rightarrow \text{Tot}(C)[1/p]$ is an isomorphism in $DM_{\text{eff}}^- \otimes \mathbb{Q}$ as we shall see in Proposition 6.1.1 (see also Remark 2.7.2 2)).

For the reader’s convenience we sketch the proof of [78, 3.3.3 ff]: it first uses the equivalence of categories

$$DM_{\text{eff}}^- \otimes \mathbb{Q} \xrightarrow{\sim} DM_{\text{eff}}^- \otimes \mathbb{Q}$$

of [96, Prop. 3.3.2] (cf. Proposition 6.1.1). One then reduces to show that the morphisms

$$\text{Ext}^i(M, M') \rightarrow \text{Hom}(\text{Tot}(M), \text{Tot}(M')[i])$$

are isomorphisms for any pure 1-motives $M, M'$ and any $i \in \mathbb{Z}$. This is done by a case-by-case inspection, using the fact [96, 3.1.9 and 3.1.12] that in $DM_{\text{eff}}^- \otimes \mathbb{Q}$

$$\text{Hom}(M(X), C) \otimes \mathbb{Q} = H^0_{\text{Zar}}(X, C) \otimes \mathbb{Q}$$

for any smooth variety $X$. The key points are that 1) for such $X$ we have $H^i_{\text{Zar}}(X, G_m) = 0$ for $i > 1$ and for an abelian variety $A$, $H^i_{\text{Zar}}(X, A) = 0$ for $i > 0$ because the sheaf $A$ is flasque, and 2) that any abelian variety is up to isogeny a direct summand of the Jacobian
of a curve. This point will also be used for the essential surjectivity below.

For the second fact, the argument in the proof of [96, Prop. 3.3.3 1] shows that the functor $\text{DM}^{\text{eff}}_{\text{ét}} \to D^-(\text{Shv}((\text{Spec } k)_{\text{ét}}))$ which takes a complex of sheaves on $\text{Sm}(k)_{\text{ét}}$ to its restriction to $(\text{Spec } k)_{\text{ét}}$ is an equivalence of categories on the full subcategories of objects of prime-to-$p$ torsion. The conclusion then follows from Theorem 1.6.1.

2.4. **Gersten’s principle.** We want to formalise here an important computational method which goes back to Gersten’s conjecture but was put in a wider perspective and systematic use by Voevodsky. For the étale topology it replaces advantageously (but not completely) the recourse to proper base change.

2.4.1. **Proposition.**

a) Let $C$ be a complex of presheaves with transfers on $\text{Sm}(k)$ with homotopy invariant cohomology presheaves. Suppose that $C(K) := \lim_{\to k(U)=K} C(U)$ is acyclic for any function field $K/k$. Then the associated complex of Zariski sheaves $C_{\text{Zar}}$ is acyclic.

b) Let $f : C \to D$ be a morphism of complex of presheaves with transfers on $\text{Sm}(k)$ with homotopy invariant cohomology presheaves. Suppose that for any function field $K/k$, $f(K) : C(K) \to D(K)$ is a quasi-isomorphism. Then $f_{\text{Zar}} : C_{\text{Zar}} \to D_{\text{Zar}}$ is a quasi-isomorphism.

c) The conclusions of a) and b) hold for the étale topology if their hypotheses are weakened by replacing $K$ by $K_s$, a separable closure of $K$.

**Proof.**
a) Let $F = H^q(C)$ for some $q \in \mathbb{Z}$, and let $X$ be a smooth $k$-variety with function field $K$. By [98, Cor. 4.18], $F(\mathcal{O}_{X,x}) \hookrightarrow F(K)$ for any $x \in X$, hence $F_{\text{Zar}} = 0$. b) follows from a) by considering the cone of $f$. c) is seen similarly. \[\square\]

2.5. **An important computation.** Recall that the category $\text{DM}^{\text{eff}}_{\text{gm}, \text{ét}}$ is provided with a partial internal Hom denoted by $\text{Hom}_{\text{gm, ét}}$, defined on pairs $(M, M')$ with $M \in \text{DM}^{\text{eff}}_{\text{gm, ét}}$: it is defined analogously to the one of [96, Prop. 3.2.8] for the Nisnevich topology. We need:

2.5.1. **Definition.** Let $X \in \text{Sch}(k)$. We denote by $\pi_0(X)$ the largest étale $k$-scheme such that the structural map $X \to \text{Spec } k$ factors through $\pi_0(X)$.

(The existence of $\pi_0(X)$ is obvious, for example by Galois descent: see [37, Ch. I, §4.6].)
2.5.2. **Proposition.** Let $f : C \to \text{Spec } k$ be a smooth projective $k$-curve. Then, in $\text{DM}^\text{eff}_{-\text{ét}}$:

a) There is a canonical isomorphism

$$\text{Hom}_{\text{ét}}(M_\text{ét}(C), Z(1)[2]) \simeq R_\text{ét} f_* \mathbb{G}_m[1/p][1].$$

b) we have

$$R^q_\text{ét} f_* \mathbb{G}_m[1/p] =
\begin{cases}
R_{\pi_0(C)/k} \mathbb{G}_m[1/p] & \text{for } q = 0 \\
\text{Pic}_{C/k}[1/p] & \text{for } q = 1 \\
0 & \text{else}.
\end{cases}$$

Here, $R_{\pi_0(C)/k}$ denotes the Weil restriction of scalars from $\pi_0(C)$ to $k$.

c) The morphism

$$M_\text{ét}(C) \to \text{Hom}_{\text{ét}}(M_\text{ét}(C), Z(1)[2])$$

induced by the class $\Delta_C \in \text{Hom}(M_\text{ét}(C) \otimes M_\text{ét}(C), Z(1)[2])$ of the diagonal is an isomorphism.

This is [78, Cor. 3.1.6] with three differences: 1) the fppf topology should be replaced by the étale topology; $p$ must be inverted (cf. Corollary D.1.6); 3) the truncation is not necessary since $C$ is a curve.

**Proof.** a) is the étale analogue of [96, Prop. 3.2.8] since $\mathbb{Z}_\text{ét}(1) = \mathbb{G}_m[1/p][−1]$ (see Corollary D.1.6) and $f^*(\mathbb{G}_m,k) = \mathbb{G}_m,C$ for the big étale sites. In b), the isomorphisms for $q = 0, 1$ are clear; for $q > 2$, we reduce by Gersten’s principle (Prop. 2.4.1) to stalks at separably closed fields, and then the result is classical [SGA4, IX (4.5)].

It remains to prove c). Recall that its Nisnevich analogue is true in $\text{DM}^\text{eff}_{\text{gm}}$ ([96, Th. 4.3.2 and Cor. 4.3.6], but see [50, App. B] to avoid resolution of singularities). Let $\alpha^* : \text{DM}^\text{eff} \to \text{DM}^\text{eff}_{-\text{ét}}$ be the change of topology functor (cf. [70, Remark 14.3]). By b), the natural morphism

$$(2.2) \quad \alpha^* \text{Hom}_{\text{Nis}}(M(C), Z(1)) \to \text{Hom}_{\text{ét}}(\alpha^* M(C), Z(1))$$

is an isomorphism. Hence the result. \qed

2.6. **Essential image.** We proceed in two steps:

2.6.a. **The essential image of $T$ is contained in $T := d_{\leq 1} \text{DM}^\text{eff}_{\text{gm}, \text{ét}}$**. It is sufficient to prove that $T(N) \in T$ for $N$ a 1-motive of type $[L \to 0]$, $[0 \to G]$ ($G$ a torus) or $[0 \to A]$ ($A$ an abelian variety). For the first type, this follows from Proposition 1.7.1. For the second type, Proposition 1.7.1 applied to the character group of $G$ shows that $T([0 \to G])$ is contained in the thick subcategory generated by permutation tori, which is clearly contained in $T$. 


It remains to deal with the third type. If \( A = J(C) \) for a smooth projective curve \( C \) having a rational \( k \)-point \( c \), then \( T([0 \to A]) = A[-1] \) is the direct summand of \( M(C)[-1] \) (determined by \( c \)) corresponding to the pure motive \( h^1(C) \), so belongs to \( T \). If \( A \to A' \) is an isogeny, then Proposition 1.7.1 implies that \( A[-1] \in T \iff A'[-1] \in T \). In general we may write \( A \) as the quotient of a jacobian \( J(C) \). Let \( B \) be the connected part of the kernel: by complete reducibility there exists a third abelian variety \( B' \subseteq J(C) \) such that \( B + B' = J(C) \) and \( B \cap B' \) is finite. Hence \( B \oplus B' \in T, B' \in T \) and finally \( A \in T \) since it is isogenous to \( B' \).

2.6.b. The essential image of \( T \) contains \( T \). It suffices to show that \( M(X) \) is in the essential image of \( T \) if \( X \) is smooth projective irreducible of dimension 0 or 1. Let \( E \) be the field of constants of \( X \). If \( X = \text{Spec } E, M(X) \) is the image of \( [R_{E/k}\mathbb{Z} \to 0] \). If \( X \) is a curve, we apply Proposition 2.5.2: by c) it suffices to show that the sheaves of b) are in the essential image of \( T \). We have already observed that \( R_{E/k}\mathbb{G}_m[1/p] \) is in the essential image of \( T \). We then have a short exact sequence

\[
0 \to R_{E/k}J(X)[1/p] \to \mathbb{P}^1_{X/k}[1/p] \to R_{E/k}\mathbb{Z}[1/p] \to 0.
\]

Both the kernel and the cokernel in this extension belong to the image of \( T \), and the proof is complete.

2.7. The universal realisation functor.

2.7.1. Definition. Define the universal realisation functor

\[
\text{Tot} : D^b(\mathcal{M}_1[1/p]) \to \text{DM}_{\text{gm,ét}}^\text{eff}
\]

to be the composition of the equivalence of categories of Theorem 2.1.2 and the embedding \( d_{\leq 1} \text{DM}_{\text{gm,ét}}^\text{eff} \to \text{DM}_{\text{gm,ét}}^\text{eff} \).

2.7.2. Remarks. 1) In view of Theorem 1.8.6, the equivalence of Theorem 2.1.2, yields two "motivic" \( t \)-structures on \( d_{\leq 1} \text{DM}_{\text{gm,ét}}^\text{eff} \): one with heart \( t\mathcal{M}_1[1/p] \) and the other with heart \( t\mathcal{M}_1[1/p] \). We shall describe a third one, the homotopy \( t \)-structure, in Theorem 3.10.1.

2) In what follows we shall frequently commit an abuse of notation in writing \( G \) rather that \( G[1/p], \) etc. for the image of (say) a semi-abelian variety in \( \text{DM}_{\text{gm,ét}}^\text{eff} \) by the functor \( \text{Tot} \). This is to keep notation light. A more mathematical justification is that, according to Proposition D.1.5, the functor \( T \) is naturally isomorphic to the composition

\[
D^b(\mathcal{M}_1[1/p]) \to D^b(\text{HI}_{\text{ét}}^{[0,1]}[1/p]) \to D^b(\text{HI}_{\text{ét}}[1/p]) \to D^-(\text{Shv}_{\text{ét}}(\text{Sm}(k))[1/p]) \overset{C_*}{\to} \text{DM}_{\text{ét}}^\text{eff}
\]

which (apparently) does not invert \( p \) on objects.
3. 1-MOTIVIC SHEAVES AND THE HOMOTOPY $t$-STRUCTURE

In this section, we introduce the notion of a 1-motivic sheaf: these sheaves form an abelian category $\text{Shv}_1$ which turns out to be the heart of a $t$-structure on $D^b(M_1[1/p])$ induced by the homotopy $t$-structure of $\text{DM}^{\text{eff,\text{gm,\text{ét}}}}$ via the embedding of Definition 2.7.1 (Theorem 3.10.1). The main technical result, Theorem 3.13.4, is that $\text{Shv}_1$ is well-behaved under internal Ext, see also Corollary 3.13.5: we shall make use of this in the next section.

A non-finitely generated version of $\text{Shv}_1$ was studied in [7] by completely different methods: in particular, [7, 1.3.4] shows that any subsheaf of a 1-motivic sheaf is 1-motivic, a fact which is not proven (nor used) here.

We recall the blanket assumption that $p$ is inverted in all Hom groups.

3.1. Some useful lemmas. This subsection is in the spirit of [87, Ch. VII].

Let $G$ be a commutative $k$-group scheme, and let us write $G$ for the associated sheaf of abelian groups for a so far unspecified Grothendieck topology. Let also $\mathcal{F}$ be another sheaf of abelian groups. We then have:

- $\text{Ext}^1(G, \mathcal{F})$ (an Ext of sheaves);
- $H^1(G, \mathcal{F})$ (cohomology of the scheme $G$);
- $\overline{H}^2(G, \mathcal{F})$: this is the homology of the complex

$$\mathcal{F}(G) \xrightarrow{d_1} \mathcal{F}(G \times G) \xrightarrow{d_2} \mathcal{F}(G \times G \times G)$$

where the differentials are the usual ones.

3.1.1. Proposition. There is a complex

$$\text{Ext}^1(G, \mathcal{F}) \xrightarrow{b} H^1(G, \mathcal{F}) \xrightarrow{c} H^1(G \times G, \mathcal{F})$$

and an injection

$$0 \to \text{Ker } b \xrightarrow{\alpha} \overline{H}^2(G, \mathcal{F}).$$

Proof. Let us first define the maps $a, b, c$:

- $c$ is given by $p_1^* + p_2^* - \mu^*$, where $\mu$ is the group law of $G$.
- For $b$: let $\mathcal{E}$ be an extension of $G$ by $\mathcal{F}$. We have an exact sequence

$$\mathcal{E}(G) \to G(G) \to H^1(G, \mathcal{F}).$$

Then $b([\mathcal{E}])$ is the image of $1_G$ by the connecting homomorphism. Alternatively, we may think of $\mathcal{E}$ as an $\mathcal{F}$-torsor over $G$ by forgetting its group structure.
• For $a$: we have $b([\mathcal{E}]) = 0$ if and only if $1_G$ has an antecedent $s \in \mathcal{E}(G)$. By Yoneda, this $s$ determines a section $s : G \to \mathcal{E}$ of the projection. The defect of $s$ to be a homomorphism gives a well-defined element of $H^2(G, F)$ by the usual cocycle computation: this is $a([\mathcal{E}])$.

The map $a$ is clearly injective. □

3.1.2. Proposition. a) Suppose that the map

$$\mathcal{F}(G) \oplus \mathcal{F}(G) \xrightarrow{(p_1^*, p_2^*)} \mathcal{F}(G \times G)$$

is surjective. Then $H^2(G, \mathcal{F}) = 0$.

b) Suppose that $\mathcal{F}(k) \xrightarrow{\sim} \mathcal{F}(G^r)$ for $r = 1, 2$. Then the condition of a) is satisfied and the complex of Proposition 3.1.1 is acyclic.

Proof. a) Let $\gamma \in \mathcal{F}(G \times G)$ be a 2-cocycle. We may write $\gamma = p_1^* \alpha + p_2^* \beta$. The cocycle condition implies that $\alpha$ and $\beta$ are constant. Hence $\gamma$ is constant, and it is therefore a 2-coboundary (of itself).

b) The first assertion is clear. The second one follows from a direct computation identical to the one in [87, Ch. VIII, §3, no 15, proof of Th. 5]. □

3.1.3. Example. $\mathcal{F}$ locally constant, $G$ smooth, the topology = the étale topology. Then the conditions of Proposition 3.1.2 are verified.

We thus get an isomorphism

$$\text{Ext}^1(G, \mathcal{F}) \xrightarrow{\sim} H^1_{\text{ét}}(G, \mathcal{F})_{\text{mult}}$$

with the group of multiplicative classes in $H^1_{\text{ét}}(G, \mathcal{F})$.

3.1.4. Lemma. Let $G$ be a semi-abelian $k$-variety and $L$ a locally constant $\mathbb{Z}$-constructible étale sheaf with torsion-free geometric fibres. Then $\text{Ext}^1(G, L) = 0$.

Proof. By the Ext spectral sequence, it suffices to show that $\mathcal{H}\text{om} (G, L) = \text{Ext}^1(G, L) = 0$. This reduces us to the case $L = \mathbb{Z}$. Then the first vanishing is obvious and the second follows from Example 3.1.3 (see [SGA4, IX 3.6]). □

3.1.5. Lemma. Let $\mathcal{E} \in \text{Ext}^1(G, \mathbb{G}_m)$ and let $g \in G(k)$. Denote by $\tau_g$ the left translation by $g$. Then $\tau_g^* b(\mathcal{E}) = b(\mathcal{E})$. Here $b$ is the map of Proposition 3.1.1.

Proof. By Hilbert’s theorem 90, $g$ lifts to an $e \in \mathcal{E}(k)$. Then $\tau_e$ induces a morphism from the $\mathbb{G}_m$-torsor $b(\mathcal{E})$ to the $\mathbb{G}_m$-torsor $\tau_g^* b(\mathcal{E})$: this morphism must be an isomorphism. □
3.2. **Breen's method.** For the proof of Theorems 3.4.1 and 3.13.4 below we shall need the following proposition, which unfortunately cannot be proven with the above elementary methods.

3.2.1. **Proposition.** Let $G$ be a smooth commutative algebraic $k$-group. Let $\mathcal{A} = \text{Shv}_\text{\acute{e}t}(\text{Sm}(k))$ be the category of abelian \acute{e}tale sheaves on the category of smooth $k$-varieties. Let $\mathcal{F} \in \mathcal{A}$; assume that $\mathcal{F}$ is

(i) discrete or

(ii) represented by a semi-abelian variety.

Then, for any $i \geq 2$,

a) The group $\text{Ext}^i_{\mathcal{A}}(G, \mathcal{F})$ is torsion.

b) The sheaf $\mathcal{E}xt^i_{\mathcal{A}}(G, \mathcal{F})$ is $p$-torsion.

*Proof.* This follows from the results and techniques of L. Breen [27].

In [27], Breen works with the fppf topology but his methods carry over here without any change: see remark in *loc. cit.* top of p. 34. Case (ii) can be directly read off [27]: we explain this, then treat case (i) in some detail.

Considering the connected part $G^0$ of $G$, we reduce to the case where $G$ is connected, hence geometrically connected. In order to prove the torsion claim of a), we may and do reduce to the case where $k$ is algebraically closed by a transfer argument; similarly for the vanishing in b), since this claim is local for the \acute{e}tale topology.

Suppose we are in case (ii). Using Chevalley’s structure theorem for algebraic groups, we reduce to the cases where $G$ is of the form $\mathbb{G}_a$, $\mathbb{G}_m$ or an abelian variety and $\mathcal{F}$ is represented by $\mathbb{G}_m$ or an abelian variety. If $\mathcal{F}$ is represented by $\mathbb{G}_m$, then a) follows from [27, §7] if $G$ is an abelian variety (resp. from [27, §8] if $G = \mathbb{G}_a$ or $\mathbb{G}_m$); if $\mathcal{F}$ is represented by an abelian variety, it follows from [27, §9] (even for $i \geq 1$). This proves a) in this case.

For b), we use the fact that a) is true over any regular Noetherian base $S$: this is explicitly written in [27], except in the case where $\mathcal{F}$ is represented by an abelian variety (*loc. cit.*, §9). In this case however, Breen uses rigidity results for an abelian variety over a field, which can be extended over such an $S$ by using [75, p. 116, Cor. 6.2] (or obtained directly, as our $S$-group schemes come from $k$-group schemes). This shows that the sheaf $\mathcal{E}xt^i_{\mathcal{A}}(G, \mathcal{F})$ is torsion for $i \geq 2$. To get the $p$-torsion statement, we argue as in [27, §10], using the torsion subsheaves $nG$ of $G$. For $n$ prime to $p$, such a subsheaf is locally constant for the \acute{e}tale topology, so the computation of *loc. cit.* goes through at the stalks. This proves b) in case (ii).

---

6We thank L. Illusie for pointing out this reference.
It remains to treat Case (i). We go back to the method of [27] that we now summarise: using essentially the Eilenberg-Mac Lane spectrum associated to $G$, Breen gets two spectral sequences $E_{r}^{p,q}$ and $E_{r}^{p,q}$ converging to the same abutment, with

- $E_{r}^{p,1} = \text{Ext}^{p}_{A}(G,F)$;
- $E_{r}^{p,q}$ is torsion for $q \neq 1$;
- $E_{r}^{p,q}$ is the $p$-th cohomology group of a complex involving terms of the form $H^{q}_{\text{ét}}(G^{a},F)$.

In case (i), it follows for example from [38, (2.1)] that $H^{q}_{\text{ét}}(G^{a},F)$ is torsion for any $q > 0$: to see this easily, reduce to the case where $L$ is constant by a transfer argument involving a finite extension of $k$. Hence $E_{2}^{p,q}$ is torsion for $q > 0$. On the other hand, since $G$ is geometrically connected, so are its powers $G^{a}$, which implies that $H^{0}(G^{a},F) = H^{0}(k,F)$ for any $a$. Since the complex giving $E_{2}^{0,0}$ is just the bar complex, we get that $E_{2}^{0,0} = F(k)$ and $E_{2}^{p,0} = 0$ for $p > 0$. Thus all degree $> 0$ terms of the abutment are torsion, and the conclusion follows for a) and similarly for b).

3.2.2. Remark. The results of §3.1 could also be deduced from [27], see its introduction.

3.3. 1-motivic sheaves.

3.3.1. Definition. An étale sheaf $F$ on $\text{Sm}(k)$ is 1-motivic if there is a morphism of sheaves

\[(3.1) \quad G \xrightarrow{b} F\]

where $G$ is a semi-abelian variety and $\text{Ker} \ b, \text{Coker} \ b$ are discrete (see Definition 1.1.1). We denote by $\text{Shv}_{0}$ the full subcategory of $\text{Shv}_{\text{ét}}(\text{Sm}(k))[1/p]$ consisting of discrete sheaves and by $\text{Shv}_{1}$ the full subcategory of $\text{Shv}_{\text{ét}}(\text{Sm}(k))[1/p]$ consisting of 1-motivic sheaves.

3.3.2. Remark. The category $\text{Shv}_{0}$ is equivalent to the category $\text{M}_{0}[1/p]$ of Definition 1.1.1.

3.3.3. Proposition. a) In Definition 3.3.1 we may choose $b$ such that $\text{Ker} \ b$ is torsion-free: we then say that $b$ is normalised.

b) Given two 1-motivic sheaves $F_{1}, F_{2}$, normalised morphisms $b_{i} : G_{i} \rightarrow F_{i}$ and a map $\varphi : F_{1} \rightarrow F_{2}$, there exists a unique homomorphism of
group schemes $\varphi_G : G_1 \to G_2$ such that the diagram
\[
\begin{array}{ccc}
G_1 & \xrightarrow{b_1} & F_1 \\
\varphi_G \downarrow & & \varphi \downarrow \\
G_2 & \xrightarrow{b_2} & F_2
\end{array}
\]
commutes.
c) Given a 1-motivic sheaf $F$, a pair $(G, b)$ with $b$ normalised is uniquely determined by $F$.
d) The categories $\text{Shv}_0$ and $\text{Shv}_1$ are exact abelian subcategories of $\text{Shv}_{\text{et}}(\text{Sm}(k))$.

Proof. a) If $\text{Ker} b$ is not torsion-free, simply divide $G$ by the image of its torsion.
b) We want to construct a commutative diagram
\[
\begin{array}{cccccccc}
0 & \longrightarrow & L_1 & \xrightarrow{a_1} & G_1 & \xrightarrow{b_1} & F_1 & \xrightarrow{c_1} & E_1 & \longrightarrow & 0 \\
\varphi_L \downarrow & & \varphi_G \downarrow & & \varphi \downarrow & & \varphi_E \downarrow \\
0 & \longrightarrow & L_2 & \xrightarrow{a_2} & G_2 & \xrightarrow{b_2} & F_2 & \xrightarrow{c_2} & E_2 & \longrightarrow & 0
\end{array}
\] (3.2)
where $L_i = \text{Ker} b_i$ and $E_i = \text{Coker} b_i$. It is clear that $c_2 \varphi b_1 = 0$: this proves the existence of $\varphi_E$. We also get a homomorphism of sheaves $G_1 \to G_2 / L_2$, which lifts to $\varphi_G : G_1 \to G_2$ by Lemma 3.1.4, hence $\varphi_L$.

From the construction, it is clear that $\varphi_E$ is uniquely determined by $\varphi$ and that $\varphi_L$ is uniquely determined by $\varphi_G$. It remains to see that $\varphi_G$ is unique. Let $\varphi'_G$ be another choice. Then $b_2 (\varphi_G - \varphi'_G) = 0$, hence $(\varphi_G - \varphi'_G)(G_1) \subseteq L_2$, which implies that $\varphi_G = \varphi'_G$.
c) Follows from b).
d) The case of $\text{Shv}_0$ is obvious. For $\text{Shv}_1$, given a map $\varphi$ as in b), we want to show that $F_3 = \text{Ker} \varphi$ and $F_4 = \text{Coker} \varphi$ are 1-motivic. Let $G_3 = (\text{Ker} \varphi_G)^0$ and $G_4 = \text{Coker} \varphi_G$: we get induced maps $b_i : G_i \to F_i$ for $i = 3, 4$. An easy diagram chase shows that $\text{Ker} b_i$ and $\text{Coker} b_i$ are both discrete. \qed

Here is an extension of Proposition 3.3.3 which elucidates the structure of $\text{Shv}_1$ somewhat:

3.3.4. Theorem. a) Let $\text{SAb}$ be the category of semi-abelian $k$-varieties. Then the inclusion functor
\[
\text{SAb} \to \text{Shv}_1
\]
\[
G \mapsto \overline{G}
\]
has a right adjoint/left inverse $\gamma$; the counit of this adjunction is given by (3.1) (with $b$ normalised). The functor $\gamma$ is faithful and “exact up to isogenies”. For a morphism $\varphi \in \text{Shv}_1$, $\gamma(\varphi) = \varphi_G$ is an isogeny if and only if $\text{Ker} \varphi$ and $\text{Coker} \varphi \in \text{Shv}_0$. In particular, $\gamma$ induces an equivalence of categories

$$\text{Shv}_1 / \text{Shv}_0 \sim \rightarrow \text{SAb} \otimes \mathbb{Q}$$

where $\text{SAb} \otimes \mathbb{Q}$ is the category of semi-abelian varieties up to isogenies.

b) The inclusion functor $\text{Shv}_0 \rightarrow \text{Shv}_1$ has a left adjoint/left inverse $\pi_0$; the unit of this adjunction is given by $\text{Coker} b$ in (3.1). The right exact functor $(\pi_0)_Q : \text{Shv}_1 \rightarrow \text{Shv}_0 \otimes \mathbb{Q}$ has one left derived functor $(\pi_1)_Q$ given by $\text{Ker} b$ in (3.1).

Proof. a) The only delicate thing is the exactness of $\gamma$ up to isogenies. This means that, given a short exact sequence $0 \rightarrow F' \rightarrow F \rightarrow F'' \rightarrow 0$ of 1-motivic sheaves, the sequence

$$0 \rightarrow \gamma(F') \rightarrow \gamma(F) \rightarrow \gamma(F'') \rightarrow 0$$

is half exact and the middle homology is finite. This follows from a chase in the diagram

$$
\begin{array}{cccccccc}
0 & \rightarrow & L' & \xrightarrow{a'} & G' & \xrightarrow{b'} & F' & \xrightarrow{c'} & E' & \rightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\
0 & \rightarrow & L & \xrightarrow{a} & G & \xrightarrow{b} & F & \xrightarrow{c} & E & \rightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\
0 & \rightarrow & L'' & \xrightarrow{a''} & G'' & \xrightarrow{b''} & F'' & \xrightarrow{c''} & E'' & \rightarrow & 0 \\
\end{array}
$$

of which we summarize the main points: (1) $G' \rightarrow G$ is injective because its kernel is the same as $\text{Ker}(L' \rightarrow L)$. (2) $G \rightarrow G''$ is surjective because (i) $\text{Hom}(G'' \rightarrow \text{Coker}(E' \rightarrow E)) = 0$ and (ii) if $L'' \rightarrow \text{Coker}(G \rightarrow G'')$ is onto, then this cokernel is 0. (3) The middle homology is finite because the image of $\text{Ker}(G' \rightarrow G) \rightarrow E'$ must be finite.

In b), the existence and characterisation of $(\pi_1)_Q$ follows from the exactness of $\gamma$ in a).

3.3.5. Remark. One easily sees that $\pi_1$ does not exist integrally. Rather, it exists as a functor to the category of pro-objects of $\text{Shv}_0$. (Actually to a finer subcategory: compare [89].)
3.4. Extensions of 1-motivic sheaves, I. The aim of this subsection is to prove:

3.4.1. Theorem. The categories $\text{Shv}_0$ and $\text{Shv}_1$ are stable by extensions in the abelian category $\text{Shv}_\text{ét}(\text{Sm}(k))[1/p]$.

Proof. For simplicity, let us write $\mathcal{A} := \text{Shv}_\text{ét}(\text{Sm}(k))[1/p]$ as in Proposition 3.2.1. The statement is obvious for $\text{Shv}_0$. Let us now show that $\text{Shv}_1$ is closed under extensions in $\mathcal{A}$. Let $\mathcal{F}_1, \mathcal{F}_2$ be as in (3.2) (no map given between them). We have to show that the injection

$$\text{Ext}^1_{\text{Shv}_1}(\mathcal{F}_2, \mathcal{F}_1) \hookrightarrow \text{Ext}^1_{\mathcal{A}}(\mathcal{F}_2, \mathcal{F}_1)$$

is surjective. This is certainly so in the following special cases:

1. $\mathcal{F}_1$ and $\mathcal{F}_2$ are semi-abelian varieties;
2. $\mathcal{F}_2$ is semi-abelian and $\mathcal{F}_1$ is discrete (see Example 3.1.3).

For $m > 1$, consider

$$\mathcal{F}^m = \text{Coker}(L_1 \xrightarrow{(a_1,m)} G_1 \oplus L_1)$$

so that we have two exact sequences

$$0 \longrightarrow G_1 \xrightarrow{(1_{G_1},0)} \mathcal{F}^m \longrightarrow L_1/m \longrightarrow 0$$

$$0 \longrightarrow L_1 \xrightarrow{(a_1,0)} \mathcal{F}^m \longrightarrow G_1/L_1 \oplus L_1/m \longrightarrow 0.$$

The first one shows that (3.3) is surjective for $(\mathcal{F}_2, \mathcal{F}_1) = (G_2, \mathcal{F}^m)$. Let us now consider the commutative diagram with exact rows associated to the second one, for an unspecified $m$:

$$\begin{array}{ccc}
\text{Ext}^1_{\text{Shv}_1}(G_2, \mathcal{F}^m) & \rightarrow & \text{Ext}^1_{\text{Shv}_1}(G_2, G_1/L_1 \oplus L_1/m) \\
& i & \downarrow \\
& \text{Ext}^1_{\mathcal{A}}(G_2, \mathcal{F}^m) & \rightarrow & \text{Ext}^1_{\mathcal{A}}(G_2, G_1/L_1 \oplus L_1/m) \\
& & \downarrow \delta^m \\
& & \text{Ext}^2_{\mathcal{A}}(G_2, L_1).
\end{array}$$

Note that the composition

$$\text{Ext}^1_{\mathcal{A}}(G_2, G_1/L_1) \rightarrow \text{Ext}^1_{\mathcal{A}}(G_2, G_1/L_1 \oplus L_1/m) \xrightarrow{\delta^m} \text{Ext}^2_{\mathcal{A}}(G_2, L_1)$$

coincides with the boundary map $\delta$ associated to the exact sequence

$$0 \rightarrow L_1 \rightarrow G_1 \rightarrow G_1/L_1 \rightarrow 0.$$

Let $e \in \text{Ext}^1_{\mathcal{A}}(G_2, G_1/L_1)$. By Proposition 3.2.1 a), $f = \delta(e)$ is torsion. Choose now $m$ such that $mf = 0$. Then there exists $e' \in \text{Ext}^1_{\mathcal{A}}(G_2, L_1/m)$ which bounds to $f$ via the Ext exact sequence associated to the exact sequence of sheaves

$$0 \rightarrow L_1 \xrightarrow{m} L_1 \rightarrow L_1/m \rightarrow 0.$$
Since \( \delta^m(e, -e') = 0 \), (3.4) shows that \((e, -e')\) comes from the left, which shows that (3.3) is surjective for \((\mathcal{F}_2, \mathcal{F}_1) = (G_2, G_1/L_1)\).

By Lemma 3.1.4, in the commutative diagram

\[
\begin{array}{ccc}
\text{Ext}_{\text{Shv}}^1(G_2, G_1/L_1) & \longrightarrow & \text{Ext}_{\text{Shv}}^1(G_2, \mathcal{F}_1) \\
\downarrow & & \downarrow \\
\text{Ext}_{\mathcal{A}}^1(G_2, G_1/L_1) & \longrightarrow & \text{Ext}_{\mathcal{A}}^1(G_2, \mathcal{F}_1)
\end{array}
\]

the horizontal maps are isomorphisms. Hence (3.3) is surjective for \(F_2 = G_2\) and any \(F_1\).

To conclude, let \(F\) be an extension of \(F_2\) by \(F_1\) in \(\mathcal{A}\). By the above, \(F' := b^*_2 F\) is 1-motivic as an extension of \(G_2\) by \(F_1\), and we have an exact sequence

\[0 \to L_2 \to F' \to F \to E_2 \to 0.\]

Let \(b' : G \to F'\) be a normalised map (in the sense of Proposition 3.3.3) from a semi-abelian variety to \(F'\) and let \(b : G \to F\) be its composite with the above map. It is then an easy exercise to check that \(\text{Ker} b\) and \(\text{Coker} b\) are both discrete. Hence \(F\) is 1-motivic.

3.4.2. **Remark.** We may similarly define 1-motivic sheaves for the fppf topology over \(\text{Spec} \, k\); as one easily checks, all the above results hold equally well in this context. This is also the case for \(\S 3.8\) below.

In fact, let \(\text{Shv}_{\text{fppf}}^1\) be the \(\mathbb{Z}[1/p]\)-linear category of fppf 1-motivic sheaves and \(\pi : (\text{Spec} \, k)_{\text{fppf}} \to \text{Sm}(k)_{\text{ét}}\) be the projection functor. Then the functors \(\pi^*\) and \(\pi_*\) induce **quasi-inverse equivalences of categories** between \(\text{Shv}^1\) and \(\text{Shv}_{\text{fppf}}^1\). Indeed it suffices to check that \(\pi_*\pi^*\) is naturally isomorphic to the identity on \(\text{Shv}^1\): if \(\mathcal{F} \in \text{Shv}^1\) and we consider its normalised representation, then in the commutative diagram

\[
\begin{array}{cccccc}
0 & \longrightarrow & L & \longrightarrow & G & \longrightarrow & F & \longrightarrow & E & \longrightarrow & 0 \\
\downarrow & & & & & & & & & & \\
0 & \longrightarrow & \pi_*\pi^* L & \longrightarrow & \pi_*\pi^* G & \longrightarrow & \pi_*\pi^* F & \longrightarrow & \pi_*\pi^* E & \longrightarrow & 0
\end{array}
\]

the first, second and fourth vertical maps are isomorphisms and the lower sequence is still exact: both facts follow from [71, p. 14, Th. III.3.9].

In particular the restriction of \(\pi_*\) to \(\text{Shv}_{\text{fppf}}^1\) is exact. Actually, \((R^q\pi_*|_{\text{Shv}_{\text{fppf}}^1})| = 0\) for \(q > 0\) (use same reference).

3.5. **A basic example.** For \(\pi : X \to k\) we shall denote \(R^1\pi_*\mathbb{G}_m[1/p]\) by \(\underline{\text{Pic}}_{X/k}\) considered as a sheaf on \(\text{Sm}(k)_{\text{ét}}\).

3.5.1. **Proposition.** Let \(X \in \text{Sm}(k)\), with structural morphism \(\pi\). Then the sheaf \(R^i\pi_*\mathbb{G}_m[1/p]\) is 1-motivic for \(i = 0, 1\).
Proof. Suppose first that $X$ is smooth projective. Then $R^0\pi_*\mathbb{G}_m = \mathbb{G}_m$ and $\text{Pic}^{0}_{X/k}$ is an extension of the discrete sheaf $\text{NS}^{0}_{X/k}$ (Néron-Severi) by the abelian variety $\text{Pic}^{0}_{X/k}$ (Picard variety). Both sheaves are clearly 1-motivic.

In general, we apply de Jong’s theorem [54, Th. 4.1]: there exists a diagram

$$
\begin{array}{ccc}
\tilde{U} & \longrightarrow & \bar{X} \\
p & \downarrow & \\
U & \longrightarrow & X
\end{array}
$$

where the horizontal maps are open immersions, $\bar{X}$ is smooth projective and the vertical map is finite étale. Then we get a corresponding diagram of Pics

$$
\begin{array}{ccc}
\text{Pic}^{*}_{\tilde{U}/k} & \leftarrow & \text{Pic}_{\bar{X}/k} \\
p^* & \uparrow & \\
\text{Pic}^{*}_{U/k} & \leftarrow & \text{Pic}_{X/k}.
\end{array}
$$

The horizontal morphisms are epimorphisms and their kernels are lattices. This already shows by Proposition 3.3.3 d) that $\overline{\text{Pic}}^{*}_{U/k} \in \text{Shv}_{1}$.

Consider the Čech spectral sequence associated to the étale cover $p$. It yields an exact sequence

$$
0 \rightarrow H^1(p, \mathcal{H}^0_{\text{ét}}(\tilde{U}, \mathbb{G}_m)) \rightarrow \text{Pic}^{*}_{U/k} \rightarrow H^0(p, \text{Pic}^{*}_{\tilde{U}/k}) \rightarrow H^2(p, \mathcal{H}^0_{\text{ét}}(\tilde{U}, \mathbb{G}_m)).
$$

All the $H^i$ are cohomology sheaves of complexes of objects of the abelian category $\text{Shv}_{1}$, hence belong to $\text{Shv}_{1}$; it then follows from Theorem 3.4.1 that $\overline{\text{Pic}}^{*}_{U/k} \in \text{Shv}_{1}$, as well as $\overline{\text{Pic}}^{*}_{X/k}$.

The argument for $R^0\pi_*\mathbb{G}_m$ is similar and easier. ☐

3.6. Application: the Néron-Severi group of a smooth scheme.

3.6.1. Definition. Let $X \in \text{Sm}(k)$.

a) Suppose that $k$ is algebraically closed. Then we write $\text{NS}(X)$ for the group of cycles of codimension 1 on $X$ modulo algebraic equivalence.

b) In general, we define $\text{NS}^{*}_{X/k}$ as the étale sheaf on $\text{Sm}(k)$ given by

$$
\text{NS}^{*}_{X/k}(U) = \text{NS}(X \times_{k} \overline{k(U)})^G
$$

where $U \in \text{Sm}(k)$ is irreducible, $\overline{k(U)}$ is a separable closure of $k(U)$ and $G = \text{Gal}(\overline{k(U)}/k(U))$. 


3.6.2. **Proposition.** The natural map $e : \text{Pic}_{X/k} \to \text{NS}_{X/k}$ identifies $\text{NS}_{X/k}$ with $\pi_0(\text{Pic}_{X/k})$ (cf. Theorem 3.3.4 b)). In particular, $\text{NS}_{X/k} \in \text{Shv}_0$.

**Proof.** It is well-known that cycles modulo algebraic equivalence are invariant by extension of algebraically closed base field. By Proposition 3.7.2 b), this implies that $e$ induces a map $\overline{e} : \pi_0(\text{Pic}_{X/k}) \to \text{NS}_{X/k}$, which is evidently epi. But let $\text{Pic}^0_{X/k} = \text{Ker} e$; by [22, Lemma 7.10], $\text{Pic}^0(X_\overline{k}) = \text{Pic}^0_{X/k}(\overline{k})$ is divisible, which forces $\overline{e}$ to be an isomorphism. $\square$

3.6.3. **Remark.** In particular, $\text{NS}(X)$ is finitely generated if $k$ is algebraically closed: this was proven in [56, Th. 3] in a quite different way.

3.7. **Technical results on 1-motivic sheaves.**

3.7.1. **Proposition.** The functor

$$ev : \text{Shv}_1 \to \text{Ab}$$

$$\mathcal{F} \mapsto \mathcal{F}(\overline{k})$$

to the category $\text{Ab}$ of abelian groups is exact and faithful, hence (cf. [26, Ch. 1, p. 44, prop. 1]) “faithfully exact”: a sequence $\mathcal{E}$ is exact if and only if $ev(\mathcal{E})$ is exact.

**Proof.** The exactness of $ev$ is clear. For faithfulness, let $\varphi : \mathcal{F}_1 \to \mathcal{F}_2$ be such that $ev(\varphi) = 0$. In $ev(3.2)$, we have $\varphi_G(\mathcal{G}_1(\overline{k})) \subseteq L_2(\overline{k})$; since the former group is divisible and the latter is finitely generated, $ev(\varphi_G) = 0$. Hence $\varphi_G = 0$. On the other hand, $ev(\varphi_E) = 0$, hence $\varphi_E = 0$. This implies that $\varphi$ is of the form $\psi e_1$ for $\psi : E_1 \to E_2$. But $ev(\psi) = 0$, which implies that $\psi = 0$. $\square$

The following strengthens Theorem 3.3.4 b):

3.7.2. **Proposition.** a) Let $G$ be a commutative algebraic $k$-group and let $E$ be a $\text{Gal}(\overline{k}/k)$-module, viewed as an étale sheaf over $\text{Sm}(k)$ ($E$ is not supposed to be constructible). Then $\text{Hom}(G, E) = 0$.

b) Let $\mathcal{F} \in \text{Shv}_1$ and $E$ as in a). Then any morphism $\mathcal{F} \to E$ factors canonically through $\pi_0(\mathcal{F})$.

**Proof.** a) Thanks to Proposition 3.7.1 we may assume $k$ algebraically closed. By Yoneda, $\text{Hom}(G, E)$ is a subgroup of $E(G)$ (it turns out to be the subgroup of multiplicative sections but we don’t need this). Since $E(k) \to E(G)$, any homomorphism from $G$ to $E$ is constant, hence 0.

b) follows immediately from a) and Proposition 3.3.3. $\square$
3.7.3. Lemma. Let $\mathcal{F} \in \text{Shv}_1$, $K$ a separably closed extension of $k$ and $M/K$ an algebraic extension. Then the map $\mathcal{F}(K) \to \mathcal{F}(M)$ is injective.

Proof. Consider a normalised representation of $\mathcal{F}$:

$$0 \to L \to G \xrightarrow{b} \mathcal{F} \to E \to 0.$$ (3.5)

The lemma then follows from an elementary chase in the diagram:

$$
\begin{array}{ccc}
0 & \longrightarrow & L(K) \longrightarrow G(K) \longrightarrow F(K) \longrightarrow E(K) \longrightarrow 0 \\
& \downarrow & \text{mono} \downarrow & \downarrow & \downarrow \\
0 & \longrightarrow & L(M) \longrightarrow G(M) \longrightarrow F(M) \longrightarrow E(M) \longrightarrow 0.
\end{array}
$$

□

3.7.4. Definition. We denote by $\mathcal{C}_{\text{AbS}}(k) = \mathcal{C}_{\text{AbS}}(k)$ the $\mathbb{Z}[1/p]$-linear category of commutative $k$-group schemes $G$ such that $G^0$ is semi-abelian and $\pi_0(G)$ is discrete. An object of $\mathcal{C}_{\text{AbS}}$ is called a semi-abelian scheme with torsion. We denote by $\text{AbS}$ the full subcategory of $\mathcal{C}_{\text{AbS}}$ formed by those $G$ such that $\pi_0(G)$ is a lattice.

3.7.5. Proposition. The functor

$$\mathcal{C}_{\text{AbS}} \to \text{Shv}_1$$

has a left adjoint/left inverse $\Omega$.

Proof. Let $\mathcal{F} \in \text{Shv}_1$ with normalised representation (3.5). As the set of closed subgroups of $H \subseteq G$ is Artinian, there is a minimal $H$ such that the composition

$$L \to G \to G/H$$

is trivial. Then $\mathcal{F}/b(H)$ represents an object $\Omega(\mathcal{F})$ of $\mathcal{C}_{\text{AbS}}$ and it follows from Proposition 3.3.3 b) that the universal property is satisfied. (In other words, $\Omega(\mathcal{F})$ is the quotient of $\mathcal{F}$ by the Zariski closure of $L$ in $G$.) □

3.7.6. Proposition. Let $f : \mathcal{F}_1 \to \mathcal{F}_2$ be a morphism in $\text{Shv}_1$. Assume that for any $n > 1$ prime to $p$, $f$ is an isomorphism on $n$-torsion and injective on $n$-cotorsion. Then $f$ is injective with lattice cokernel. If $f$ is even bijective on $n$-cotorsion, it is an isomorphism.
Proof. a) We first treat the special case where $F_1 = 0$. Consider multiplication by $n$ on the normalised presentation of $F_2$:

\[
\begin{array}{ccccccc}
0 & \longrightarrow & L & \longrightarrow & G & \longrightarrow & F_2 & \longrightarrow & E & \longrightarrow & 0 \\
0 & \longrightarrow & nL & \longrightarrow & nG & \longrightarrow & nF_2 & \longrightarrow & nE & \longrightarrow & 0.
\end{array}
\]

Since $L$ is torsion-free, $nG$ is injective for all $n$, hence $G = 0$ and $F_2 = E$. If moreover multiplication by $n$ is surjective for any $n$, we have $F_2 = 0$ since $E$ is finitely generated.

b) The general case. Split $f$ into two short exact sequences:

\[
\begin{array}{ccccccc}
0 & \longrightarrow & K & \longrightarrow & F_1 & \longrightarrow & I & \longrightarrow & 0 \\
0 & \longrightarrow & I & \longrightarrow & F_2 & \longrightarrow & C & \longrightarrow & 0.
\end{array}
\]

We get torsion/cotorsion exact sequences

\[
\begin{array}{ccccccc}
0 & \longrightarrow & nK & \longrightarrow & nF_1 & \longrightarrow & I/n & \rightarrow & K/n & \rightarrow & F_1/n & \rightarrow & I/n & \rightarrow & 0 \\
0 & \longrightarrow & nI & \longrightarrow & nF_2 & \rightarrow & C & \rightarrow & I/n & \rightarrow & F_2/n & \rightarrow & C/n & \rightarrow & 0.
\end{array}
\]

A standard diagram chase successively yields $nK = 0$, $nF_1 \sim nF_2$, $nF_1/n \sim I/n$, $K/n = 0$ and $nC = 0$. By a), we find $K = 0$ and $C$ a lattice, which is what we wanted. □

3.8. Presenting 1-motivic sheaves by group schemes. In this subsection, we give another description of the category $\text{Shv}_1$; it will be used in the next subsection.

3.8.1. Definition. We denote by $S_1^{\text{eff}}$ the full subcategory of $\text{tAbS}^{[-1,0]}$ consisting of those complexes $F = [F_1 \rightarrow F_0]$ such that

(i) $F_1$ is discrete (i.e. in $\text{tM}_0$);
(ii) $F_0$ is of the form $L_0 \oplus G$, with $L_0 \in \text{tM}_0$ and $G \in \text{SAb}$;
(iii) $F_1 \rightarrow F_0$ is a monomorphism;
(iv) $\text{Ker}(F_1 \rightarrow L_0)$ is free.

We call $S_1^{\text{eff}}$ the category of presentations.

We shall view $S_1^{\text{eff}}$ as a full subcategory of $\text{Shv}_1^{[-1,0]}$ via the functor $G \mapsto G$ which sends a group scheme to the associated representable sheaf. In this light, $F$ may be viewed as a presentation of $F := H_0(F)$. In the next definition, quasi-isomorphisms are also understood from this viewpoint.

3.8.2. Definition. We denote by $\Sigma$ the collection of quasi-isomorphisms of $S_1^{\text{eff}}$, by $S_1^{\text{h}}$ the homotopy category of $S_1^{\text{eff}}$ (Hom groups quotiented
by homotopies) and by $S_1 = \Sigma^{-1}\bar{S}^\text{eff}_1$ the localisation of $\bar{S}^\text{eff}_1$ with respect to (the image of) $\Sigma$.

The functor $F \mapsto H_0(F)$ induces a functor

\[(3.6) \quad h_0 : S_1 \to \text{Shv}_1.\]

Let $F = (F_1, L_0, G)$ be a presentation of $F \in \text{Shv}_1$. Let $L = \text{Ker}(F_1 \to L_0)$ and $E = \text{Coker}(F_1 \to L_0)$. Then we clearly have an exact sequence

\[(3.7) \quad 0 \to L \to G \to F \to E \to 0.\]

3.8.3. Lemma. Let $F = (F_1, L_0, G) \in S^\text{eff}_1$. Then, for any finite Galois extension $\ell/k$ such that $L_0$ is constant over $\ell$, there exists a q.i. $\tilde{F} \to F_1$, with $\tilde{F} = \left[\tilde{F}_1 \xrightarrow{\mathfrak{u}} \tilde{L}_0 \oplus G\right]$ such that $\mathfrak{u}$ is diagonal and $\tilde{L}_0$ is a free $\text{Gal}(\ell/k)$-module.

Proof. Just take for $\tilde{L}_0$ a free module projecting onto $L_0$ and for $\tilde{F}_1 \to \tilde{L}_0$ the pull-back of $F_1 \to L_0$. \qed

3.8.4. Lemma. The set $\Sigma$ admits a calculus of right fractions within $S^\text{eff}_1$ in the sense of (the dual of) [42, Ch. I, §2.3].

Proof. The statement is true by Lemma A.2.2 if we replace $S^\text{eff}_1$ by $\text{Shv}_{[1]}^{[-1,0]}$; but one easily checks that the constructions in the proof of Lemma A.2.2 preserve $S^\text{eff}_1$. \qed

3.8.5. Proposition. The functor $h_0$ of (3.6) is an equivalence of categories. In particular, $S_1$ is abelian.

Proof. Step 1. $h_0$ is essentially surjective. Let $F \in \text{Shv}_1$ and let (3.7) be the exact sequence attached to it by Proposition 3.3.3 b). We shall construct a presentation of $F$ from (3.7). Choose elements $f_1, \ldots, f_r \in F(\bar{k})$ whose images generate $E(\bar{k})$. Let $\ell/k$ be a finite Galois extension such that all $f_i$ belong to $F(\ell)$, and let $\Gamma = \text{Gal}(\ell/k)$. Let $\tilde{L}_0 = \mathbb{Z}[\Gamma]^r$ and define a morphism of sheaves $\tilde{L}_0 \to F$ by mapping the $i$-th basis element to $f_i$. Then $\text{Ker}(\tilde{L}_0 \to E)$ maps to $G/L$. Let $M_0$ be the kernel of this morphism, and let $L_0 = \tilde{L}_0/M_0$. Then $\tilde{L}_0 \to E$ factors into a morphism $L_0 \to E$, whose kernel $K$ injects into $G/L$.

Pick now elements $g_1, \ldots, g_s \in G(\bar{k})$ whose image in $G(\bar{k})/L(\bar{k})$ generate the image of $K(\bar{k})$, and $g_{s+1}, \ldots, g_t \in G(\bar{k})$ be generators of the image of $L(\bar{k})$. Let $\ell'/k$ be a finite Galois extension such that all the $g_i$ belong to $G(\ell')$, and let $\Gamma' = \text{Gal}(\ell'/k)$. Let $\tilde{F}_1 = \mathbb{Z}[\Gamma']^t$, and define a map $f : \tilde{F}_1 \to G$ by mapping the $i$-th basis element to $g_i$. By construction, $f^{-1}(L) = \text{Ker}(\tilde{F}_1 \to K)$ and $f' : f^{-1}(L) \to L$ is onto. Let
$M_1$ be the kernel of $f'$ and $F_1 = \tilde{F}_1/M_1$: then $\tilde{F}_1 \to K$ factors through $F_1$ and $\text{Ker}(F_1 \to K) = \text{Ker}(F_1 \to L_0) \sim \to L$. In particular, condition (iii) of Definition 3.8.1 is verified.

**Step 2.** $h_0$ is faithful. Let $f : F \to F'$ be a map in $S_1$ such that $h_0(f) = 0$. By Lemma 3.8.4, we may assume that $f$ is an effective map (i.e. comes from $S_1^\text{eff}$). We have $f(L_0 \oplus G) \subseteq \text{Im}(L_1' \to L_0' \oplus G')$, hence $f|_G = 0$ and $f(L_0)$ is contained in $\text{Im}(L_1' \to L_0' \oplus G')$. Pick a finite Galois extension $\ell/k$ such that $L_0$ and $L_1'$ are constant over $\ell$. By Lemma 3.8.3, take a $q.i.$ $u : [\tilde{F}_1 \to \tilde{L}_0] \to [F_1 \to L_0]$ such that $\tilde{L}_0$ is $\text{Gal}(\ell/k)$-free. Then the composition $\tilde{L}_0 \to L_0 \to \text{Im}(L_1' \to L_0' \oplus G')$ lifts to a map $s : \tilde{L}_0 \to L_1'$, which defines a homotopy between 0 and $fu$.

**Step 3.** $h_0$ is full. Let $F, F' \in S_1$ and let $\varphi : \mathcal{F} \to \mathcal{F}'$, where $\mathcal{F} = h_0(F)$ and $\mathcal{F}' = h_0(F')$. In particular, we get a map $\varphi_G : G \to G'$ and a map $\psi : L_0 \to L_0' \oplus G'/F'_1$. Let $\ell/k$ be a finite Galois extension such that $L_0'$ is constant over $\ell$. Pick a $q.i.$ $u : \tilde{F} \to F$ as in Lemma 3.8.3 such that $\tilde{L}_0$ is $\text{Gal}(\ell/k)$-free. Then $\psi u$ lifts to a map $\tilde{\psi} : \tilde{L}_0 \to L_0' \oplus G'$. The map
\[ f = (\tilde{\psi}, \varphi_G) : \tilde{L}_0 \oplus G \to L_0' \oplus G' \]
sends $\tilde{F}_1$ into $F_1'$ by construction, hence yields a map $f : \tilde{F} \to F'$ such that $h_0(fu^{-1}) = \varphi$. $\square$

**3.8.6. Corollary.** The obvious functor
\[ S_1 \to D^b(\text{Shv}_1) \]
is fully faithful.

**Proof.** The composition of this functor with $H_0$ is the equivalence $h_0$ of Proposition 3.8.5. Therefore it suffices to show that the restriction of $H_0$ to the image of $S_1$ is faithful. This is obvious, since the objects of this image are homologically concentrated in degree 0. $\square$

**3.9. The transfer structure on 1-motivic sheaves.** Recall the category $^t \text{AbS}$ from Definition 3.7.4. Lemma 1.3.2 provides a functor
\[ (3.8) \quad \rho : ^t \text{AbS} \to \text{HI}_{\text{et}}[1/p]. \]

The aim of this subsection is to prove:

**3.9.1. Proposition.** The functor (3.8) extends to a full embedding
\[ \rho : \text{Shv}_1 \hookrightarrow \text{HI}_{\text{et}}[1/p] \]
where $\text{HI}_{\text{et}}$ is the category of Definitions 1.3.1 and D.1.2. This functor is exact with thick image (i.e. stable under extensions).
**Proof.** By Proposition 3.8.5, it suffices to construct a functor $\rho : S_1 \to \text{HI}_\text{et}[1/p]$. First define a functor $\tilde{\rho} : S_\text{eff}^1 \to \text{HI}_\text{et}[1/p]$ by

$$\tilde{\rho}(\mathcal{F}_1 \to \mathcal{F}_0) = \text{Coker}(\rho(\mathcal{F}_1) \to \rho(\mathcal{F}_0)),$$

using (3.8). Note that the forgetful functor $f : \text{HI}_\text{et} \to \text{Shv}_\text{et}(\text{Sm}(k))$ is faithful and exact, hence conservative. This first gives that $\tilde{\rho}$ factors into the desired $\rho$.

Proposition 3.3.3 d) says that $f\rho$ is (fully faithful and) exact. Since $f$ is faithful, $\rho$ is fully faithful and exact.

It remains to show that $\rho$ is thick. Recall that $\text{Shv}_1$ is thick in $\text{Shv}_\text{et}(\text{Sm}(k))[1/p]$ by Theorem 3.4.1. Since $f$ is exact, we are then left to show:

**3.9.2. Lemma.** The transfer structure on a sheaf $\mathcal{F} \in \text{Shv}_1$ is unique.

**Proof.** Let $\mu$ be the transfer structure on $\mathcal{F}$ given by the beginning of the proof of Proposition 3.9.1, and let $\mu'$ be another transfer structure. Thus, for $X, Y \in \text{Sm}(k)$, we have two homomorphisms

$$\mu, \mu' : \mathcal{F}(X) \otimes c(Y, X) \to \mathcal{F}(Y)$$

and we want to show that they are equal. We may clearly assume that $Y$ is irreducible.

Let $F = k(Y)$ be the function field of $Y$. Since $\mathcal{F}$ is a homotopy invariant Zariski sheaf with transfers, the map $\mathcal{F}(Y) \to \mathcal{F}(F)$ is injective by [98, Cor. 4.19]. Thus we may replace $Y$ by $F$.

Moreover, it follows from the fact that $\mathcal{F}$ is an étale sheaf and from Lemma 3.7.3 that $\mathcal{F}(F) \hookrightarrow \mathcal{F}(\overline{F})$, where $\overline{F}$ is an algebraic closure of $F$. Thus, we may even replace $Y$ by $\overline{F}$.

Then the group $c(Y, X)$ is replaced by $c(\overline{F}, X) = Z_0(X_{\overline{F}})$. Since $\overline{F}$ is algebraically closed, all closed points of $X_{\overline{F}}$ are rational, hence all finite correspondences from $\text{Spec} \overline{F}$ to $X$ are linear combinations of morphisms. Therefore $\mu$ and $\mu'$ coincide on them. \[ \square \]

This concludes the proof of Proposition 3.9.1. \[ \square \]

3.10. 1-motivic sheaves and DM. Recall from Definition D.1.2 the subcategory $\text{HI}_\text{et}^s \subset \text{HI}_\text{et}$ of strictly homotopy invariant étale sheaves with transfers: this is a full subcategory of $\text{DM}_\text{eff, et}^s$. By Proposition D.1.4, we have

$$\text{HI}_\text{et}^s = \{ \mathcal{F} \otimes_{\mathbb{Z}} \mathbb{Z}[1/p] \mid \mathcal{F} \in \text{HI}_\text{et} \}.$$ 

The introduction of $\text{Shv}_1$ is now made clear by the following
3.10.1. **Theorem.** Let $\text{Shv}_1^s \subseteq \text{HI}^s_{\text{ét}}$ be the full subcategory image of $\text{Shv}_1$ by the functor $F \mapsto F[1/p]$ of Lemma D.1.3. Then $\text{Shv}_1 \to \text{Shv}_1^s$ is an equivalence of categories. Moreover, let $M \in d_{\leq 1} \text{DM}_{\text{gm, ét}}^{\text{eff}}$. Then for all $i \in \mathbb{Z}$, $\mathcal{H}_i(M) \in \text{Shv}_1^s$. In particular, there is a $t$-structure on $d_{\leq 1} \text{DM}_{\text{gm, ét}}^{\text{eff}}$, with heart $\text{Shv}_1^s$; it is induced by the homotopy $t$-structure of Corollary D.3.3 on $\text{DM}_{\text{fr, ét}}^{\text{eff}}$ (see Definition D.2.1 and Theorem D.2.2).

**Proof.** The first assertion is clear since $\text{HI}^s_{\text{ét}} \to \text{HI}_{\text{ét}} \to \text{HI}_{\text{ét}}[1/p]$ is an equivalence of categories by Proposition D.1.4. By Proposition 3.3.3, we reduce to the case $M = M(C), C \xrightarrow{P} \text{Spec } k$ a smooth projective curve. By Proposition 2.5.2, the cohomology sheaves of $M(C)$ belong to $\text{Shv}_1^s$: for $\mathcal{H}^1$ this is clear and for $\mathcal{H}^2$ it is a (trivial) special case of Proposition 3.5.1. □

Note that the functor $M_1 \to \text{HI}_{\text{ét}}^{[0,1]}$ refines to a functor $M_1 \to \text{Shv}_1^{[0,1]}$, hence, using Lemma A.2.1 again, we get a composed triangulated functor

$$\text{(3.9)} \quad \text{tot} : D^b(M_1[1/p]) \to D^b(\text{Shv}_1^{[0,1]}) \to D^b(\text{Shv}_1)$$

refining the one from Lemma 2.2.1 (same proof). We then get:

3.10.2. **Corollary.** The two functors

$$D^b(M_1[1/p]) \xrightarrow{\text{tot}} D^b(\text{Shv}_1) \to d_{\leq 1} \text{DM}_{\text{gm, ét}}^{\text{eff}}$$

are equivalences of categories.

**Proof.** For the composition, this is Theorem 2.1.2. This implies that the second functor is full and essentially surjective, and to conclude, it suffices by Lemma A.1.1 to see that it is conservative. But this follows immediately from Theorem 3.10.1. Note that by Proposition D.1.4 we have that $\text{Shv}_1^s \simeq \text{Shv}_1$ (see Theorem 3.10.1 for the definition of $\text{Shv}_1^s$). □

3.10.3. **Definition.** We call the $t$-structure defined on $D^b(M_1[1/p])$ or on $d_{\leq 1} \text{DM}_{\text{gm, ét}}^{\text{eff}}$ by Corollary 3.10.2 the homotopy $t$-structure.

3.10.4. **Remark** (cf. §1.9). In [15], A. Bertapelle defines an integral version of the category $\text{Shv}_1^{\text{fppf}}$ of Remark 3.4.2 and constructs an equivalence of categories

$$D^b(M_1) \simeq D^b(\text{Shv}_1^{\text{fppf}})$$

without inverting $p$ (not going via DM). Hence the homotopy $t$-structure of Definition 3.10.3 exists integrally.
3.11. Extensions of 1-motivic sheaves, II. The aim of this subsection is to prove:

3.11.1. Proposition. Let $\mathcal{F}_1, \mathcal{F}_2 \in \text{Shv}_1$. Then the natural map

$$\text{Ext}^i_{\text{EST}[1/p]}(\mathcal{F}_1, \mathcal{F}_2) \to \text{Ext}^i_{\text{Shv}_{\text{et}}(\text{Sm}(k))[1/p]}(\mathcal{F}_1, \mathcal{F}_2)$$

is bijective for $i = 0, 1$. Here we implicitly used the full embedding $\text{Shv}_1 \hookrightarrow \text{HI}_s \hookrightarrow \text{EST}[1/p]$ from Theorem 3.10.1.

Proof. a) $i = 0$. Injectivity is obvious. Surjectivity: we have to show that, for any $f : \mathcal{F}_1 \to \mathcal{F}_2$ in $\text{Shv}_{\text{et}}(\text{Sm}(k))[1/p]$ and any finite correspondence $\gamma : X \to Y$, the diagram

$$\begin{array}{ccc}
\mathcal{F}_1(X) & \xrightarrow{f_X} & \mathcal{F}_2(X) \\
\gamma^* & & \gamma^* \\
\mathcal{F}_1(Y) & \xrightarrow{f_Y} & \mathcal{F}_2(Y)
\end{array}$$

commutes. As in the proof of Lemma 3.9.2, we may assume $X$ connected and then replace it by the algebraic closure of its function field, which trivialises the correspondence $\gamma$.

b) $i = 1$. Injectivity: let $0 \to \mathcal{F}_2 \to \mathcal{F} \to \mathcal{F}_1 \to 0$ be an extension in $\text{EST}[1/p]$ which becomes split in $\text{Shv}_{\text{et}}(\text{Sm}(k))[1/p]$. Let $f : \mathcal{F}_1 \to \mathcal{F}$ be a section of the projection in $\text{Shv}_{\text{et}}(\text{Sm}(k))[1/p]$. By a), $f$ is a morphism in $\text{EST}[1/p]$, hence $\mathcal{F}$ is split in $\text{EST}[1/p]$. Surjectivity: let $0 \to \mathcal{F}_0 \to \mathcal{F} \to \mathcal{F}_1 \to 0$ be an extension in $\text{Shv}_{\text{et}}(\text{Sm}(k))[1/p]$. By Theorem 3.4.1, $\mathcal{F} \in \text{Shv}_1$. $\square$

3.12. Comparing $t$-structures. In this subsection, we want to compare the homotopy $t$-structure of Definition 3.10.3 with the motivic $t$-structure of Theorem 1.6.1 a).

Let $C \in D^b(\mathcal{M}_1[1/p])$. Recall from 1.8.7 the notation $^tH_\eta(C) \in ^t\mathcal{M}_1[1/p]$ for its homology relative to the torsion 1-motivic $t$-structure from Theorem 1.6.1. We also write $\mathcal{H}^\eta(C) \in \text{Shv}_1$ for its cohomology objects of relative to the homotopy $t$-structure.

Consider the functor $\text{tot}$ of (3.9). Let $\mathcal{F}$ be a 1-motivic sheaf and $(G, b)$ its associated normalised pair (see Proposition 3.3.3 a)). Let $L = \text{Ker} b$ and $E = \text{Coker} b$. In $D^b(\mathcal{M}_1[1/p])$, we have an exact triangle

$$[L \to G][1] \to \text{tot}^{-1}(\mathcal{F}) \to [E \to 0] \to$$

(see Corollary 3.10.2). This shows:
3.12.1. **Lemma.** We have

\[ ^tH_0(\text{tot}^{-1}(\mathcal{F})) = [E \to 0] \]

\[ ^tH_1(\text{tot}^{-1}(\mathcal{F})) = [L \to G] \]

\[ ^tH_q(\text{tot}^{-1}(\mathcal{F})) = 0 \text{ for } q \neq 0, 1. \]

On the other hand, given a 1-motive (with torsion or cotorsion) \( M = [L \to G] \), we clearly have

\[ H^0(M) = \text{Ker } f \]

\[ H^1(M) = \text{Coker } f \]

(3.10)

\[ H^q(M) = 0 \text{ for } q \neq 0, 1. \]

by considering it as a complex of length 1 of 1-motivic sheaves.

In particular, \( ^t\mathcal{M}_1[1/p] \cap \text{Shv}_1 = \text{Shv}_0 \), \( ^t\mathcal{M}_1[1/p] \cap \text{Shv}_1[−1] \) consists of quotients of semi-abelian varieties by discrete subsheaves and \( ^t\mathcal{M}_1[1/p] \cap \text{Shv}_1[q] = 0 \) for \( q \neq 0, −1 \).

Here is a more useful result relating \( H^i \) with the two motivic \( t \)-structures:

3.12.2. **Proposition.** Let \( C \in D^b(\mathcal{M}_1[1/p]) \); write \( [L_i \to G_i] \) for \( ^tH_i(C) \) and \( [L^i \to G^i] \) for \( ^tH^i(C) \).

Then we have exact sequences in \( \text{Shv}_1 \):

\[ \cdots \to L_{i+1} \overset{u_{i+1}}{\to} G_{i+1} \to H_i(C) \to L_i \overset{u_i}{\to} G_i \to \cdots \]

\[ \cdots \to L^{i-1} \overset{u^{i-1}}{\to} G^{i-1} \to H^i(C) \to L^i \overset{u^i}{\to} G^i \to \cdots \]

**Proof.** For the first one, argue by induction on the length of \( C \) with respect to the motivic \( t \)-structure with heart \( ^t\mathcal{M}_1[1/p] \) (the case of length 0 is (3.10)). For the second one, same argument with the other motivic \( t \)-structure.

Note finally that the homotopy \( t \)-structure is far from being invariant under Cartier duality: this can easily be seen by using Proposition 3.8.5.

3.13. **Ext** with and without transfers. As we have already mentioned in the proof of Proposition 3.2.1 Grothendieck-Breen spectral sequences [27] provide a method for computing Ext of commutative group schemes regarded as sheaves for a suitable Grothendieck topology. Actually, this method applies to sheaves with transfers as well.

\[ ^7 \text{Note that } (L_i, G_i) \text{ and } (L^i, G^i) \text{ are determined only up to the relevant q.i.'s.} \]
We keep the notations of §1.3 and §3.1. For simplicity, we write
\[ \text{Ext}^i = \text{Ext}^i_{\text{Shv}_{\text{et}}(\text{Sm}(k))[1/p]}; \quad \text{Ext}^i_{\text{tr}} = \text{Ext}^i_{\text{EST}[1/p]}. \]

Following Breen [27, §2] consider the abelian category \( \text{PST}(k, \mathbb{Z}[1/p]) \) of presheaves on \( \text{SmCor}(k) \otimes \mathbb{Z}[1/p] \) (we now drop \( \mathbb{Z}[1/p] \)). For \( P \in \text{PST}(k) \) we obtain Breen’s complex \( A_N(P) \) of presheaves with transfers (cf. [27, (2.5)]). Recall [70, 6.18] that the inclusion \( \text{EST}(k) \hookrightarrow \text{PST}(k) \) has an exact left adjoint \( a_\text{ét} \) which commutes with the forgetful functors to sheaves and presheaves without transfers. For a sheaf \( F \in \text{EST}(k) \) we obtain \( a_\text{ét} A_N(F) \): Breen’s complex of étale sheaves with transfers.

As \( \text{EST}(k) \) has enough injectives (see [70, 6.19]) we get the canonical spectral sequences \( E_{1}^{p,q} = \text{Ext}^{p+q}_{\text{tr}}(F, G) \rightarrow \cdots \) associated to the double complex \( \text{Hom}_{\text{tr}}(a_\text{ét} A_{N}(F), G) \) for any injective resolution \( G \in \text{EST}(k) \).

Now suppose that \( F = G \in \text{EST}(k) \) is representable by a smooth commutative \( k \)-algebraic group \( G \) as in the Lemma 1.3.2. For \( G \in \text{EST}(k) \) we have the analogue with transfers of [27, Lemma 1]

(3.11) \[ \text{Ext}^p_{\text{tr}}(L(G), G) \cong H^p_{\text{ét}}(G, G) \]

(see [70, 6.24]). We also have natural maps

\[ E_{2}^{p,1} = \text{Ext}^p_{\text{tr}}(G, G) \rightarrow E_{2}^{p,1} = \text{Ext}^p(G, G) \]

given by forgetting transfers. Now the same conclusions as in [27, §7 − §10] apply with transfers. This yields:

3.13.1. \textbf{Lemma.} Suppose \( k = \overline{k} \). Then, we have \( \text{Ext}^i_{\text{tr}}(F_1, F_2) = 0 \) for and \( F_1, F_2 \in \text{Sh}_{1} \) and any \( i \geq 2 \) (remember that we work with \( p \) inverted).

\textbf{Proof.} Using the définition of 1-motivic sheaves, the same dévissage as in the proof of Proposition 3.2.1 reduces us to the following basic cases for \( F_1 \) and \( F_2 \): \( \mathbb{Z}/m, \mathbb{Z} \), or a semi-abelian variety. In case \( F_1 \) is a semi-abelian variety, the proof is strictly parallel to that of Proposition 3.2.1 in view of the above remarks. If \( F_1 = \mathbb{Z} \), we have \( \text{Ext}^i_{\text{tr}}(F_1, F_2) = H^i_{\text{ét}}(k, F_2) = 0 \) for \( i > 0 \). Finally, if \( F_1 = \mathbb{Z}/m \), the exact sequence

\[ \text{Ext}^i_{\text{tr}}(\mathbb{Z}, F_2) \rightarrow \text{Ext}^i_{\text{tr}}(\mathbb{Z}/m, F_2) \rightarrow \text{Ext}^i_{\text{tr}}(\mathbb{Z}, F_2) \xrightarrow{m} \text{Ext}^{i+1}_{\text{tr}}(\mathbb{Z}, F_2) \]

gives the conclusion. \( \square \)

We now get back to the case of an arbitrary perfect field \( k \). Recall that the category \( \text{EST} \) has enough injectives [70, 6.19] so that we can define \( \mathcal{E}xt^i_{\text{tr}}(F, G) \in \text{EST} \) as the derived functors of \( \mathcal{H}om_{\text{tr}}(F, G) \). We need:
3.13.2. Lemma. Let $K/k$ be an algebraically closed extension. Write $\mathcal{F} \mapsto \mathcal{F}_K$ for the natural functor $\text{EST}(k) \to \text{EST}(K)$. Then, for $\mathcal{F}, \mathcal{G} \in \text{EST}(k)$, we have isomorphisms, natural in $\mathcal{F}, \mathcal{G}, K$:

$$\text{Ext}^i_{\text{tr}}(\mathcal{F}_K, \mathcal{G}_K) \simeq \text{Ext}^i_{\text{tr}}(\mathcal{F}, \mathcal{G})(K) := \lim_{\to U} \text{Ext}^i_{\text{tr}}(\mathcal{F}, \mathcal{G})(U)$$

where the colimit is taken on the inverse system of dominant $k$-morphisms $\text{Spec} K \to U, U \in \text{Sm}(k)$, with affine transition morphisms.

Proof. Working in the unbounded derived category $D(\text{EST})$, $\text{Ext}^i_{\text{tr}}(\mathcal{F}, \mathcal{G})$ is the étale sheaf associated to the presheaf $U \mapsto H^i(U, \mathcal{R}\text{Hom}(\mathcal{F}, \mathcal{G}))$. The latter is computed by a double adjunction:

$$H^i(U, \mathcal{R}\text{Hom}(\mathcal{F}, \mathcal{G})) \simeq \text{Hom}(L(U) \otimes \mathcal{F}, \mathcal{G})[i] \simeq \text{Hom}(\mathcal{F}, \mathcal{R}\text{Hom}(L(U), \mathcal{G})[i]).$$

Note that there are no “convergence” issues in these isomorphisms since $L(U), \mathcal{F}$ and $\mathcal{G}$ are sheaves.

The map

$$\mathcal{H}\text{om}(L(U), \mathcal{G})[0] \to \mathcal{R}\text{Hom}(L(U), \mathcal{G})$$

yields a map

$$\text{Ext}^i(\mathcal{F}, \mathcal{H}\text{om}(L(U), \mathcal{G})) \to \text{Hom}(\mathcal{F}, \mathcal{R}\text{Hom}(L(U), \mathcal{G})[i])$$

which becomes an isomorphism in the colimit, because so does (3.12). So it is sufficient to produce compatible maps

$$\text{Ext}^i(\mathcal{F}, \mathcal{H}\text{om}(L(U), \mathcal{G})) \to \text{Ext}^i(\mathcal{F}_K, \mathcal{G}_K)$$

and to show that they yield an isomorphism in the colimit.

Let $0 \to \mathcal{H}\text{om}(L(U), \mathcal{G}) \to \mathcal{G}_1 \to \cdots \to \mathcal{G}_i \to \mathcal{F} \to 0$ be a Yoneda extension, hence its image under the exact functor $(-)_K$:

$$0 \to \mathcal{H}\text{om}(L(U), \mathcal{G})_K \to (\mathcal{G}_1)_K \to \cdots \to (\mathcal{G}_i)_K \to \mathcal{F}_K \to 0.$$

The monoidal functor $(-)_K$ applied to the evaluation morphism yields a map

$$\mathcal{H}\text{om}(L(U), \mathcal{G})_K \to \mathcal{H}\text{om}(L(U)_K, \mathcal{G}_K) = \mathcal{H}\text{om}(L(U_K), \mathcal{G}_K).$$

The map $\text{Spec} K \to U$ give a rational point of $U_K$, hence a morphism $\mathbb{Z} \to L(U_K)$ and a morphism $\mathcal{H}\text{om}(L(U), \mathcal{G})_K \to \mathcal{G}_K$. Pushing out by this morphism gives a Yoneda extension of $\mathcal{F}_K$ by $\mathcal{G}_K$, hence (3.13).

To show bijectivity in the colimit, we may reduce by Voevodsky’s canonical resolutions to the case $\mathcal{F} = L(X)$ for some $X \in \text{Sm}(k)$. Then $\mathcal{F}_K = L(X_K)$ and [70, 6.24] converts (3.13) into

$$H^i_{\text{ét}}(X \times U, \mathcal{G}) \to H^i_{\text{ét}}(X_K, \mathcal{G}).$$
The bijectivity now follows from the commutation of étale cohomology with filtering inverse limits of schemes with affine transition morphisms. □

3.13.3. **Proposition.** For \( F_1, F_2 \in \text{Shv}_1 \), the étale sheaves with transfers \( \mathcal{E}xt^i_{tr}(F_1, F_2) \) are homotopy invariant for all \( i \geq 0 \). These sheaves are \( p \)-primary torsion for \( i \geq 2 \).

**Proof.** These are the cohomology sheaves of \( \mathcal{R} \text{Hom}^{\text{EST}[1/p]}(F_1, F_2) \), which belongs to \( \text{DM}^{\text{eff}, \text{ét}} \) because so does \( F_2 \) (compare [70, Rk. 14.12]). Since \( \mathcal{R} \text{Hom}^{\text{EST}[1/p]}(F_1, F_2) \) is obviously friendly in the sense of Definition D.2.1, the first claim follows from Proposition D.3.1.

We may now apply Gersten’s principle (Proposition 2.4.1 c)) to \( G = \mathcal{E}xt^i_{tr}(F_1, F_2) \). This says that \( G \) is \( p \)-primary torsion if and only if \( G(K_s) \) is \( p \)-primary torsion for any separable closure \( K_s \) of the function field \( K \) of a smooth \( K \)-variety. By a transfer argument, \( \text{Ker}(G(K_s) \to G(\overline{K})) \) is \( p \)-primary torsion if \( \overline{K} \) is an algebraic closure of \( K \), so we may even replace \( K_s \) by \( \overline{K} \). The second claim now follows from Lemmas 3.13.1 and 3.13.2. □

3.13.4. **Theorem.** Let \( F_1, F_2 \in \text{Shv}_1 \). Then

a) The natural homomorphism of sheaves

\[
\hat{f}^n : \omega \mathcal{E}xt^n_{tr}(F_1, F_2) \to \mathcal{E}xt^n(F_1, F_2)
\]

is an isomorphism for all \( n \geq 0 \), where \( \omega : \text{EST}[1/p] \to \text{Shv}_{\text{ét}}(\text{Sm}(K))[1/p] \) is the (exact) forgetful functor. These sheaves are 0 for \( n \geq 2 \).

b) \( \mathcal{E}xt^n_{tr}(F_1, F_2) \in \text{Shv}_1 \) for any \( n \geq 0 \).

c) The natural homomorphism of abelian groups

\[
\hat{f}^n : \text{Ext}^n_{tr}(F_1, F_2) \to \text{Ext}^n(F_1, F_2)
\]

is an isomorphism for all \( n \geq 0 \).

**Proof.** Since c) follows from a) by the local to global spectral sequences, we are left to prove a) and b). If \( n \geq 2 \), the right hand side is 0 by Proposition 3.2.1 b) and a dévissage. The left hand side is also 0 by Proposition 3.13.3.

Suppose now \( n \leq 1 \). The assertion is local for the étale topology, so we reduce by dévissage to the same basic cases as in the proof of Lemma 3.13.1; we may even reduce from discrete to \( \mathbb{Z} \) and from semi-abelian varieties to \( \mathbb{G}_m \) and abelian varieties. We may argue as for \( n \geq 2 \) whenever we know that \( \mathcal{E}xt^n(F_1, F_2) = 0 \) and \( \text{Ext}^n_{tr}(F_1 K, (F_2) K) = 0 \) for any algebraically closed extension \( K \) of \( k \). This is the case except when:
\[ \text{If } n = 0: \mathcal{F}_1 = \mathbb{Z}, (\mathcal{F}_1, \mathcal{F}_2) = (\mathbb{G}_m, \mathbb{G}_m), (\mathcal{F}_1, \mathcal{F}_2) = (A, B), \text{ } A, B \text{ abelian varieties.} \]

\[ \text{If } n = 1: (\mathcal{F}_1, \mathcal{F}_2) = (A, \mathbb{G}_m), A \text{ an abelian variety.} \]

By the same technique as in 2.6.a, we may further reduce to the case where \( A \) above is of the form \( \mathcal{J}(C) \) for \( C \) a smooth projective curve with a rational point.

When \( n = 0 \) and \( F_1 = \mathbb{Z} \), \( f^n \) is the identity map \( F_2 \rightarrow F_2 \). If \( F_1 = \mathbb{G}_m \) or \( \mathcal{J}(C) \), we may write both sides in a) as direct summands of \( R_\pi^* \pi_* \mathcal{F}_2 \) for \( \pi : X \rightarrow \text{Spec } k \) with \( X = \mathbb{A}^1 - \{0\} \) or \( C \), and the isomorphism is clear.

This completes the proof of a). b) is obvious for \( n \geq 2 \) and is proven for \( n = 0, 1 \) by the same dévissage as above.

Adopting the notation in §2.5 we obtain:

3.13.5. **Corollary.** Let \( C_1, C_2 \in d_{\leq 1} \text{DM}_{\text{gm, ét}}^\text{eff} \). Then \( \text{Hom}_{\text{ét}}(C_1, C_2) \in d_{\leq 1} \text{DM}_{\text{gm, ét}}^\text{eff} \).

**Proof.** This follows from Theorem 3.13.4 b) by dévissage, using Theorem 3.10.1.

---

3.14. **t-exactness.** Theorem 2.1.2 and Corollary 3.13.5 provide the category \( D^b(\mathcal{M}_1[1/p]) \) with an internal \( \text{Hom} \text{Hom}_1 \), which is by construction left exact with respect to the homotopy \( t \)-structure of Definition 3.10.3. We now show:

3.14.1. **Theorem.** The bifunctor \( \text{Hom}_1 \) is left exact with respect to the two \( t \)-structures with respective hearts \( ^1\mathcal{M}_1[1/p] \) and \( ^1\mathcal{M}_1[1/p] \). It becomes \( t \)-exact after tensoring with \( \mathbb{Q} \).

**Proof.** By dévissage, it suffices to check that \( \text{Hom}_1(M, N) \) is \( t \)-concentrated in degrees 0, 1 if \( M, N \) are 1-motives with (co)torsion which have pure weight after tensoring with \( \mathbb{Q} \), and that moreover \( ^1H^1(\text{Hom}_1(M, N)) \) resp. \( ^1H^1(\text{Hom}_1(M, N)) \) is torsion. We do the case of 1-motives with torsion; the other case is checked by a similar computation.

If \( L \) is discrete, write \( L \) for \( [L \rightarrow 0] \), and if \( G \) is semi-abelian, write \( G[-1] \) for \( [0 \rightarrow G] \). Also write \( A \) for an abelian variety and \( T \) for a
torus. and \( \mathcal{H}om, \mathcal{E}xt \) the étale sheaves \( \mathcal{H}om \) and \( \mathcal{E}xt \). Then

\[
^{t}H^{i}(\mathcal{H}om_{1}(L, L')) = \begin{cases} 
\mathcal{H}om(L, L') & \text{for } i = 0 \\
\mathcal{E}xt(L', L') & \text{for } i = 1 \\
0 & \text{else.}
\end{cases}
\]

\[
^{t}H^{i}(\mathcal{H}om_{1}(L, G'[-1])) = \begin{cases} 
\mathcal{H}om(L/L_{\text{tors}}, G')[-1] & \text{for } i = 0 \\
\mathcal{H}om(L_{\text{tors}}, G') & \text{for } i = 1 \\
0 & \text{else.}
\end{cases}
\]

\[
^{t}H^{i}(\mathcal{H}om_{1}(G[-1], L')) = \begin{cases} 
\mathcal{E}xt(G, L'_{\text{tors}}) & \text{if } i = 0 \\
0 & \text{else.}
\end{cases}
\]

\[
^{t}H^{i}(\mathcal{H}om_{1}(T[-1], T'[-1])) = \begin{cases} 
\mathcal{H}om(T, T') & \text{if } i = 0 \\
0 & \text{else.}
\end{cases}
\]

\[
\mathcal{H}om_{1}(T[-1], A'[-1]) = 0.
\]

\[
^{t}H^{i}(\mathcal{H}om_{1}(A[-1], T'[-1])) = \begin{cases} 
\mathcal{E}xt(A, T')[-1] & \text{if } i = 0 \\
0 & \text{else.}
\end{cases}
\]

\[
^{t}H^{i}(\mathcal{H}om_{1}(A[-1], A'[-1])) = \begin{cases} 
\mathcal{H}om(A, A') & \text{if } i = 0 \\
0 & \text{else.}
\end{cases}
\]

In this display, we use for example that \( \mathcal{E}xt(A, T') \) has the structure of an abelian variety when \( A \) is an abelian variety and \( T' \) a torus, and that \( \mathcal{H}om(A, A') \) is a lattice when \( A, A' \) are two abelian varieties. This completes the proof. \( \square \)

4. Comparing two dualities

In this section, we show that the classical Cartier duality for 1-motives is compatible with a “motivic Cartier duality” on triangulated motives, described in Definition 4.5.2 below.

4.1. Biextensions of 1-motives. This material is presumably well-known to experts, and the only reason why we write it up is that we could not find it in the literature. Exceptionally, we put 1-motives in degrees \(-1\) and \(0\) in this subsection and in the next one, for compatibility with Deligne’s conventions in [32].

Recall (see [32, §10.2]) that for \( M_{1} = [L_{1} \xrightarrow{u_{1}} G_{1}] \) and \( M_{2} = [L_{2} \xrightarrow{u_{2}} G_{2}] \) two complexes of abelian sheaves over some site \( S \), concentrated in degrees \(-1\) and \(0\), a biextension of \( M_{1} \) and \( M_{2} \) by an abelian sheaf \( H \) is given by a (Grothendieck) biextension \( P \) of \( G_{1} \) and \( G_{2} \) by \( H \) and a pair of compatible trivializations of the biextensions of \( L_{1} \times G_{2} \)
and $G_1 \times L_2$ obtained by pullbacks. Let $\text{Biext}(M_1, M_2; H)$ denote the group of isomorphism classes of biextensions. We have the following fundamental formula (see [32, §10.2.1]):

\[(4.1) \quad \text{Biext}(M_1, M_2; H) = \text{Ext}^1_S(M_1 \otimes L M_2, H).\]

Suppose now that $M_1$ and $M_2$ are two Deligne 1-motives. Since $G_1$ and $G_2$ are smooth, we may compute biextensions by using the étale topology. Hence, we shall take here

$$S = \text{Sm}(k)_{\text{ét}}.$$  

Let $M^*_2$ denote the Cartier dual of $M_2$ as constructed by Deligne (see [32, §10.2.11] and [11, §0]) along with the Poincaré biextension $P_{M_2} \in \text{Biext}(M_2, M^*_2; \mathbb{G}_m)$. We also have the transpose $^t P_{M_2} = P_M \in \text{Biext}(M_2, M_2; \mathbb{G}_m)$. Pulling back $^t P_{M_2}$ yields a map

\[(4.2) \quad \gamma_{M_1, M_2} : \text{Hom}(M_1, M^*_2) \to \text{Biext}(M_1, M_2; \mathbb{G}_m) \quad \varphi \mapsto (\varphi \times 1_{M_1})^t(P_{M_2})\]

which is clearly additive and natural in $M_1$.

4.1.1. Proposition. The map $\gamma_{M_1, M_2}$ yields a natural equivalence of functors from 1-motives to abelian groups, i.e. the functor

$$M_1 \mapsto \text{Biext}(M_1, M_2; \mathbb{G}_m)$$

on 1-motives is representable by the Cartier dual $M^*_2$. Moreover, $\gamma_{M_1, M_2}$ is also natural in $M_2$.

Proof. We start with a few lemmas:

4.1.2. Lemma. For $q \leq 0$, we have

$$\text{Hom}_k(M_1 \otimes M_2, \mathbb{G}_m[q]) = 0.$$  

Proof. For $q < 0$ this is trivial and for $q = 0$ this is [32, Lemma 10.2.2.1].

4.1.3. Lemma. Let $\overline{k}$ be an algebraic closure of $k$ and $G = \text{Gal}(\overline{k}/k)$. Then

$$\text{Hom}_k(M_1, M^*_2) \longrightarrow \text{Hom}_G(M_1, M^*_2)^G$$

$$\text{Biext}_k(M_1, M_2; \mathbb{G}_m) \longrightarrow \text{Biext}_G(M_1, M_2; \mathbb{G}_m)^G.$$  

Proof. The first isomorphism is obvious. For the second, thanks to (4.1) we may use the spectral sequence

$$H^p(G, \text{Hom}_k(M_1 \otimes M_2, \mathbb{G}_m[q])) \Rightarrow \text{Hom}_k(M_1 \otimes M_2, \mathbb{G}_m[p + q]).$$
(This is the only place in the proof of Proposition 4.1.1 where we shall use (4.1).) The assertion then follows from Lemma 4.1.2. □

Lemma 4.1.3, reduces the proof of Proposition 4.1.1 to the case where \( k \) is algebraically closed, which we now assume. The following is a special case of this proposition:

4.1.4. Lemma. The map \( \gamma_{M_1, M_2} \) is an isomorphism when \( M_1 \) and \( M_2 \) are abelian varieties \( A_1 \) and \( A_2 \), and is natural in \( A_2 \).

Again this is certainly well-known and explicitly mentioned as such in [SGA7, VII, p. 176, (2.9.6.2)]. Unfortunately we have not been able to find a proof in the literature, so we provide one for the reader’s convenience.

Proof. We shall use the universal property of the Poincaré bundle [74, Th. p. 125]. Let \( P \in \text{Biext}(A_1, A_2) \). Then

1. \( P|_{A_1 \times \{0\}} \) is trivial;
2. \( P|_{\{(a)\} \times A_2} \in \text{Pic}^0(A_2) \) for all \( a \in A_1(k) \).

Indeed, (1) follows from the multiplicativity of \( P \) on the \( A_2 \)-side. For (2) we offer two proofs (note that they use multiplicativity on different sides):

- By multiplicativity on the \( A_1 \)-side, \( a \mapsto P|_{\{(a)\} \times A_2} \) gives a homomorphism \( A_1(k) \to \text{Pic}(A_2) \). Composing with the projection to \( \text{NS}(A_2) \) gives a homomorphism from a divisible group to a finitely generated group, which must be trivial.

- (More direct but more confusing): we have to prove that \( T_b^* P|_{\{(a)\} \times A_2} = P|_{\{(a)\} \times A_2} \) for all \( b \in A_2(k) \). Using simply \( a \) to denote the section \( \text{Spec} k \to A_1 \) defined by \( a \), we have a commutative diagram

\[
\begin{array}{ccc}
A_2 & \xrightarrow{a \times 1_{A_2}} & A_1 \times A_2 \\
\downarrow T_b & & \downarrow 1_{A_1 \times T_b} \\
A_2 & \xrightarrow{a \times 1_{A_2}} & A_1 \times A_2.
\end{array}
\]

Let \( \pi_1 : A_1 \to \text{Spec} k \) and \( \pi_2 : A_2 \to \text{Spec} k \) be the two structural maps. Then by multiplicativity on the \( A_2 \)-side, an easy computation gives

\[
(1_{A_1} \times T_b)^* P = P \otimes (1_{A_1} \times (\pi_2 \circ b))^* P.
\]

Applying \((a \times 1_{A_2})^* \) to this gives the result since \((a \times 1_{A_2})^* \circ (1_{A_1} \times (\pi_2 \circ b))^* P = \pi_{A_2}^* P_{a,b} \) is trivial.
By the universal property of the Poincaré bundle, there exists a unique morphism\(^8\) \(f : A_1 \to A'_2\) such that \(P \simeq (f \times 1_{A_2})^*(tP_{A_2})\). It remains to see that \(f\) is a homomorphism: for this it suffices to show that \(f(0) = 0\). But

\[
\mathcal{O}_{A_2} \simeq P_{\{0\} \times A_2} = (0 \times 1_{A_2})^* \circ (f \times 1_{A_2})^*(tP_{A_2}) = (f(0) \times 1_{A_2})^*(tP_{A_2}) = (P_{A_2}|_{A_2 \times \{f(0)\}} = f(0)
\]

where the first isomorphism holds by multiplicativity of \(P\) on the \(A_1\)-side.

Finally, the naturality in \(A_2\) reduces to the fact that, if \(f : A_1 \to A'_2\), then \((f \times 1_{A_2})^*(tP_{A_2}) \simeq (1_{A_1} \times f')^*(P_{A_1})\). This follows from the description of \(f'\) on \(k\)-points as the pull-back by \(f\) of line bundles. \(\square\)

We also have the following easier

4.1.5. **Lemma.** Let \(L\) be a lattice and \(A\) an abelian variety. Then the natural map

\[
\text{Hom}(L, A') \to \text{Biext}(L[0], A[0]; \mathbb{G}_m)
\]

\[
f \mapsto (1 \times f)^*(tP_A)
\]

is bijective.

**Proof.** Reduce to \(L = \mathbb{Z}\); then the right hand side can be identified with \(\text{Ext}(A, \mathbb{G}_m)\) and the claim comes from the Weil-Barsotti formula. \(\square\)

Let us now come back to our two 1-motives \(M_1, M_2\). We denote by \(L_i, T_i\) and \(A_i\) the discrete, toric and abelian parts of \(M_i\) for \(i = 1, 2\). Let us further denote by \(u'_i : L'_i \to A'_i\) the map corresponding to \(G_i\) under the isomorphism \(\text{Ext}(A_i, T_i) \simeq \text{Hom}(L'_i, A'_i)\) where \(L'_i = \text{Hom}(T_i, \mathbb{G}_m)\) and \(A'_i = \text{Pic}^0(A_i)\).

We shall use the symmetric avatar \((L_i, A_i, L'_i, A'_i, \psi_i)\) of \(M_i\) (see [32, 10.2.12] or [11, p. 17]): recall that \(\psi_i\) denotes a certain section of the Poincaré biextension \(P_{A_i} \in \text{Biext}(A_i, A'_i; \mathbb{G}_m)\) over \(L_i \times L'_i\). The symmetric avatar of the Cartier dual is \((L'_i, A'_i, L_i, A_i, \psi'_i)\). By loc. cit. a map of 1-motives \(\varphi : M_1 \to M_2^*\) is equivalent to a homomorphism \(f : A_1 \to A'_2\) of abelian varieties and, if \(f'\) is the dual of \(f\), liftings \(g\) and \(g'\) of \(fu_1\) and \(f'u_2\) respectively, i.e. to the following commutative

\[\text{(diagram)}\]

\(^8\)For convenience we denote here by \(A'\) the dual of an abelian variety \(A\) and by \(f'\) the dual of a homomorphism \(f\) of abelian varieties.
squares

\[
\begin{array}{ccc}
L_1 & \xrightarrow{g} & L_2 \\
\downarrow {u_1} & & \downarrow {u_2} \\
A_1 & \xrightarrow{f} & A_2
\end{array}
\quad \text{and} \quad
\begin{array}{ccc}
L_2 & \xrightarrow{g'} & L_1' \\
\downarrow {u_2'} & & \downarrow {u_1'} \\
A_2 & \xrightarrow{f'} & A_1'
\end{array}
\]

under the condition that

\[
(4.4) \quad (1_{L_1} \times g')^* \psi_1 = (g \times 1_{L_2})^* \psi_2 \text{ on } L_1 \times L_2.
\]

Now let \((P, \tau, \sigma)\) be a biextension of \(M_1\) and \(M_2\) by \(\mathbb{G}_m\), i.e. a biextension \(P \in \text{Biext}(G_1, G_2; \mathbb{G}_m)\), a section \(\tau\) on \(L_1 \times G_2\) and a section \(\sigma\) on \(G_1 \times L_2\) such that

\[
(4.5) \quad \tau \mid_{L_1 \times L_2} = \sigma \mid_{L_1 \times L_2}.
\]

We have to show that \((P, \tau, \sigma) = (\varphi \times 1)^* (tP_{A_2}, \tau_2, \sigma_2)\) for a unique \(\varphi : M_1 \to M_2\), where \(\tau_2\) and \(\sigma_2\) are the universal trivializations.

Recall that \(\text{Biext}(G_1, G_2; \mathbb{G}_m) = \text{Biext}(A_1, A_2; \mathbb{G}_m)\) (cf. [32, 10.2.3.9]) so that, by Lemma 4.1.4, \(P\) is the pull-back to \(G_1 \times G_2\) of \((f \times 1_{A_2})^* (tP_{A_2})\) for a unique homomorphism \(f : A_1 \to A_2\). We thus have obtained the map \(f\) and its dual \(f'\) in (4.3), and we now want to show that the extra data \((\tau, \sigma)\) come from a pair \((g, g')\) in a unique way.

We may view \(E = (fu_1 \times 1_{A_2})^* (tP_{A_2})\) as an extension of \(L_1 \otimes A_2\) by \(\mathbb{G}_m\). Consider the commutative diagram of exact sequences

\[
\begin{array}{ccccccccc}
0 & \to & 0 & \to & L_1 \otimes T_2 & \to & L_1 \otimes T_2 & \to & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\
0 & \to & \mathbb{G}_m & \to & Q & \to & L_1 \otimes G_2 & \to & 0 \\
\mid & & \mid & & \mid & & \mid & & \mid \\
0 & \to & \mathbb{G}_m & \to & E & \to & L_1 \otimes A_2 & \to & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\
0 & \to & 0 & \to & 0 & \to & 0
\end{array}
\]

where \(i_2\) (resp. \(p_2\)) is the inclusion \(T_2 \hookrightarrow G_2\) (resp. the projection \(G_2 \to A_2\)). The section \(\tau\) yields a retraction \(\tilde{\tau} : Q \to \mathbb{G}_m\) whose restriction to \(L_1 \otimes T_2\) yields a homomorphism

\[
\tilde{g} : L_1 \otimes T_2 \to \mathbb{G}_m
\]
which in turn defines a homomorphism as in (4.3). We denote the negative of this morphism by $g$.

4.1.6. Lemma. With this choice of $g$, the left square of (4.3) commutes and $\tau = (g \times 1_{G_2})^* \tau_2$.

Proof. To see the first assertion, we may apply $\text{Ext}^*(\cdot, \mathbb{G}_m)$ to (4.6) and then apply [20, Lemma 2.8] to the corresponding diagram. Here is a concrete description of this argument: via the map of Lemma 4.1.5, $u_2'\gamma_2$ goes to the following pushout

$$
\begin{array}{ccccccccc}
0 & \longrightarrow & L_1 \otimes T_2 & \xrightarrow{\mathbf{1} \otimes q_2} & L_1 \otimes G_2 & \xrightarrow{\mathbf{1} \otimes p_2} & L_1 \otimes A_2 & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow \pi \tau & & \downarrow & & \\
0 & \longrightarrow & \mathbb{G}_m & \longrightarrow & E & \longrightarrow & L_1 \otimes A_2 & \longrightarrow & 0
\end{array}
$$

because, due to the relation $i \tilde{\tau} + \tau \pi' = 1$, the left square in this diagram commutes.

In particular, we have

$$
Q = (1 \otimes p_2)^* (f u_1 \otimes 1)^* P_{A_2} = (f u_1 \otimes p_2)^* P_{A_2}
$$

$$
= (u_2' \gamma \otimes p_2)^* P_{A_2} = (g \otimes 1)^* (u_2' \otimes p_2)^* P_{A_2}.
$$

For the second assertion, since $\text{Hom}(L_1 \otimes A_2, \mathbb{G}_m) = 0$ it suffices to check the equality after restricting to $L_1 \otimes T_2$. This is clear because under the isomorphism $\text{Hom}(L_1 \otimes T_2, \mathbb{G}_m) = \text{Hom}(L_1, L_1')$, the canonical trivialization $\psi_1$ corresponds to the identity.

Note that if we further pullback we obtain that

$$
(4.7) \quad \tau |_{L_1 \times L_2} = \psi_2 |_{L_1 \times L_2}.
$$

The same computation with $\sigma$ yields a map

$$
g' : L_2 \rightarrow L_1'
$$

and the same argument as in Lemma 4.1.6 shows that with this choice of $g'$ the right square of (4.3) commutes. We now use that $P = (1_{A_1} \times f')^* (P_{A_1})$, which follows from the naturality statement in Lemma 4.1.4. As in the proof of Lemma 4.1.6, this implies that its trivialization $\sigma$ on $G_1 \times L_2$ is the pullback of the canonical trivialization $\psi_1$ on $G_1 \times L_1'$ along $1_{G_1} \times g' : G_1 \times L_2 \rightarrow G_1 \times L_1$. In particular:

$$
(4.8) \quad \sigma |_{L_1 \times L_2} = \psi_1 |_{L_1 \times L_2}.
$$

Put together, (4.5), (4.7) and (4.8) show that Condition (4.4) is verified: thus we get a morphism $\varphi : M_1 \rightarrow M_2'$. Let $h : G_1 \rightarrow G_2'$ be its group component. It remains to check that $\sigma = (h \times 1_{L_2})^* \sigma_2$. As in the proof of Lemma 4.1.6 we only need to check this after restriction.
to $T_1 \otimes L_2$. But the restriction of $h$ to the toric parts is the Cartier dual of $g'$, so we conclude by the same argument.

Finally, let us show that $\gamma_{M_1,M_2}$ is natural in $M_2$. This amounts to comparing two biextensions. For the bitorsors this follows from Lemma 4.1.4 and for the sections we may argue again as in the proof of Lemma 4.1.6.

\[ \square \]

4.2. Biextensions of complexes of 1-motives. Let $\mathcal{A}$ be a category of abelian sheaves, and consider two bounded complexes $C_1, C_2$ of objects of $\mathcal{A}^{[-1,0]}$. Let $H \in \mathcal{A}$. We have a double complex

\[
\text{Biext}(C_1, C_2; H)^{p,q} := \text{Biext}(C_1^p, C_2^q; H).
\]

4.2.1. Definition. A biextension of $C_1$ and $C_2$ by $H$ is an element of the group of cycles

\[
\text{Biext}(C_1, C_2; H) := Z^0(\text{TotBiext}(C_1, C_2; H)).
\]

Here $\text{Tot}$ denotes the total complex associated to a double complex.

Concretely: such a biextension $P$ is given by a collection of biextensions $P_p \in \text{Biext}(C_1^p, C_2^{-p}; H)$ such that, for any $p$,

\[
(d_1^p \otimes 1)^*P_{p+1} = (1 \otimes d_2^{-p-1})^*P_p
\]

where $d_1$ (resp. $d_2$) are the differentials of $C_1$ (resp. of $C_2$).

Now suppose that $\mathcal{A}$ is the category of fppf sheaves, that $H = \mathbb{G}_m$ and that all the $C_i$ are Deligne 1-motives. By Lemma 4.1.2, we have

\[
\text{Ext}^i(C_1^p, C_2^q; \mathbb{G}_m) = 0 \text{ for } i \leq 0.
\]

Therefore, a spectral sequence argument yields an edge homomorphism

\[
\text{Biext}(C_1, C_2; \mathbb{G}_m) \rightarrow \text{Ext}^1(C_1^L \otimes C_2^L, \mathbb{G}_m).
\]

Recall that Deligne’s Cartier duality [32] provides an exact functor

\[
M \mapsto M^* : \mathcal{M}_1[1/p] \rightarrow \mathcal{M}_1[1/p]
\]

yielding by Proposition 1.8.4 a triangulated functor

\[
(\ )^* : D^b(\mathcal{M}_1[1/p]) \rightarrow D^b(\mathcal{M}_1[1/p]).
\]

Note that for a complex of 1-motives

\[
C = (\cdots \rightarrow M^i \rightarrow M^{i+1} \rightarrow \cdots)
\]

we can compute $C^*$ by means of the complex

\[
C^* = (\cdots \rightarrow (M^{i+1})^* \rightarrow (M^i)^* \rightarrow \cdots)
\]

of Cartier duals here placed in degrees ..., $-i-1$, $-i$, etc.
Let us now take in (4.9) $C_1 = C$, $C_2 = C^*$. For each $p \in \mathbb{Z}$, we have the Poincaré biextension $P_p \in \text{Biext}(C^p, (C^p)^*; \mathbb{G}_m)$. By Proposition 4.1.1, the $\{P_p\}$ define a class in $\text{Biext}(C, C^*; \mathbb{G}_m)$.

4.2.2. Definition. This class $P_C$ is the Poincaré biextension of the complex $C$.

Let $C_1, C_2 \in C^b(\mathcal{M}_1)$. As in Subsection 4.1, pulling back $tP_C = P_C^* \in \text{Biext}(C_1, C_1^*; \mathbb{G}_m)$ yields a map generalising (4.2):

$$\gamma_{C_1, C_2} : \text{Hom}(C_1, C_2^*) \to \text{Biext}(C_1, C_2^*; \mathbb{G}_m) \quad \varphi \mapsto (\varphi \times 1_{C_1})^*(tP_C).$$

which is clearly additive and natural in $C_1$. We then have the following trivial extension of the functoriality in Proposition 4.1.1:

4.2.3. Proposition. $\gamma_{C_1, C_2}$ is also natural in $C_2$. \hfill \Box

4.3. A pairing with finite coefficients. In this section, we assume that $k$ is algebraically closed.

If $C$ is a complex of 1-motives and $n > 1$ is prime to $\text{char } k$, we define

$$C/n = \text{cone}(C \xrightarrow{n} C)$$

the mapping cone of multiplication by $n$. This defines a functor on $C^b(\mathcal{M}_1)$; we clearly have a natural isomorphism

$$C^*/n \simeq (C/n[-1])^* \simeq (C/n)^*[1].$$

This functor and this natural isomorphism are easily seen to pass to $D^b(\mathcal{M}_1)$. Composition of morphisms now yields a pairing (Hom groups computed in $D^b(\mathcal{M}_1)$):

$$\text{Hom}(\mathbb{Z}, C/n) \times \text{Hom}(\mathbb{Z}, C^*/n) = \text{Hom}(\mathbb{Z}, C/n) \times \text{Hom}(\mathbb{Z}, (C/n)^*[1])$$

$$\simeq \text{Hom}(\mathbb{Z}, C/n) \times \text{Hom}(C/n, \mathbb{Z}^*[1]) \to \text{Hom}(\mathbb{Z}, \mathbb{Z}^*[1]) = k^*.$$

4.3.1. Lemma. For any $C \in C^b(\mathcal{M}_1)$, the map $C/n \xrightarrow{n} C/n$ is homotopic to 0.

Proof. We may embed 1-motives in a category of complexes of sheaves of length 1, and then the proof is standard. \hfill \Box

This lemma implies that the above pairing refines into a pairing

$$\text{Hom}(\mathbb{Z}, C/n) \times \text{Hom}(\mathbb{Z}, C^*/n) \to \mu_n.$$  

4.3.2. Theorem. This pairing is perfect.
Proof. Convert (4.12) into a morphism

\[ \text{Hom}(\mathbb{Z}, C/n) \to \text{Hom}(\text{Hom}(\mathbb{Z}, C^*/n), \mu_n). \]

This map is clearly natural in \( C \), hence by d\'evissage we may check that it is an isomorphism on “generators” \( C = N[i], \) \( i \in \mathbb{Z}, \) where \( N \) is a 1-motive. We may further reduce to \( N = [\mathbb{Z} \to 0], [0 \to \mathbb{G}_m] \) or \([0 \to A]\) where \( A \) is an abelian variety.

It is convenient to replace \( D^b(\mathcal{M}_1) \) by \( D^b(\mathcal{M}_1) \) (Theorem 1.6.1), which allows us to represent \( N/n \) by

\[
\begin{cases}
[Z/n \to 0][0] & \text{if } N = [\mathbb{Z} \to 0] \\
[\mu_n \to 0][0] & \text{if } N = [0 \to \mathbb{G}_m] \\
[nA \to 0][0] & \text{if } N = [0 \to A].
\end{cases}
\]

This implies that \( \text{Hom}(\mathbb{Z}, N[i]/n) = 0 \) if \( i \neq 0 \) (the best way to see this is to use the functor Tot). Suppose \( i = 0 \). In the cases \( N = [\mathbb{Z} \to 0] \) or \([0 \to \mathbb{G}_m]\), the pairing is easily seen to be the obvious pairing \( \mathbb{Z}/n \times \mu_n \to \mu_n \) or \( \mu_n \times \mathbb{Z}/n \to \mu_n \), which is clearly perfect. In the case \( N = [0 \to A] \), so that \( N^* = [0 \to A'] \) is the dual abelian variety, we get a pairing

\[ nA \times nA' \to \mu_n \]

which is by construction the Weil pairing (see [74, IV.20] and [72, §16]). Therefore it is perfect too. \( \square \)

4.4. Comparing two Ext groups. The aim of this subsection is to prove:

4.4.1. Proposition. Let \( C_1, C_2, C_3 \in d_{\leq 1} \text{DM}_{\text{gm, ét}} \). Then the forgetful triangulated functors

\[ \text{DM}_{\text{eff, ét}}(k) \overset{i}{\to} D^-(\text{EST}[1/p]) \overset{\omega}{\to} D^-(\text{Shv}_{\text{ét}}(\text{Sm}(k))) \]

induce an isomorphism

\[ \text{Hom}_{\text{DM}_{\text{eff, ét}}} (C_1 \otimes C_2, C_3[q]) \overset{\sim}{\to} \text{Hom}_{D^-(\text{Shv}_{\text{ét}})} (C_1 \otimes C_2, C_3[q]) \]

for any \( q \in \mathbb{Z} \).

Proof. By adjunction, it is enough to provide isomorphisms

\[ \text{Hom}_{\text{DM}_{\text{eff, ét}}} (C_1, \text{Hom}_{\text{ét}}(C_2, C_3)[q]) \overset{\sim}{\to} \text{Hom}_{D^-(\text{Shv}_{\text{ét}})} (C_1, \text{Hom}(C_2, C_3)[q]) \]

where the right hand \( \text{Hom} \) is the (partially defined) internal Hom of \( D^-(\text{Shv}_{\text{ét}}(\text{Sm}(k))) \); note that \( \text{Hom}_{\text{ét}}(C_2, C_3) \) is well-defined and belongs to \( d_{\leq 1} \text{DM}_{\text{gm, ét}} \) by Corollary 3.13.5. For this, it suffices to prove that
the composite functor $\omega i$ of Proposition 4.4.1 carries $\text{Hom}_{\text{ét}}(C_2, C_3)$ to (the well-defined) $\text{Hom}(C_2, C_3)$.

We first note that $i$ carries $\text{Hom}_{\text{ét}}(C_2, C_3)$ to the internal Hom of $D^-(\text{EST}[1/p])$ (compare [70, Rk. 9.28]). Since $\text{Hom}_{\text{ét}}(iC_2, iC_3)$ belongs to $D^+(\text{EST}[1/p])$, it suffices to show that the natural map in $D^+(\text{Shv}_\text{ét}(\text{Sm}(k)))$

$$\omega \text{Hom}_{\text{ét}}(C_2, C_3) \to \text{Hom}(\omega iC_2, \omega iC_3)$$

is an isomorphism. By dévissage, we reduce to the case where $C_2$ and $C_3$ are single sheaves of $\text{Shv}_1$ concentrated in degree 0, and the claim follows from Theorem 3.13.4 a) \hfill \Box

4.5. Two Cartier dualities. Recall the internal Hom $\text{Hom}_{\text{ét}}$ from §2.5. We define

$$D^\text{ét}_{\leq 1}(M) := \text{Hom}_{\text{ét}}(M, \mathbb{Z}(1))$$

for any object $M \in \text{DM}^\text{eff}_{\text{gm, ét}}$.

We now want to compare the duality (4.10) with the following duality on triangulated 1-motives:

4.5.1. Proposition. The functor $D^\text{ét}_{\leq 1}$ restricts to a self-duality ($\bigvee$) (anti-equivalence of categories) on $d_{\leq 1} \text{DM}^\text{eff}_{\text{gm, ét}}$.

Proof. It suffices to compute on motives of smooth projective curves $M(C)$. Then it is obvious in view of Proposition 2.5.2 c) \hfill \Box

4.5.2. Definition. For $M \in d_{\leq 1} \text{DM}^\text{eff}_{\text{gm, ét}}$, we say that $M^\vee$ is the motivic Cartier dual of $M$.

Note that motivic Cartier duality exchanges Artin motives and Tate motives, e.g. $\mathbb{Z}^\vee = \mathbb{Z}(1)$. We are going to compare it with the Cartier duality on $D^b(\mathcal{M}_1[1/p])$ (see Proposition 1.8.4) via Theorem 2.1.2.

For two complexes of 1-motives $C_1$ and $C_2$, by composing (4.11) and (4.9) and applying Proposition 4.2.3, we get a bifunctorial morphism

$$\text{Hom}(C_1, C_2^\vee) \to \text{Biext}(C_1, C_2; \mathbb{G}_m) \to \text{Hom}(C_1 \otimes C_2, \mathbb{G}_m[-1])$$

where the right hand side is computed in the derived category of étale sheaves. This natural transformation trivially factors through $D^b(\mathcal{M}_1[1/p])$.

From Proposition 4.4.1 and [70, Thm. 4.1], taking $C_3 = \mathbb{Z}(1) \equiv \mathbb{G}_m[-1]$, it follows that the map (4.14) may be reinterpreted as a natural transformation

$$\text{Hom}_{D^b(\mathcal{M}_1[1/p])}(C_1, C_2^\vee) \to \text{Hom}_{d_{\leq 1} \text{DM}^\text{eff}_{\text{gm, ét}}}((\text{Tot}(C_1), \text{Tot}(C_2)^\vee)).$$
Now we argue à la Yoneda: taking $C_1 = C$ and $C_2 = C^*$, the image of the identity yields a canonical morphism of functors:

$$\eta_C : \text{Tot}(C^*) \to \text{Tot}(C)^\vee.$$ 

4.5.3. Theorem. The natural transformation $\eta$ is an isomorphism of functors.

Proof. It suffices to check this on 1-motives, since they are dense in the triangulated category $D^b(M_1[1/p])$. Using Yoneda again and the previous discussion, it then follows from Theorem 2.1.2 and the isomorphisms (4.1) and (4.2) (the latter being proven in Proposition 4.1.1). The following commutative diagram explains this:

\[
\begin{array}{ccc}
\text{Hom}(N, M^*) & \xrightarrow{\text{Th. 2.1.2}} & \text{Hom}(\text{Tot}(N), \text{Tot}(M^*)) \\
\downarrow i \quad (4.1)+(4.2) & & \downarrow \eta \\
\mathbb{E}xt^1_{\text{Sm}(k)_{\text{ét}}}(N \overset{L}{\otimes} M, G_m) & \xleftarrow{\text{Prop. 4.4.1}} & \text{Hom}(\text{Tot}(N), \text{Tot}(M)^\vee).
\end{array}
\]
Part 2. The functors $L\text{Alb}$ and $RPic$

5. Definition of $L\text{Alb}$ and $RPic$

The aim of this section is to construct the closest integral approximation to a left adjoint of the full embedding $Tot$ of Definition 2.7.1. In order to work it out, we first recollect some ideas from [94]. We shall show in Theorem 6.2.1 that the functor $L\text{Alb}$ of Definition 5.2.1 does provide a left adjoint to $Tot$ after we tensor Hom groups with $\mathbb{Q}$: this will provide a proof of Pretheorems announced in [94, Preth. 0.0.18] and [95]. See Remark 5.2.2 for an integral caveat.

5.1. Motivic Cartier duality. Recall the functor $D_{\leq 1}^{\text{ét}} : \text{DM}^{\text{eff}}_{\text{gm, ét}} \to \text{DM}^{\text{eff}}_{-\text{ét}}$ of (4.13). On the other hand, by Corollary D.3.3 and Theorem D.2.2, we may consider truncation on $\text{DM}^{\text{eff}}_{\text{gm, ét}}$ with respect to the homotopy $t$-structure. We have:

5.1.1. Lemma. Let $p : X \to \text{Spec} k$ be a smooth variety. Then the truncated complex $\tau_{\leq 2} D_{\leq 1}^{\text{ét}}(M_{\text{ét}}(X))$ belongs to $d_{\leq 1} \text{DM}^{\text{eff}}_{\text{gm, ét}}$ (here we set $M_{\text{ét}}(X) := \alpha^* M(X)$).

Proof. Recall that $Z_{\text{ét}}(1) = \mathbb{G}_m[1/p][-1]$ so that this is a consequence of an analogue of Proposition 2.5.2 a) and b) in higher dimension. In fact, the nonvanishing cohomology sheaves are $\mathcal{H}^1 = R_{\pi_0(X)/k} \mathbb{G}_m[1/p]$ and $\mathcal{H}^2 = \text{Pic}_{X/k}[1/p]$. Both belong to $\text{Shv}_1$ by Proposition 3.5.1, hence the claim follows from Theorem 3.10.1.

Unfortunately, $\mathcal{H}^i(D_{\leq 1}^{\text{ét}}(M_{\text{ét}}(X)))$ does not belong to $d_{\leq 1} \text{DM}^{\text{eff}}_{\text{gm, ét}}$ for $i > 2$ in general: indeed, it is well-known that this is a torsion sheaf of cofinite type, with nonzero divisible part in general (for $i \geq 3$ and in characteristic 0, its corank is equal to the $i$-th Betti number of $X$). It might be considered as an ind-object of $d_{\leq 0} \text{DM}^{\text{eff}}_{\text{gm, ét}}$, but this would take us too far. To get around this problem, we shall restrict to the standard category of geometric triangulated motives of [96], $\text{DM}^{\text{eff}}_{\text{gm}}$.

Let us denote by $D_{\leq 1}^{\text{Nis}}$ the same functor as $D_{\leq 1}^{\text{ét}}$ in the category $\text{DM}^{\text{eff}}$, defined with the Nisnevich topology. Let as before $\alpha^* : \text{DM}^{\text{eff}}_{-\text{ét}} \to \text{DM}^{\text{eff}}_{\text{gm, ét}}$ denote the “change of topology” functor.

5.1.2. Lemma. a) For any smooth $X$ with motive $M(X) \in \text{DM}^{\text{eff}}_{\text{gm}}$, we have

$$\alpha^* D_{\leq 1}^{\text{Nis}} M(X) \xrightarrow{\sim} \tau_{\leq 2} D_{\leq 1}^{\text{ét}} \alpha^* M(X).$$

b) The functor $\alpha^* D_{\leq 1}^{\text{Nis}}$ induces a triangulated functor

$$\alpha^* D_{\leq 1}^{\text{Nis}} : \text{DM}^{\text{eff}}_{\text{gm}} \to d_{\leq 1} \text{DM}^{\text{eff}}_{\text{gm, ét}}.$$
Proof. a) This is the weight 1 case of the Beilinson-Lichtenbaum conjecture (here equivalent to Hilbert’s theorem 90.) b) follows from a) and Lemma 5.1.1. □

5.1.3. Definition. We denote by \( d_{\leq 1} : \text{DM}_{\text{gm}}^{\text{eff}} \to d_{\leq 1} \text{DM}_{\text{gm, ét}} \) the composite functor \( D_{\text{ét}}^{\leq 1} \circ \alpha^* \circ D_{\text{Nis}}^{\leq 1} \).

Thus, for \( M \in \text{DM}_{\text{gm}}^{\text{eff}} \), we have

\[
d_{\leq 1}(M) = \text{Hom}_{\text{ét}}(\alpha^* \text{Hom}_{\text{Nis}}(M, \mathbb{Z}(1)), \mathbb{Z}(1)).
\]

The evaluation map \( M \otimes \text{Hom}_{\text{Nis}}(M, \mathbb{Z}(1)) \to \mathbb{Z}(1) \) then yields a canonical map

\[
a_M : \alpha^* M \to d_{\leq 1}(M)
\]

for any object \( M \in \text{DM}_{\text{gm}}^{\text{eff}} \). We call \( a_M \) the motivic Albanese map associated to \( M \) for reasons that will appear later.

5.1.4. Proposition. The restriction of \( a_M \) to \( d_{\leq 1} \text{DM}_{\text{gm}}^{\text{eff}} \) is an isomorphism of functors. In particular, we have an equality

\[
\alpha^* D_{\leq 1}(\text{DM}_{\text{gm}}^{\text{eff}}) = \alpha^* d_{\leq 1} \text{DM}_{\text{gm}}^{\text{eff}}.
\]

Proof. For the first claim, we reduce to the case \( M = M(C) \) where \( C \) is a smooth proper curve. The argument is then exactly the same as in Proposition 4.5.1, using (2.2). The other claim is then clear. □

5.2. Motivic Albanese.

5.2.1. Definition. The motivic Albanese functor

\( \text{LAlb} : \text{DM}_{\text{gm}}^{\text{eff}} \to D^b(\mathcal{M}_1[1/p]) \)

is the composition of \( d_{\leq 1} \) with a quasi-inverse to the equivalence of categories of Theorem 2.1.2.

5.2.2. Remark. With this definition we get the following form of (5.2)

\[
a_M : \alpha^* M \to \text{Tot} \text{LAlb}(M)
\]

By Theorem 2.1.2, we then have the following relationship between \( \text{LAlb} \) and the functor \( \text{Tot} \) of Definition 2.7.1: for \( M \in \text{DM}_{\text{gm}}^{\text{eff}} \) and \( N \in D^b(\mathcal{M}_1[1/p]) \), the map \( a_M \) of (5.2) induces a map

\[
\text{Hom}(\text{LAlb}(M), N) \to \text{Hom}(\alpha^* M, \text{Tot}(N)).
\]

In Section 6, we prove that this map is an isomorphism rationally, showing that \( \text{LAlb} \) yields a left adjoint of \( \text{Tot} \) after \( \text{Hom} \) groups have been tensored with \( \mathbb{Q} \). However, it is not so in general: \textit{e.g.} take
$M = \mathbb{Z}(2), N = \mathbb{Z}/n$ (n prime to p). Then $\text{LAlb} M = 0$ because $\text{Hom}_{\text{Nis}}(\mathbb{Z}(2), \mathbb{Z}(1)) = 0$, but

$$\text{Hom}(\alpha^* M, \text{Tot}(N)) = H^0_{\text{et}}(k, \mathbb{Z}/n(-2))$$

which is in general nonzero.

The same example shows that Tot does not have a left adjoint. Indeed, suppose that such a left adjoint exists, and let us denote it by $\text{LAlb}^{\text{ét}}$. For simplicity, suppose $k$ algebraically closed. Let $n \geq 2$. For any $m > 0$, the exact triangle in $\text{DM}^{\text{eff}}_{\text{gm, ét}}$

$$\mathbb{Z}(n) \to \mathbb{Z}(n) \to \mathbb{Z}/m(\mathbb{Z}(n)) + 1 \to$$

must yield an exact triangle

$$\text{LAlb}^{\text{ét}} \mathbb{Z}(n) \to \text{LAlb}^{\text{ét}} \mathbb{Z}(n) \to \text{LAlb}^{\text{ét}} \mathbb{Z}/m(n) \to$$

Since Tot is an equivalence on torsion objects, so must be $\text{LAlb}^{\text{ét}}$. Since $k$ is algebraically closed, $\mathbb{Z}/m(n) \simeq \mu^\infty_m$ is constant, hence we must have $\text{LAlb}^{\text{ét}} \mathbb{Z}/m(n) \simeq [\mathbb{Z}/m \to 0]$. Hence, multiplication by $m$ must be bijective on the 1-motives $H^q(\text{LAlb}^{\text{ét}}(\mathbb{Z}(n)))$ for all $q \neq 0, 1$, which forces these 1-motives to vanish. For $q = 0, 1$ we must have exact sequences

$$0 \to H^0(\text{LAlb}^{\text{ét}}(\mathbb{Z}(n))) \to H^0(\text{LAlb}^{\text{ét}}(\mathbb{Z}(n))) \to [\mathbb{Z}/m \to 0]$$

which force either $H^0 = [\mathbb{Z} \to 0], H^1 = 0$ or $H^0 = 0, H^1 = [0 \to \mathbb{G}_m]$. But both cases are impossible as one easily sees by computing

$$\text{Hom}(M(\mathbb{P}^n), \text{Tot}([\mathbb{Z} \to 0])[2n + 1]) = H^{2n+1}_{\text{ét}}(\mathbb{P}^n, \mathbb{Z})[1/p]$$

$$\simeq H^{2n}_{\text{ét}}(\mathbb{Q}, \mathbb{Q}/\mathbb{Z}) \simeq (\mathbb{Q}/\mathbb{Z})'$$

via the trace map, where $(\mathbb{Q}/\mathbb{Z})' = \bigoplus_{l \neq p} \mathbb{Q}_l/\mathbb{Z}_l$.

Presumably, $\text{LAlb}^{\text{ét}}$ does exist with values in a suitable pro-category containing $D^b(M_1[1/p])$, and sends $\mathbb{Z}(n)$ to the complete Tate module of $\mathbb{Z}(n)$ for $n \geq 2$. Note that, by 8.1.c below, $\text{LAlb}(\mathbb{Z}(n)) = 0$ for $n \geq 2$, so that the natural transformation $\text{LAlb}^{\text{ét}}(\alpha^* M) \to \text{LAlb}(M)$ will not be an isomorphism of functors in general.

5.3. Motivic Pic.

5.3.1. Definition. The motivic Picard functor (a contravariant functor) is the functor

$$\text{RPic} : \text{DM}^{\text{eff}}_{\text{gm}} \to D^b(M_1[1/p])$$

given by $\text{Tot}^{-1} \alpha^* D^N_{\text{Nis}}$ (cf. Definition 5.2.1).
For $M \in \text{DM}_{\text{gm}}^{\text{eff}}$ we then have the following tautology

$$(\text{Tot } \text{RPic}(M))^\vee = \text{Tot } \text{LAlb}(M).$$

Actually, from Theorem 4.5.3 we deduce:

5.3.2. Corollary. For $M \in \text{DM}_{\text{gm}}^{\text{eff}}$ we have

$$\text{RPic}(M)^* = \text{LAlb}(M). \quad \square$$

Therefore we get $\check{H}^i(\text{RPic}(M)) = (\check{H}^i(\text{LAlb}(M)))^*$. 

6. The adjunction $\text{LAlb} - \text{Tot}$ with rational coefficients

Throughout this section, we use the notations $\otimes \mathbb{Q}$ and $\boxtimes \mathbb{Q}$ from Definition 1.1.3.

6.1. Rational coefficients revisited. Let $\text{DM}_{\text{eff}}^*(k; \mathbb{Q})$ and $\text{DM}_{\text{-,ét}}^*(k; \mathbb{Q})$ denote the full subcategories of $\text{DM}_{\text{eff}}^*(k)$ and $\text{DM}_{\text{-,ét}}^*(k)$ formed of those complexes whose cohomology sheaves are uniquely divisible. Recall that by [96, Prop. 3.3.2], the change of topology functor

$$\alpha^*: \text{DM}_{\text{eff}}^*(k) \rightarrow \text{DM}_{\text{-,ét}}^*(k)$$

induces an equivalence of categories

$$\text{DM}_{\text{eff}}^*(k; \mathbb{Q}) \overset{\sim}{\longrightarrow} \text{DM}_{\text{-,ét}}^*(k; \mathbb{Q}).$$

Beware that in loc. cit., these two categories are respectively denoted by $\text{DM}_{\text{eff}}^*(k) \otimes \mathbb{Q}$ and $\text{DM}_{\text{-,ét}}^*(k) \otimes \mathbb{Q}$, while this notation is used here according to Definition 1.1.3. The composite functors (with our notation)

$$\text{DM}_{\text{eff}}^*(k; \mathbb{Q}) \rightarrow \text{DM}_{\text{-,ét}}^*(k; \mathbb{Q})$$

are fully faithful but not essentially surjective. The functor $\alpha^* \otimes \mathbb{Q}$ is not essentially surjective, nor (a priori) fully faithful. Nevertheless, these two composite functors have a left adjoint/left inverse $C \mapsto C \otimes \mathbb{Q}$, and

6.1.1. Proposition. a) The compositions

$$\text{DM}_{\text{gm}}^{\text{eff}}(k) \otimes \mathbb{Q} \rightarrow \text{DM}_{\text{eff}}^{\text{gm}}(k) \otimes \mathbb{Q} \overset{\otimes \mathbb{Q}}{\longrightarrow} \text{DM}_{\text{eff}}^*(k; \mathbb{Q})$$

$$\text{DM}_{\text{gm, ét}}^{\text{eff}}(k) \otimes \mathbb{Q} \rightarrow \text{DM}_{\text{-, ét}}^{\text{eff}}(k) \otimes \mathbb{Q} \overset{\otimes \mathbb{Q}}{\longrightarrow} \text{DM}_{\text{-, ét}}^*(k; \mathbb{Q})$$

are fully faithful.

b) Via these full embeddings, the functor $\alpha^*$ induces equivalences of
categories

$$\text{DM}_{\text{gm}}(k) \boxtimes \mathbb{Q} \xrightarrow{\sim} \text{DM}_{\text{gm, ét}}(k) \boxtimes \mathbb{Q}$$

$$d_{\leq 1} \text{DM}_{\text{gm}}(k) \boxtimes \mathbb{Q} \xrightarrow{\sim} d_{\leq 1} \text{DM}_{\text{gm, ét}}(k) \boxtimes \mathbb{Q}.$$ 

Here $d_{\leq 1} \text{DM}_{\text{gm}}(k)$ is the thick subcategory of $\text{DM}_{\text{gm}}(k)$ generated by motives of smooth curves.

Proof. a) We shall give it for the first composition (for the second one it is similar). Let $M, N \in \text{DM}_{\text{gm}}(k)$: we have to prove that the obvious map

$$\text{Hom}(M, N) \otimes \mathbb{Q} \to \text{Hom}(M \otimes \mathbb{Q}, N \otimes \mathbb{Q})$$

is an isomorphism. We shall actually prove this isomorphism for any $M \in \text{DM}_{\text{gm}}(k)$ and any $N \in \text{DM}^-_-(k)$. By adjunction, the right hand side coincides with $\text{Hom}(M, N \otimes \mathbb{Q})$ computed in $\text{DM}^-_-(k)$. We may reduce to $M = M(X)$ for $X$ smooth. By [96, Prop. 3.2.8], we are left to see that the map

$$H^q_{\text{Nis}}(X, N) \otimes \mathbb{Q} \to H^q_{\text{Nis}}(X, N \otimes \mathbb{Q})$$

is an isomorphism for any $q \in \mathbb{Z}$. By hypercohomology spectral sequences, we reduce to the case where $N$ is a sheaf concentrated in degree 0; then the assertion follows from the fact that Nisnevich cohomology commutes with filtering direct limits of sheaves.

b) It is clear that the two compositions commute with $\alpha^*$, which sends $\text{DM}_{\text{gm}}(k) \otimes \mathbb{Q}$ into $\text{DM}_{\text{gm, ét}}(k) \otimes \mathbb{Q}$. By a) and [96, Prop. 3.3.2], this functor is fully faithful, and the induced functor on the $\boxtimes$ categories remains so and is essentially surjective by definition of the two categories. Similarly for the $d_{\leq 1}$ categories. \qed

6.1.2. Remarks. 1) In fact, $d_{\leq 1} \text{DM}_{\text{gm, ét}}(k) \otimes \mathbb{Q} = d_{\leq 1} \text{DM}^\text{eff}_{\text{gm, ét}}(k) \boxtimes \mathbb{Q}$ thanks to Corollary 1.6.2 and Theorem 2.1.2. We don’t know whether the same is true for the other categories.

2) See [83, A.2.2] for a different, more general approach to Proposition 6.1.1.

6.1.3. Definition. With rational coefficients, we identify $\text{DM}_{\text{gm}}(k) \boxtimes \mathbb{Q}$ with $\text{DM}_{\text{gm, ét}}(k) \boxtimes \mathbb{Q}$ via $\alpha^*$ (using Proposition 6.1.1 b)) and define

$$D_{\leq 1} = D_{\leq 1}^{\text{Nis}} = D_{\leq 1}^\text{ét},$$

$$d_{\leq 1} = D_{\leq 1}^\text{ét},$$

$$\text{LAlb}^\mathbb{Q} = \text{Tot}^{-1} \circ d_{\leq 1}.$$ 

6.1.4. Remark. This definition is compatible with the formula $d_{\leq 1} = D_{\leq 1}^\text{ét} \circ \alpha^* \circ D_{\leq 1}^{\text{Nis}}$ of Definition 5.1.3.
6.2. The functor $\text{LAlb}^\mathbb{Q}$. We now get the announced adjunction by taking (5.1) with rational coefficients, thanks to Corollary 1.6.2 and Proposition 6.1.1.

6.2.1. Theorem. Let $M \in \text{DM}_{\text{eff}}^\text{gm}(k) \boxtimes \mathbb{Q}$. Then the map $a_M$ from (5.2) induces an isomorphism

$$\text{Hom}(d_{\leq 1} M, M') \iso \text{Hom}(M, M')$$

for any $M' \in d_{\leq 1} \text{DM}_{\text{eff}}^\text{gm}(k) \boxtimes \mathbb{Q}$. Equivalently, (5.3) is an isomorphism with rational coefficients.

Proof. By Proposition 4.5.1, $M'$ can be written as $N \boxplus D_{\leq 1}(N)$ for some $N \in d_{\leq 1} \text{DM}_{\text{eff}}^\text{gm}(k) \boxtimes \mathbb{Q}$. We have the following commutative diagram

$$\text{Hom}(M, D_{\leq 1}(N)) = \text{Hom}(M \otimes N, \mathbb{Z}(1)) = \text{Hom}(N, D_{\leq 1}(M))$$

$$\text{Hom}(d_{\leq 1} M, D_{\leq 1}(N)) = \text{Hom}(d_{\leq 1} M \otimes N, \mathbb{Z}(1)) = \text{Hom}(N, D_{\leq 1}(d_{\leq 1} M)).$$

But $D_{\leq 1}(a_M) \circ a_{D_{\leq 1}M} = 1_{D_{\leq 1}M}$ [84, p. 56, (3.2.3.9)]\(^9\) and $a_{D_{\leq 1}M}$ is an isomorphism by Proposition 5.1.4, which proves the claim. \(\square\)

6.2.2. Corollary. The functor $d_{\leq 1}$ of (5.1) induces a left adjoint to the embedding $d_{\leq 1} \text{DM}_{\text{eff}}^\text{gm}(k) \boxtimes \mathbb{Q} \hookrightarrow \text{DM}_{\text{eff}}^\text{gm}(k) \boxtimes \mathbb{Q}$. The Voevodsky-Orgogozo full embedding $\text{Tot} : D^b(\mathcal{M}_1 \otimes \mathbb{Q}) \rightarrow \text{DM}_{\text{eff}}^\text{gm} \boxtimes \mathbb{Q}$ has a left adjoint/left inverse $\text{LAlb}^\mathbb{Q}$. \(\square\)

7. A tensor structure on $D^b(\mathcal{M}_1 \otimes \mathbb{Q})$

In this section, coefficients are tensored with $\mathbb{Q}$ and we use the functor $\text{LAlb}^\mathbb{Q}$ of Corollary 6.2.2.

7.1. Tensor structure.

7.1.1. Lemma. Let $G_1, G_2$ be two semi-abelian varieties. Then, we have in $\text{DM}_{\text{eff,et}}^\text{gm} \boxtimes \mathbb{Q}$:

$$\mathcal{H}^q(D_{\leq 1}(G_1[-1] \otimes G_2[-1])) = \begin{cases} \text{Biext}(G_1, G_2; \mathbb{G}_m) & \text{if } q = 0 \\ 0 & \text{else.} \end{cases}$$

Proof. By Gersten’s principle (Proposition 2.4.1), it is enough to show that the isomorphisms are valid over function fields $K$ of smooth $k$-varieties and that $\mathcal{H}^0$ comes from the small étale site of $\text{Spec } k$. Since we work up to torsion, we may even replace $K$ by its perfect closure.

\(\footnote{Note that this proof carries over in our case.}"
Thus, without loss of generality, we may assume $K = k$ and we have to show the lemma for sections over $k$.

For $q \leq 0$, we use Proposition 4.4.1: for $q < 0$ this follows from Lemma 4.1.2, while for $q = 0$ it follows from the isomorphisms (4.1) and (4.2) (see Proposition 4.1.1), which show that $\text{Biext}(G_1, G_2; \mathbb{G}_m)$ is rigid.

For $q > 0$, we use the formula

$$D_{\leq 1}(G_1[-1] \otimes G_2[-1]) \simeq \text{Hom}(G_1[-1], \text{Tot}([0 \to G_2]^*))$$

coming from Theorem 4.5.3. Writing $[0 \to G_2]^* = [L_2 \to A_2]$ with $L_2$ a lattice and $A_2$ an abelian variety, we are left to show that

$$\text{Hom}_{\text{DM}^\text{eff}_{\text{gm}} \boxtimes \mathbb{Q}}(G_1, L_2[q + 1]) = 0 \text{ for } q > 0$$

$$\text{Hom}_{\text{DM}^\text{eff}_{\text{gm}} \boxtimes \mathbb{Q}}(G_1, A_2[q]) = 0 \text{ for } q > 0.$$

For this, we may reduce to the case where $G_1$ is either an abelian variety or $\mathbb{G}_m$. If $G_1 = \mathbb{G}_m$, $G_1$ is a direct summand of $M(\mathbb{P}^1)[-1]$ and the result follows. If $G_1$ is an abelian variety, it is isogenous to a direct summand of $J(C)$ for $C$ a smooth projective geometrically irreducible curve. Then $G_1$ is a direct summand of $M(C)$, and the result follows again since $L_2$ and $A_2$ define locally constant (flasque) sheaves for the Zariski topology. □

7.1.2. Proposition. a) The functor $L_{\text{Alb}}^\mathbb{Q} : \text{DM}^\text{eff}_{\text{gm}} \boxtimes \mathbb{Q} \to D^b(M_1 \otimes \mathbb{Q})$ is a localisation functor; it carries the tensor structure $\otimes$ of $\text{DM}^\text{eff}_{\text{gm}} \boxtimes \mathbb{Q}$ to a tensor structure $\otimes_1$ on $D^b(M_1 \otimes \mathbb{Q})$, which is left adjoint to the internal $\text{Hom}$ $\text{Hom}_1$ of §3.14.

b) For $(M, N) \in \text{DM}^\text{eff}_{\text{gm}} \boxtimes \mathbb{Q} \times D^b(M_1 \otimes \mathbb{Q})$, we have

$$L_{\text{Alb}}^\mathbb{Q}(M \otimes \text{Tot}(N)) \simeq L_{\text{Alb}}^\mathbb{Q}(M) \otimes_1 N.$$

c) We have

$$[\mathbb{Z} \to 0] \otimes_1 C = C$$

for any $C \in D^b(M_1 \otimes \mathbb{Q})$;

$$N_1 \otimes_1 N_2 = [L \to G]$$

for two Deligne 1-motives $N_1 = [L_1 \to G_1]$, $N_2 = [L_2 \to G_2]$, where

$$L = L_1 \otimes L_2;$$

there is an extension

$$0 \to \text{Biext}(G_1, G_2; \mathbb{G}_m)^* \to G \to L_1 \otimes G_2 \oplus L_2 \otimes G_1 \to 0.$$

d) The tensor product $\otimes_1$ is exact with respect to the motivic $t$-structure and respects the weight filtration. Moreover, it is right exact with respect
to the homotopy $t$-structure.
e) For two 1-motives $N_1, N_2$ and a semi-abelian variety $G$, we have
\[ \text{Hom}(N_1 \otimes_1 N_2, [0 \to G]) \simeq \text{Biext}(N_1, N_2; G) \otimes \mathbb{Q}. \]

**Proof.**
a) The first statement is clear since $L\text{Alb}^\mathbb{Q}$ is left adjoint to the fully faithful functor $\text{Tot}$. For the second, it suffices to see that if $L\text{Alb}^\mathbb{Q}(M) = 0$ then $L\text{Alb}^\mathbb{Q}(M \otimes N) = 0$ for any $N \in \text{DM}^\text{eff} \otimes \mathbb{Q}$. We may check this after applying $\text{Tot}$. Note that, by Proposition 4.5.1 and Remark 6.1.4 3), $\text{Tot} L\text{Alb}^\mathbb{Q}(M) = d_{\leq 1}(M) = 0$ is equivalent to $D_{\leq 1}(M) = 0$. We have:
\[ D_{\leq 1}(M \otimes N) = \text{Hom}(M \otimes N, \mathbb{Z}(1)) = \text{Hom}(N, \text{Hom}(M, \mathbb{Z}(1))) = 0. \]
The last statement follows by adjunction from the fact that $\text{Tot}$ commutes with internal Homs.
b) Let $M' = \text{fibre}(\text{Tot} L\text{Alb}^\mathbb{Q}(M) \to M)$; then $L\text{Alb}^\mathbb{Q}(M') = 0$. By definition of $\otimes_1$ we then have
\[ L\text{Alb}^\mathbb{Q}(M) \otimes_1 N = L\text{Alb}^\mathbb{Q}(\text{Tot} L\text{Alb}^\mathbb{Q}(M) \otimes \text{Tot}(N)) \rightarrow L\text{Alb}^\mathbb{Q}(M \otimes \text{Tot}(N)). \]
c) The first formula is obvious. For the second, we have an exact triangle
\[ G_1[-1] \otimes G_2[-1] \rightarrow \text{Tot}(N_1) \otimes \text{Tot}(N_2) \]
\[ \rightarrow \text{Tot}([L_1 \otimes L_2 \to L_1 \otimes G_2 \oplus L_2 \otimes G_1]) \xrightarrow{+1} \]
hence an exact triangle
\[ \text{Hom}(\text{Tot}([L_1 \otimes L_2 \to L_1 \otimes G_2 \oplus L_2 \otimes G_1]), \mathbb{Z}(1)) \]
\[ \rightarrow \text{Hom}(\text{Tot}(N_1) \otimes \text{Tot}(N_2), \mathbb{Z}(1)) \rightarrow \text{Hom}(G_1[-1] \otimes G_2[-1], \mathbb{G}_m) \xrightarrow{+1} \]
By Lemma 7.1.1, the last term is $\text{Biext}(G_1, G_2; \mathbb{G}_m)$, hence the claim.
d) Exactness and compatibility with weights follow from the second formula of c); right exactness for the homotopy $t$-structure holds because it holds on $\text{DM}^\text{eff} \otimes \mathbb{Q}$.
e) We have:
\[ \text{Hom}_{M_1 \otimes \mathbb{Q}}(N_1 \otimes_1 N_2, [0 \to G]) = \text{Hom}_{d_{\leq 1} \text{DM} \otimes \mathbb{Q}}(\text{Tot}(N_1 \otimes_1 N_2), G[-1]) \]
\[ = \text{Hom}_{\text{DM} \otimes \mathbb{Q}}(\text{Tot}(N_1) \otimes \text{Tot}(N_2), G[-1]) = \text{Biext}(N_1, N_2; G) \otimes \mathbb{Q} \]
by Proposition 4.4.1 and formula (4.1).

7.1.3. **Remarks.**
1) By the same argument as in Remark 5.2.2, one can see that $\otimes_1$ is not defined integrally on $(\mathbb{Z}(1), \mathbb{Z}(1))$. Details are left to the reader.
2) It is likely that Proposition 7.1.2 e) generalises to an isomorphism
\[ \text{Hom}_{\mathcal{M}_1 \otimes \mathbb{Q}}(N_1 \otimes_1 N_2, N) = \text{Biext}(N_1, N_2; N) \otimes \mathbb{Q} \]
for three 1-motives \( N_1, N_2, N \), where the right hand side is the biextension group introduced by Cristiana Bertolin [17], but we have not tried to check it\(^{10}\). This puts in perspective her desire to interpret these groups as Hom groups in the (future) tannakian category generated by 1-motives.

More precisely, one expects that \( \text{DM}_{\text{gm}} \otimes \mathbb{Q} \) carries a motivic \( t \)-structure whose heart \( \mathcal{M} \) would be the searched-for abelian category of mixed motives. Then \( \mathcal{M}_1 \otimes \mathbb{Q} \) would be a full subcategory of \( \mathcal{M} \) and we might consider the thick tensor subcategory \( \mathcal{M}_1 \otimes_1 \mathcal{M} \) generated by \( \mathcal{M}_1 \otimes \mathbb{Q} \) and the Tate motive (inverse to the Lefschetz motive): this is the putative category Bertolin has in mind.

Since the existence of the abelian category of mixed Tate motives (to be contained in \( \mathcal{M}_1 \otimes \mathbb{Q} \)) depends on the truth of the Beilinson-Soulé conjecture, this basic obstruction appears here too.

Extrapolating from Corollary 6.2.2 and Proposition 7.1.2, it seems that the embedding \( \mathcal{M}_1 \otimes \mathbb{Q} \hookrightarrow \mathcal{M} \) (where \( \mathcal{M} \) is the intersection of \( \mathcal{M} \) with \( \text{DM}_{\text{gm}} \otimes \mathbb{Q} \)) is destined to have a left adjoint/left inverse \( \text{Alb}_\mathbb{Q} = H_0 \circ L\text{Alb}_{\mathcal{M}, \mathcal{M}_{\text{eff}}} \), which would carry the tensor product of \( \mathcal{M} \) to \( \otimes_1 \). Restricting \( \text{Alb}_\mathbb{Q} \) to \( \mathcal{M}_1 \otimes_1 \mathcal{M} \) would provide the link between Bertolin’s ideas and Proposition 7.1.2 e).

7.2. A formula for the internal Hom, rationally.

7.2.1. Proposition. We have
\[ \text{Hom}_1(C_1, C_2) = (C_1 \otimes_1 C_2^*)^* \]
for \( C_1, C_2 \in D^b(\mathcal{M}_1 \otimes \mathbb{Q}) \).

Proof. In view of Theorem 4.5.3, we are left to show that \( \text{Hom}(M_1, M_2) \simeq (M_1 \otimes_1, M_2^\vee)^\vee \) for \( M_1, M_2 \in d_{\leq 1} \text{DM}_{\text{gm}} \otimes \mathbb{Q} \). By duality, we may replace \( M_2 \) by \( M_2^\vee \). Then:
\[ \text{Hom}(M_1, M_2^\vee) = \text{Hom}(M_1, \text{Hom}(M_2, \mathbb{Z}(1))) \]
\[ \simeq \text{Hom}(M_1 \otimes M_2, \mathbb{Z}(1)) \simeq \text{Hom}(M_1 \otimes_1 M_2, \mathbb{Z}(1)) = (M_1 \otimes_1 M_2)^\vee \]
where the second isomorphism follows from Proposition 7.1.2 b). \( \square \)

\(^{10}\text{This was since proven in [18].} \)
Part 3. Some computations

8. The Albanese complexes and their basic properties

We introduce homological and Borel-Moore Albanese complexes of an algebraic variety providing a computation of their 1-motivic homology.

We also consider a slightly more sophisticated cohomological Albanese complex $\text{LAlb}^*(X)$ which is only contravariantly functorial for maps between schemes of the same dimension. All these complexes coincide for smooth proper schemes.

8.1. The homological Albanese complex. Let $p : X \to \text{Spec} \, k$ be a smooth variety. Recall that $X$ has a motive $M(X) \in \text{DM}^\text{eff}_{\text{gm}}$ [96]: $M$ is a covariant functor from the category $\text{Sm}(k)$ of smooth $k$-schemes of finite type to $\text{DM}^\text{eff}_{\text{gm}}$. The image of $M(X)$ via the full embedding $\text{DM}^\text{eff}_{\text{gm}} \to \text{DM}^\text{eff}$ is given by the Suslin complex $C_*(L)$ of the representable Nisnevich sheaf with transfers $L(X)$ associated to $X$.

For $X$ an arbitrary $k$-scheme of finite type, the formula $M(X) = C_*(L(X))$ still defines an object of $\text{DM}^\text{eff}$; if $\text{char} \, k = 0$, this object is in $\text{DM}^\text{eff}_{\text{gm}}$ by [96, §4.1].

Convention. In this subsection, “scheme” means separated $k$-scheme of finite type if $\text{char} \, k = 0$ and smooth (separated) $k$-scheme of finite type if $\text{char} \, k > 0$.

8.1.1. Definition. We define the homological Albanese complex of $X$ by

$$\text{LAlb}(X) := \text{LAlb}(M(X)).$$

Define, for $i \in \mathbb{Z}$

$$\text{L}_i \text{Alb}(X) := \iota H_i(\text{LAlb}(X))$$

the 1-motives with cotorsion (see Definition 1.8.1 and Notation 1.8.7) determined by the homology of the Albanese complex.

8.1.2. Remark. We could have chosen to define the homology with respect to the dual $\iota$-structure, corresponding to 1-motives with torsion according to Theorem 1.8.6. Actually, the interested reader is invited to investigate the finite groups appearing in $\iota H_i(\text{LAlb}(X))$ and $\iota H_i(\text{LAlb}(X))$ taking care of both $\iota$-structures. There is no difference with rational coefficients as these two $\iota$-structures coincide after tensoring with $\mathbb{Q}$. The functor $\text{LAlb}$ has the following properties, easily deduced from [96, 2.2]:
8.1.a. **Homotopy invariance.** For any scheme $X$ the map
\[ \text{LAlb}(X \times \mathbb{A}^1) \to \text{LAlb}(X) \]
is an isomorphism, thus
\[ L_i\text{Alb}(X \times \mathbb{A}^1) \sim L_i\text{Alb}(X) \]
for all $i \in \mathbb{Z}$.

8.1.b. **Mayer-Vietoris.** For a scheme $X$ and an open covering $X = U \cup V$ there is a distinguished triangle
\[ \text{LAlb}(U \cap V) \to \text{LAlb}(U) \oplus \text{LAlb}(V) \to \text{LAlb}(X) \]
and therefore a long exact sequence of 1-motives
\[ \cdots \to L_i\text{Alb}(U \cap V) \to L_i\text{Alb}(U) \oplus L_i\text{Alb}(V) \to L_i\text{Alb}(X) \to \cdots \]

8.1.c. **Tate twists.** If $X$ is a smooth scheme and $n > 0$, then
\[ \text{Tot LAlb}(\mathcal{M}(X)(n)) = \begin{cases} 0 & \text{if } n > 1 \\ M(\pi_0(X))(1) & \text{if } n = 1 \end{cases} \]
where $\pi_0(X)$ is the scheme of constants of $X$, see Definition 2.5.1. Indeed
\[ \text{Tot LAlb}(\mathcal{M}(X)(n)) = \text{Hom}_{\text{et}}(\alpha^*(\text{Hom}_{\text{Nis}}(\mathcal{M}(X)(n), \mathbb{Z}(1)), \mathbb{Z}(1)) \]
by the cancellation theorem [97]. Now
\[ \text{Hom}_{\text{Nis}}(\mathcal{M}(X)(n-1), \mathbb{Z}) = \begin{cases} 0 & \text{if } n > 1 \\ \text{Hom}_{\text{Nis}}(\mathcal{M}(\pi_0(X)), \mathbb{Z}) & \text{if } n = 1. \end{cases} \]
The last formula should follow from [55, Lemma 2.1 a)] but the formulation there is wrong; however, the formula immediately follows from the argument in the proof of loc. cit., i.e. considering the Zariski cohomology of $X$ with coefficients in the flasque sheaf $\mathbb{Z}$.

This gives
\[ (8.1) \quad L_i\text{Alb}(\mathcal{M}(X)(1)) = \begin{cases} [0 \to R_{\pi_0(X)/k}\mathbb{G}_m] & \text{if } i = 0 \\ 0 & \text{else} \end{cases} \]
where $R_{L/k}(-)$ is Weil’s restriction of scalars.

From this computation we formally deduce:

8.1.3. **Proposition.** For any $\mathcal{M} \in \text{DM}_{\text{gm}}^{\text{eff}}$, we have
\( \text{LAlb}(M(n)) = 0 \) for \( n \geq 2; \)
\( \text{LAlb}(M(1)) \) is a complex of toric 1-motives.

8.1.d. Gysin. Let \( Z \) be a closed smooth subscheme purely of codimension \( n \) of a smooth scheme \( X \), and let \( U = X - Z \). Then
\[
\text{LAlb}(U) \xrightarrow{\sim} \text{LAlb}(X) \text{ if } n > 1
\]
and if \( n = 1 \) we have an exact triangle
\[
\text{LAlb}(U) \to \text{LAlb}(X) \to \left[ 0 \to R_{\tau_0(Z)/kG_m} \right][2] \to \text{LAlb}(U)[1]
\]
hence a long exact sequence of 1-motives
\[
0 \to L_2\text{Alb}(U) \to L_2\text{Alb}(X) \to \left[ 0 \to R_{\tau_0(Z)/kG_m} \right]
\to L_1\text{Alb}(U) \to L_1\text{Alb}(X) \to 0
\]
and an isomorphism \( L_0\text{Alb}(U) \to L_0\text{Alb}(X) \).

8.1.e. Blow ups. If \( X \) is a scheme and \( Z \subseteq X \) is a closed subscheme, denote by \( p : \tilde{X} \to X \) a proper surjective morphism such that \( p^{-1}(X - Z) \to X - Z \) is an isomorphism, e.g. the blow up of \( X \) at \( Z \). Then there is a distinguished triangle
\[
\text{LAlb}(\tilde{Z}) \rightarrowtail \text{LAlb}(\tilde{X}) \oplus \text{LAlb}(Z) \quad \xrightarrow{+1} \quad \text{LAlb}(X) \quad \twoheadleftarrow
\]
with \( \tilde{Z} = p^{-1}(Z) \), yielding a long exact sequence of 1-motives
\[
\cdots \to L_i\text{Alb}(\tilde{Z}) \to L_i\text{Alb}(\tilde{X}) \oplus L_i\text{Alb}(Z) \to L_i\text{Alb}(X) \to \cdots
\]
If \( X \) and \( Z \) are smooth, we get (using [96, Prop. 3.5.3] and the above)
\[
\text{LAlb}(\tilde{X}) = \text{LAlb}(X) \oplus \left[ 0 \to R_{\tau_0(Z)/kG_m} \right][2]
\]
and corresponding formulas for homology.

8.1.f. Albanese map. If \( X \) is a scheme we have the natural map (5.2) in \( \text{DM}_{gm,\acute{e}t}^{\text{eff}} \)
\[
a_X : \alpha^*M(X) \to \text{Tot LAlb}(X)
\]
inducing homomorphisms on étale motivic cohomology
\[
\text{Hom}(M(X), Z(1)[j]) \to \text{Hom}(\text{LAlb}(X), G_m[j - 1])
\]
which are isomorphisms rationally by Theorem 6.2.1.
8.2. **Cohomological Pic.** Dual to 8.1.1 we set:

8.2.1. **Definition.** Define the *cohomological Picard complex* of $X$ by

$$\text{RPic}(X) := \text{RPic}(M(X)).$$

Define, for $i \in \mathbb{Z}$

$$\text{R}^i\text{Pic}(X) := \mathcal{H}^i(\text{RPic}(X))$$

the 1-motives with torsion determined by the cohomology of the Picard complex (see Notation 1.8.7).

The functor $\text{RPic}$ has similar properties to $\text{LAlb}$, deduced by duality. Homotopical invariance, Mayer-Vietoris, Gysin and the distinguished triangle for abstract blow-ups are clear, and moreover we have

$$\text{RPic}(M(X)(n)) = \begin{cases} 0 & \text{if } n > 1 \\ [\mathbb{Z} \pi_0(X) \to 0] & \text{if } n = 1. \end{cases}$$

We also have that $\text{RPic}(X) = \text{LAlb}(X)^\vee$, hence

$$\text{R}^i\text{Pic}(X) = \text{L}^i\text{Alb}(X)^\vee.$$  

We shall complete §8.1.d by

8.2.a. **RPic and LAlb with supports.** Let $X \in \text{Sm}(k)$, $U$ a dense open subset of $X$ and $Z = X - U$ (reduced structure). In DM, we have the *motive with supports* $M^Z(X)$ fitting in an exact triangle

$$M(U) \to M(X) \to M^Z(X) \xrightarrow{+1}$$

hence the cohomological complex with supports

$$\text{RPic}^Z(X) := \text{RPic}(M^Z(X))$$

fitting in an exact triangle

$$\text{RPic}_Z(X) \to \text{RPic}(X) \to \text{RPic}(U) \xrightarrow{+1}.$$

Dually, we have $\text{LAlb}^Z(X) := \text{LAlb}(M^Z(X))$.

8.2.2. **Lemma.** If $\dim X = d$, $\text{RPic}_Z(X) \simeq [\text{CH}_{d-1}(Z) \to 0][-2]$, where $\text{CH}_{d-1}(Z)$ is the lattice corresponding to the Galois module $\text{CH}_{d-1}(Z \overline{\mathbb{F}})$.

Note that $\text{CH}_{d-1}(Z \overline{\mathbb{F}})$ is simply the free abelian group with basis the irreducible components of $Z \overline{\mathbb{F}}$ which are of codimension 1 in $X \overline{\mathbb{F}}$.

**Proof.** This follows readily from the exact sequence

$$0 \to \Gamma(X \overline{\mathbb{F}}, \mathbb{G}_m) \to \Gamma(U \overline{\mathbb{F}}, \mathbb{G}_m) \to \text{CH}_{d-1}(Z \overline{\mathbb{F}})$$

$$H^1(X \overline{\mathbb{F}}, \mathbb{G}_m) \to H^1(U \overline{\mathbb{F}}, \mathbb{G}_m) \to 0.$$

$\square$
8.3. **Relative** LAlb and RPic. For $f : Y \to X$ a map of schemes we let $M(X,Y)$ denote the cone of $C_*(Y) \to C_*(X)$. Note that for a closed embedding $f$ in a proper scheme $X$ we have an isomorphism $M(X,Y) \to M^c(X-Y)$.

We denote by $\text{LAlb}(X,Y)$ and $\text{RPic}(X,Y)$ the resulting complexes of 1-motives.

### 9. Borel-Moore variants

**9.1. The Borel-Moore Albanese complex.** Let $p : X \to \text{Spec } k$ be a scheme of finite type over a field $k$ which admits resolution of singularities. Recall that the motive with compact support of $X$, denoted $M^c(X) \in \text{DM}^{\text{eff}}_c$, has also been defined in [96, Sect. 4]. It is the Suslin complex $C_*$ of the representable presheaf with transfers $L^c(X)$ given by quasi-finite correspondences. Since finite implies quasi-finite we have a canonical map $M(X) \to M^c(X)$ which is an isomorphism if $X$ is proper over $k$.

In general, $M^c : \text{Sch}^c(k) \to \text{DM}^{\text{eff}}_{\text{gm}}$ is a covariant functor from the category of schemes of finite type over $k$ and proper maps between them.

**9.1.1. Definition.** We define the **Borel-Moore Albanese complex** of $X$ by

$$\text{LAlb}^c(X) := \text{LAlb}(M^c(X)).$$

Define, for $i \in \mathbb{Z}$

$$L_i \text{Alb}^c(X) := H_i(\text{LAlb}^c(X))$$

the 1-motivic homology of this complex.

Note that we have the following properties:

**9.1.a. Functoriality.** The functor $X \mapsto \text{LAlb}^c(X)$ is covariant for proper maps and contravariant with respect to flat morphisms of relative dimension zero, for example étale morphisms. We have a canonical, covariantly functorial map

$$\text{LAlb}(X) \to \text{LAlb}^c(X)$$

which is an isomorphism if $X$ is proper.
9.1.b. Localisation triangle. For any closed subscheme $Y$ of a scheme $X$ we have a triangle

$$
\begin{array}{ccc}
\text{LAlb}^c(Y) & \longrightarrow & \text{LAlb}^c(X) \\
\uparrow & & \downarrow \\
\text{LAlb}^c(X - Y) & & \\
\end{array}
$$

and therefore a long exact sequence of 1-motives

(9.1)$$
\cdots \rightarrow \text{L}^i\text{Alb}^c(Y) \rightarrow \text{L}^i\text{Alb}^c(X) \rightarrow \text{L}^i\text{Alb}^c(X - Y) \rightarrow \text{L}^{i+1}\text{Alb}^c(Y) \rightarrow \cdots
$$

In particular, let $X$ be a scheme obtained by removing a divisor $Y$ from a proper scheme $X$, i.e. $X = X - Y$. Then

$$
\cdots \rightarrow \text{L}^1\text{Alb}(Y) \rightarrow \text{L}^1\text{Alb}(\overline{X}) \rightarrow \text{L}^1\text{Alb}^c(X) \rightarrow \text{L}^0\text{Alb}(Y) \\
\rightarrow \text{L}^0\text{Alb}(\overline{X}) \rightarrow \text{L}^0\text{Alb}^c(X) \rightarrow \cdots
$$

9.1.c. Albanese map. We have the following natural map (5.2)

$$
a_X^c : \alpha^* M^c(X) \rightarrow \text{Tot LAlb}^c(X)
$$

which is an isomorphism if $\dim(X) \leq 1$. In general, for any $X$, $a_X^c$ induces an isomorphism on motivic cohomology with compact supports, i.e. $H^j_c(X, \mathbb{Q}(1)) = \text{Hom}(\text{LAlb}^c(X), \mathbb{G}_m[j - 1]) \otimes \mathbb{Q}$.

9.2. Cohomological Albanese complex.

9.2.1. Lemma. Suppose $p = 1$ (i.e. char $k = 0$), and let $n \geq 0$. For any $X$ of dimension $\leq n$, the motive $M(X)^*(n)[2n]$ is effective. (Here, contrary to the rest of the paper, $M(X)^*$ denotes the “usual” dual $\text{Hom}(M(X), \mathbb{Z})$ in $\text{DM}_{gm}$.)

Proof. First assume $X$ irreducible. Let $\tilde{X} \rightarrow X$ be a resolution of singularities of $X$. With notation as in $\S 8.1.e$, we have an exact triangle

$$
M(X)^*(n) \rightarrow M(\tilde{X})^*(n) \oplus M(Z)^*(n) \oplus M(\tilde{Z})^*(n) \rightarrow ^{+1}.
$$

Since $\tilde{X}$ is smooth, $M(\tilde{X})^*(n) \simeq M^c(X)[-2n]$ is effective by [96, Th. 4.3.2]; by induction on $n$, so are $M(Z)^*(n)$ and $M(\tilde{Z})^*(n)$ and therefore $M(X)^*(n)$ is effective.

In general, let $X_1, \ldots, X_r$ be the irreducible components of $X$. Suppose $r \geq 2$ and let $Y = X_2 \cup \cdots \cup X_r$: since $(X_1, Y)$ is a cdh cover of $X$, we have an exact triangle

$$
M(X)^*(n) \rightarrow M(X_1)^*(n) \oplus M(Y)^*(n) \oplus M(X_1 \cap Y)^*(n) \rightarrow ^{+1}.
$$

The same argument then shows that $M(X)^*(n)$ is effective, by induction on $r$. \qed
We can therefore apply our functor $\text{LAlb}$ and obtain another complex $\text{LAlb}(M(X)^*(n)[2n])$ of 1-motives. If $X$ is smooth this is just the Borel-Moore Albanese.

9.2.2. Definition. We define the cohomological Albanese complex of a scheme $X$ of dimension $n$ by

$$\text{LAlb}^*(X) := \text{LAlb}(M(X)^{(n)}(n)[2n])$$

where $X^{(n)}$ is the union of the $n$-dimensional components of $X$. Define, for $i \in \mathbb{Z}$

$$L_i\text{Alb}^*(X) := H_i(\text{LAlb}^*(X))$$

the 1-motivic homology of this complex.

9.2.3. Lemma. a) If $Z_1, \ldots, Z_n$ are the irreducible components of dimension $n$ of $X$, then the cone of the natural map

$$\text{LAlb}^*(X) \to \bigoplus L_i\text{Alb}^*(Z_i)$$

is a complex of groups of multiplicative type.

b) If $X$ is integral and $\tilde{X}$ is a desingularisation of $X$, then the cone of the natural map

$$\text{LAlb}^*(X) \to \text{LAlb}^*(\tilde{X})$$

is a complex of groups of multiplicative type.

Proof. a) and b) follow from dualising the abstract blow-up exact triangles of [96, 2.2] and applying Proposition 8.1.3. □

9.3. Compactly supported and homological Pic. We now consider the dual complexes of the Borel-Moore and cohomological Albanese.

9.3.1. Definition. Define the compactly supported Picard complex of any scheme $X$ by

$$\text{RPic}^c(X) := \text{RPic}(M^c(X))$$

and the homological Picard complex of an equidimensional scheme $X$ of dimension $n$ by

$$\text{RPic}^*(X) := \text{RPic}(M(X)^*(n)[2n]).$$

Denote $\text{R}^i\text{Pic}^c(X) := \text{H}^i(\text{RPic}^c(X))$ and $\text{R}^i\text{Pic}^*(X) := \text{H}^i(\text{RPic}^*(X))$ the 1-motives with torsion determined by the homology of these Picard complexes.

Recall that $\text{RPic}^c(X) = \text{RPic}(X)$ if $X$ is proper and $\text{RPic}^c(X) = \text{RPic}^*(X)$ if $X$ is smooth.
9.4. **Topological invariance.** To conclude this section and the previous one, we note the following useful

9.4.1. **Lemma.** Suppose that \( f : Y \to X \) is a universal topological homeomorphism, in the sense that \( 1_U \times f : U \times Y \to U \times X \) is a homeomorphism of topological spaces for any smooth \( U \) (in particular \( f \) is proper). Then \( f \) induces isomorphisms \( \LAlb(Y) \iso \LAlb(X) \), \( \RPic(Y) \iso \RPic(X) \), \( \LAlb^c(Y) \iso \LAlb^c(X) \) and \( \RPic^c(X) \iso \RPic^c(Y) \). Similarly, \( \LAlb^*(X) \iso \LAlb^*(Y) \) and \( \RPic^*(Y) \iso \RPic^*(X) \). This applies in particular to \( Y = \) the semi-normalisation of \( X \).

**Proof.** It suffices to notice that \( f \) induces isomorphisms \( L(Y) \iso L(X) \) and \( L^c(Y) \iso L^c(X) \), since by definition these sheaves only depend on the underlying topological structures. \( \square \)

Lemma 9.4.1 implies that in order to compute \( \LAlb(X) \), etc., we may always assume \( X \) semi-normal if we wish so.

10. **Computing \( \LAlb(X) \) and \( \RPic(X) \) for smooth \( X \)**

10.1. **The Albanese scheme.** Let \( X \) be a reduced \( k \)-scheme of finite type. “Recall” ([81, Sect. 1], [91]) the Albanese scheme \( \mathcal{A}_{X/k} \) fitting in the following extension

\[
0 \to \mathcal{A}^0_{X/k} \to \mathcal{A}_{X/k} \to \mathbb{Z}[\pi_0(X)] \to 0
\]

where \( \mathcal{A}^0_{X/k} \) is Serre’s generalised Albanese semi-abelian variety, and \( \pi_0(X) \) is the scheme of constants of \( X \) viewed as an étale sheaf on \( \text{Sm}(k) \).\(^{11}\) In particular,

\( \mathcal{A}_{X/k} \in \text{AbS} \) (see Definition 3.7.4).

There is a canonical morphism

\[
\bar{\alpha}_X : X \to \mathcal{A}_{X/k}
\]

which is universal for morphisms from \( X \) to group schemes of the same type.

For the existence of \( \mathcal{A}_{X/k} \), the reference [81, Sect. 1] is sufficient if \( X \) is a variety (integral separated \( k \)-scheme of finite type), hence if \( X \) is normal (for example smooth); this will be sufficient in this section. For the general case, see §11.1.

\(^{11}\)In the said references, \( \mathcal{A}^0_{X/k} \) is denoted by \( \text{Alb}_X \) and \( \mathcal{A}_{X/k} \) is denoted by \( \tilde{\text{Alb}}_X \).
We shall denote the object \( \text{Tot}^{-1}(A_{X/k}) \in D^b(M_1[1/p]) \) simply by \( A_{X/k} \). As seen in Lemma 3.12.1, we have

\[
H_i(A_{X/k}) = \begin{cases} 
\mathbb{Z}[\pi_0(X)] \to 0 & \text{for } i = 0 \\
0 \to A^0_{X/k} & \text{for } i = 1 \\
0 & \text{for } i \neq 0, 1.
\end{cases}
\]

10.2. **The main theorem.** Suppose \( X \) smooth. Via (1.1), (10.2) induces a composite map

\[
(10.3) \quad M_{\text{\acute{e}t}}(X) \to M_{\text{\acute{e}t}}(A_{X/k}) \to A_{X/k}.
\]

Theorem 4.5.3 gives:

10.2.1. **Lemma.** We have an exact triangle

\[
Z[\pi_0(X)]^*[0] \to \text{Hom}(A_{X/k}, \mathbb{Z}(1)) \to (A^0_{X/k})^*[-2] \xrightarrow{\tau_{\leq 2}} \square
\]

By Lemma 10.2.1, the map

\[
\text{Hom}(A_{X/k}, \mathbb{Z}(1)) \to \text{Hom}(M_{\text{\acute{e}t}}(X), \mathbb{Z}(1))
\]

deduced from (10.3) factors into a map

\[
(10.4) \quad \text{Hom}(A_{X/k}, \mathbb{Z}(1)) \to \tau_{\leq 2}\text{Hom}(M_{\text{\acute{e}t}}(X), \mathbb{Z}(1)).
\]

Applying Proposition 4.5.1 and Lemma 5.1.2, we therefore get a canonical map in \( D^b(M_1[1/p]) \)

\[
(10.5) \quad \text{LAlb}(X) \to A_{X/k}.
\]

10.2.2. **Theorem.** Suppose \( X \) smooth. Then the map (10.5) sits in an exact triangle

\[
[0 \to \text{NS}^*_X[k][2]] \to \text{LAlb}(X) \to A_{X/k} \xrightarrow{+1} \text{LAlb}(X) \to \text{NS}^*_X[k][2]
\]

where \( \text{NS}^*_X[k] \) denotes the group of multiplicative type dual to \( \text{NS}_X[k] \) (cf. Definition 3.6.1 and Proposition 3.6.2).

This theorem says in particular that, on the object \( \text{LAlb}(X) \), the motivic \( t \)-structure and the homotopy \( t \)-structure are compatible in a strong sense.

10.2.3. **Corollary.** For \( X \) smooth over \( k \) we have

\[
\text{L}_{i}\text{Alb}(X) = \begin{cases} 
[Z[\pi_0(X)] \to 0] & \text{if } i = 0 \\
[0 \to A^0_{X/k}] & \text{if } i = 1 \\
[0 \to \text{NS}^*_X[k]] & \text{if } i = 2 \\
0 & \text{otherwise}.
\end{cases}
\]

10.2.4. **Corollary.** For \( X \) smooth, \( \text{L}_1\text{Alb}(X) \) is isomorphic to the homological Albanese 1-motive \( \text{Alb}^{-1}(X) \) of [11].
10.3. **Reformulation of Theorem 10.2.2.** It is sufficient to get an exact triangle after application of $D_{\leq 1} \circ \text{Tot}$, so that we have to compute the cone of the morphism (10.4) in $\text{DM}_{\text{gm, ét}}^{\text{eff}}$. We shall use:

10.3.1. **Lemma.** For $F \in \text{HI}_{\text{ét}}^s$, the morphism $b$ of Proposition 3.1.1 is induced by (1.1).

**Proof.** This is clear by construction, since $\text{Hom}_{\text{DM}_{\text{ét}}}(M(G), F[1]) = H^1_{\text{ét}}(G, F)$ [96, Prop. 3.3.1].

Taking the cohomology sheaves of (10.4), we get morphisms

$$f : \text{Ext}(A_{X/k}, \mathbb{G}_m) \xrightarrow{b} \text{Pic}_{A_{X/k}/k} \xrightarrow{\pi} \text{Pic}_{X/k}$$

where in (10.7), $b$ corresponds to the map of Proposition 3.1.1 thanks to Lemma 10.3.1. Thanks to Proposition 3.7.1, Theorem 10.2.2 is then equivalent to the following

10.3.2. **Theorem.** Suppose $k$ algebraically closed; Then

a) (10.6) yields an isomorphism $\text{Hom}(A_{X/k}, \mathbb{G}_m) \xrightarrow{\sim} \Gamma(X, \mathbb{G}_m)$.

b) (10.7) defines a short exact sequence

$$0 \rightarrow \text{Ext}(A_{X/k}, \mathbb{G}_m) \xrightarrow{f} \text{Pic}(X) \xrightarrow{e} \text{NS}(X) \rightarrow 0$$

where $e$ is the natural map.

Before proving Theorem 10.3.2, it is convenient to prove Lemma 10.3.3 below. Let $A_{X/k}$ be the abelian part of $A^0_{X/k}$; then the sheaf $\text{Ext}(A_{X/k}, \mathbb{G}_m)$ is represented by the dual abelian variety $A^\ast_{X/k}$. Composing with the map $f$ of (10.7), we get a map of 1-motivic sheaves

$$A^\ast_{X/k} \rightarrow \text{Pic}_{X/k}.$$ 

10.3.3. **Lemma.** The map (10.9) induces an isogeny in $\text{SAb}$

$$A^\ast_{X/k} \xrightarrow{\gamma} \gamma(\text{Pic}_{X/k}) = \text{Pic}^0_{X/k}$$

where $\gamma$ is the adjoint functor appearing in Theorem 3.3.4 a).

**Proof.** We proceed in 3 steps:

1. The lemma is true if $X$ is smooth projective: this follows from the representability of $\text{Pic}^0_{X}$ and the duality between the Picard and the Albanese varieties.

2. Let $j : U \rightarrow X$ be an open immersion: then the lemma is true for $X$ if and only if it is true for $U$. This is clear since $\text{Pic}_{X/k} \rightarrow \text{Pic}_{U/k}$ is an epimorphism with discrete kernel.
(3) Let \( \varphi : Y \to X \) be an étale covering. If the lemma is true for \( Y \), then it is true for \( X \). This follows from the existence of transfer maps \( \varphi_* : A^*_Y/k \to A^*_X/k, \) \( \text{Pic}_Y/k \to \text{Pic}_X/k \) commuting with the map of the lemma, plus the usual transfer argument.

We conclude by de Jong’s theorem [54, Th. 4.1]. □

10.4. **Proof of Theorem 10.3.2.** We may obviously suppose that \( X \) is irreducible.

a) is obvious from the universal property of \( \mathcal{A}_X/k \). For b) we proceed in two steps:

1. Verification of \( ef = 0 \).
2. Proof that the sequence is exact.

1. As above, let \( A = A_X/k \) be the abelian part of \( \mathcal{A}^0_X/k \). In the diagram

\[
\begin{align*}
\text{Ext}(A, \mathbb{G}_m) & \to \text{Ext}(\mathcal{A}^0_X/k, \mathbb{G}_m) \leftarrow \text{Ext}(A_X/k, \mathbb{G}_m) \\
\downarrow v & \downarrow e \downarrow \downarrow f \downarrow \\
\text{Pic}(A) & \xrightarrow{x^*} \text{Pic}(X) \\
\downarrow c & \downarrow e \\
\text{NS}(A) & \xrightarrow{x^*} \text{NS}(X)
\end{align*}
\]

the first map is surjective and the second map is an isomorphism, hence we get a surjective map

\[ v : \text{Ext}(A, \mathbb{G}_m) \to \text{Ext}(A_X/k, \mathbb{G}_m). \]

Choose a rational point \( x \in X(\overline{k}) \). We have a diagram

\[
\begin{align*}
\text{Ext}(A, \mathbb{G}_m) & \xrightarrow{v} \text{Ext}(A_X/k, \mathbb{G}_m) \\
\downarrow a & \downarrow f \\
\text{Pic}(A) & \xrightarrow{x^*} \text{Pic}(X) \\
\downarrow c & \downarrow e \\
\text{NS}(A) & \xrightarrow{x^*} \text{NS}(X)
\end{align*}
\]

in which

(i) \( a \) is given by [87, p. 170, prop. 5 and 6] (or by Proposition 3.1.1).
(ii) \( ca = 0 \) (ibid., p. 184, th. 6).
(iii) \( x^* \) is induced by the “canonical” map \( X \to A \) sending \( x \) to 0.

Lemma 3.1.5 applied to \( G = A_X/k \) implies that the top square commutes (the bottom one trivially commutes too). Moreover, since \( v \) is surjective and \( ca = 0 \), we get \( ef = 0 \).

2. In the sequence (10.8), the surjectivity of \( e \) is clear. Let us prove the injectivity of \( f \): suppose that \( f(\mathcal{E}) \) is trivial. In the pull-back
\[
\begin{array}{ccc}
\pi^* E & \xrightarrow{\pi'} & X \\
\pi & \downarrow & \pi \\
\mathcal{E} & \xrightarrow{\pi} & \mathcal{A}_{X/k}
\end{array}
\]

\(\pi'\) has a section \(\sigma'\). Observe that \(\mathcal{E}\) is a locally semi-abelian scheme: by the universal property of \(\mathcal{A}_{X/k}\), the morphism \(\overline{\sigma}'\sigma'\) factors canonically through \(\overline{\sigma}\). In other words, there exists \(\sigma : \mathcal{A}_{X/k} \to \mathcal{E}\) such that \(\overline{\sigma}\sigma' = \sigma\overline{\sigma}\). Then

\[\pi\sigma\overline{\sigma} = \pi\overline{\sigma}'\sigma' = \overline{\sigma}\pi'\sigma' = \overline{\sigma}\]

hence \(\pi\sigma = 1\) by reapplying the universal property of \(\mathcal{A}_{X/k}\), and \(\mathcal{E}\) is trivial. Finally, exactness in the middle follows immediately from Proposition 3.6.2 and Lemma 10.3.3. \(\square\)

10.4.1. Corollary. The isogeny of Lemma 10.3.3 is an isomorphism.

Proof. This follows from the injectivity of \(f\) in (10.8). \(\square\)

10.5. An application.

10.5.1. Corollary. Let \(X\) be a smooth \(k\)-variety of dimension \(d\), \(U\) a dense open subset and \(Z = X - U\) (reduced structure). Then the morphism \(\mathcal{A}_{U/k} \to \mathcal{A}_{X/k}\) is epi; its kernel \(T_{X/U,k}\) is a torus whose character group fits into a short exact sequence

\[0 \to T_{X/U,k}^* \to \text{CH}_{d-1}(Z) \to \text{NS}_Z(X) \to 0\]

where \(\text{CH}_{d-1}(Z)\) is as in Lemma 8.2.2 and \(\text{NS}_Z(X) = \text{Ker} (\text{NS}(X) \to \text{NS}(U))\).

Proof. To see that \(\mathcal{A}_{U/k} \to \mathcal{A}_{X/k}\) is epi with kernel of multiplicative type, it is sufficient to see that \(\pi_0(\mathcal{A}_{U/k}) \xrightarrow{\sim} \pi_0(\mathcal{A}_{X/k})\) and that \(\mathcal{A}_{U/k} \xrightarrow{\sim} \mathcal{A}_{X/k}\). The first isomorphism is obvious and the second one follows from [72, Th. 3.1]. The characterisation of \(T_{X/U,k}\) is then an immediate consequence of Theorem 10.2.2 and Lemma 8.2.2; in particular, it is a torus. \(\square\)

10.6. RPic(\(X\)). Recall that for \(X\) smooth projective \(\mathcal{A}^0_{X/k} = A_{X/k}\) is the classical Albanese abelian variety \(\text{Alb}(X)\). In the case where \(X\) is obtained by removing a divisor \(Y\) from a smooth proper scheme \(\overline{X}\), \(\mathcal{A}^0_{X/k}\), can be described as follows (cf. [11]). Consider the (cohomological Picard) 1-motive \(\text{Pic}^+(X) := [\text{Div}^0_Y(\overline{X}) \to \text{Pic}^0(\overline{X})]\): its Cartier dual is \(\mathcal{A}^0_{X/k}\) which can be represented as a torus bundle

\[0 \to T_{\overline{X}/X,k} \to \mathcal{A}^0_{X/k} \to \text{Alb}(\overline{X}) \to 0\]
where $T_{X/k}$ has character group $\text{Div}^0_Y(X)$ according to Corollary 10.5.1.

From the previous remarks and Corollary 10.2.4, we deduce:

**10.6.1. Corollary.** If $X$ is smooth, $R^1\text{Pic}(X)$ is isomorphic to the 1-motive $\text{Pic}^+(X)$ of [11] (the Cartier dual of $\text{Alb}^-(X)$). If $\overline{X}$ is a smooth compactification of $X$, then

$$R^i\text{Pic}(X) = \begin{cases} 
[0 \to \mathbb{Z}[\pi_0(X)]^*] & \text{if } i = 0 \\
[\text{Div}^0_Y(\overline{X}) \to \text{Pic}^0(\overline{X})] & \text{if } i = 1 \\
[\text{NS}(X) \to 0] & \text{if } i = 2 \\
0 & \text{otherwise}
\end{cases}$$

where $Y = \overline{X} - X$.

### 11. 1-MOTIVIC HOMOLOGY AND COHOMOLOGY OF SINGULAR SCHEMES

In this section, we compute many of the motives introduced in Section 8 for singular schemes. In the first version of this work, this required $\text{char } k = 0$ because Voevodsky’s theory of motives of singular schemes depended on Hironaka resolution of singularities. Thanks to recent work of Shane Kelly [60], one could now extend this to any characteristic, as well as the results of the next sections.

**11.1. $\mathcal{A}_{X/k}$ for $X \in \text{Sch}(k)$.** In this subsection, we extend the construction of $\mathcal{A}_{X/k}$ to arbitrary reduced $k$-schemes of finite type, starting from the case where $X$ is integral (which is treated in [81, Sect. 1]). So far, $k$ may be of any characteristic.

To make the definition clear:

**11.1.1. Definition.** Let $X \in \text{Sch}(k)$. We say that $\mathcal{A}_{X/k}$ exists if the functor

$$\text{AbS} \to \text{Ab}$$

$$G \mapsto G(X)$$

is corepresentable.

First note that $\mathcal{A}_{X/k}$ does not exist (as a semi-abelian scheme, at least) if $X$ is not reduced. For example, for $X = \text{Spec } k[\varepsilon]$ with $\varepsilon^2 = 0$, we have an exact sequence

$$0 \to \mathbb{G}_a(k) \to \text{Map}_k(X, \mathbb{G}_m) \to \mathbb{G}_m(k) \to 0$$

which cannot be described by $\text{Hom}(\mathcal{A}, \mathbb{G}_m)$ for any semi-abelian scheme $\mathcal{A}$. 
On the other hand, \( M(X) = M(X_{\text{red}}) \) for any \( X \in \text{Sch}(k) \), where \( X_{\text{red}} \) is the reduced subscheme of \( X \) (see proof of Lemma 9.4.1), so we are naturally led to neglect nonreduced schemes.

11.1.2. Lemma. Let \( Z \in \text{Sch}(k) \), \( G \in \text{AbS} \) and \( f_1, f_2 : Z \to G \) two morphisms which coincide on the underlying topological spaces (thus, \( f_1 = f_2 \) if \( Z \) is reduced). Then there exists a largest quotient \( \overline{G} \) of \( G \) such that \( \pi_0(G) \to \pi_0(\overline{G}) \) and the two compositions

\[
Z \to G \to \overline{G}
\]

coincide.

Proof. The set \( S \) of such quotients \( \overline{G} \) is in one-to-one correspondence with the set of closed subgroups \( H^0 \subseteq G^0 \). Clearly \( \pi_0(G) \in S \), and if \( \overline{G}_1 = G/H^0 \in S \), \( \overline{G}_2 = G/H^0_2 \in S \), then \( G_3 = G/(H^0_1 \cap H^0_2) \in S \). Therefore \( S \) has a smallest element, since it is Artinian (compare proof of Proposition 3.7.5).

11.1.3. Proposition. \( A_{X/k} \) exists for any reduced \( X \in \text{Sch}(k) \).

Proof. When \( X \) is integral, this is [81, Sect. 1]. Starting from this case, we argue by induction on \( \dim X \). Let \( Z_1, \ldots, Z_n \) be the irreducible components of \( X \) and \( Z_{ij} = Z_i \cap Z_j \).

By induction, \( A_{ij} := A_{(Z_{ij})_{\text{red}}/k} \) exists for any \((i, j)\). Consider

\[
A = \text{Coker} \left( \bigoplus A_{ij} \to \bigoplus A_i \right)
\]

with \( A_i = A_{Z_i/k} \). Let \( Z = \bigsqcup Z_{ij} \) and \( f_1, f_2 : Z \to \bigsqcup Z_i \) be the two inclusions: the compositions \( f_1, f_2 : Z \to A \) verify the hypothesis of Lemma 11.1.2. Hence there is a largest quotient \( A' \) of \( A \) with \( \pi_0(A) \to \pi_0(A') \), equalising \( f_1 \) and \( f_2 \). Then the composition

\[
\bigsqcup Z_i \to \bigoplus A_i \to A'
\]

glues down to a morphism \( X \to A' \). It is clear that \( A' = A_{X/k} \) since, for any commutative group scheme \( G \), the sequence

\[
0 \to \text{Map}_k(X, G) \to \bigoplus \text{Map}_k(Z_i, G) \to \bigoplus \text{Map}_k(Z_{ij}, G)
\]

is exact.

Unfortunately this result is only useful to understand \( L_1 \text{Alb}(X) \) for \( X \) “strictly reduced”, as we shall see below. In general, we shall have to consider Albanese schemes for the \( \acute{e} \text{h} \) topology.
11.2. The étale topology. In this subsection and the next ones, we assume that $k$ is of characteristic 0 (but see beginning of this section). Recall that $H^i_{\text{ét}} = H^i_{\text{ét}}$ in this case by Proposition D.1.4.

The following étale analogue of the cdh topology was first considered by Thomas Geisser [43]:

11.2.1. **Definition.** The étale topology on $\text{Sch}(k)$ is the topology generated by the étale topology and coverings defined by abstract blow-ups (it is the same as [96, Def. 4.1.9] by replacing the Nisnevich topology by the étale topology).

As in [96, Th. 4.1.10] (see [70, Proof of Th. 14.20] for more details), one has:

11.2.2. **Proposition.** Let $C \in \text{DM}_{\text{eff}, \text{ét}}$. Then, for any $X \in \text{Sch}(k)$ and any $q \in \mathbb{Z}$ one has

$$\text{Hom}_{\text{DM}_{\text{eff}, \text{ét}}}(M_{\text{ét}}(X), C[q]) \simeq H^q_{\text{ét}}(X, C_{\text{ét}}[q]).$$

In particular, if $X$ is smooth then $H^q_{\text{ét}}(X, C_{\text{ét}}) \xrightarrow{\sim} H^q_{\text{éh}}(X, C_{\text{éh}})$. □

(See [43, Th. 4.3] for a different proof of the second statement.)

The following lemma will be used many times:

11.2.3. **Lemma** (Blow-up induction). Let $\mathcal{A}$ be an abelian category.

a) Let $\mathcal{B} \subseteq \mathcal{A}$ be a thick subcategory and $H^* : \text{Sch}(k)^{\text{op}} \to \mathcal{A}^{(\mathbb{N})}$ a functor with the following property: given an abstract blow-up as in §8.1.e, we have a long exact sequence

$$\cdots \to H^i(X) \to H^i(\tilde{X}) \oplus H^i(Z) \to H^i(\mathcal{X}) \to H^{i+1}(X) \to \cdots$$

Let $n \geq 0$, and assume that $H^i(X) \in \mathcal{B}$ for $i \leq n$ and $X \in \text{Sm}(k)$. Then $H^i(X) \in \mathcal{B}$ for $i \leq n$ and all $X \in \text{Sch}(k)$.

b) Let $H^*_1, H^*_2$ be two functors as in a) and $\varphi^* : H^*_1 \to H^*_2$ be a natural transformation. Let $n \geq 0$, and suppose that $\varphi^*_X$ is an isomorphism for all $X \in \text{Sm}(k)$ and $i \leq n$. Then $\varphi^*_X$ is an isomorphism for all $X \in \text{Sch}(k)$ and $i \leq n$.

We get the same statements as a) and b) by replacing “$i \leq n$” by “$i \geq n + \dim X$”.

*Proof.* Induction on $\dim X$ in two steps: 1) if $X$ is integral, choose a resolution of singularities $\tilde{X} \to X$; 2) in general, if $Z_1, \ldots, Z_r$ are the irreducible components of $X$, choose $\tilde{X} = \coprod Z_i$ and $Z = \bigcup_{i \neq j} Z_i \cap Z_j$. □

11.2.4. **Examples.** 1) Thanks to [96, Th. 4.1.10] and Proposition 11.2.2, cdh or étale cohomology with coefficients in an object of $\text{DM}_{\text{eff}}$
or $\text{DM}_{\text{eff}}^{\text{et}}$ satisfy the hypothesis of a) (here $\mathcal{A}$ = abelian groups). (See also [43, Prop. 3.2] for a different proof.)

2) Étale cohomology with torsion coefficients satisfies the hypothesis of a) by [79, Prop. 2.1] (recall that the proof of loc. cit. relies on the proper base change theorem).

Here is a variant of Lemma 11.2.3:

11.2.5. **Proposition.** a) Let $X \in \text{Sch}(k)$ and $X_{\cdot} \to X$ be a hyper-envelope in the sense of Gillet-Soulé [45, 1.4.1]. Let $\tau = \text{cdh}$ or $\text{ét}$. Then, for any (bounded below) complex of sheaves $C$ over $\text{Sch}(X)_{\tau}$, the augmentation map

$$H^*_\tau(X, C) \to H^*_\tau(X_{\cdot}, C)$$

is an isomorphism.

b) Suppose that $X_0$ and $X_1$ are smooth and $\mathcal{F}$ is a homotopy invariant Nisnevich (if $\tau = \text{cdh}$) or étale (if $\tau = \text{ét}$) sheaf with transfers. Then we have

$$\mathcal{F}_\tau(X) = \text{Ker}(\mathcal{F}(X_0) \to \mathcal{F}(X_1)).$$

**Proof.** a) By [70, Lemma 12.26], $X_{\cdot}$ is a proper $\tau$-hypercovering (cf. [23, p. 46]). Therefore the proposition follows from the standard theory of cohomological descent.

b) Let us take $C = \mathcal{F}_{\tau}[0]$. By a) we have a descent spectral sequence which gives a short exact sequence

$$0 \to \mathcal{F}_{\tau}(X) \to \mathcal{F}_{\tau}(X_0) \to \mathcal{F}_{\tau}(X_1)$$

and the conclusion now follows from 11.2.2. \qed

11.3. **L_iAlb(X) for X singular.** The following is a general method for computing the 1-motivic homology of $\text{LAlb}^Q(X)$:

11.3.1. **Proposition.** If $\text{char } k = 0$ and $X \in \text{Sch}(k)$ consider cdh cohomology groups $\mathbb{H}^i_{\text{cdh}}(X, \pi^*(N))_\mathbb{Q}$, where $\pi : \text{Sch}(k)_{\text{cdh}} \to \text{Sch}(k)_{\text{Zar}}$ is the canonical map from the cdh site to the big Zariski site. Then we have short exact sequences, for all $i \in \mathbb{Z}$

$$0 \to \text{Ext}^1(L_{i-1}\text{Alb}^Q(X), N) \to \mathbb{H}^i_{\text{cdh}}(X, \pi^*(N))_\mathbb{Q} \to \text{Hom}(L_i\text{Alb}^Q(X), N) \to 0$$

$$0 \to \text{Ext}^1(N, L_{i+1}\text{Alb}^Q(X)) \to \text{Ext}^{-i}(N, \text{LAlb}^Q(X)) \to \text{Hom}(N, L_i\text{Alb}(X)) \to 0.$$
Proof. For any 1-motive $N \in \mathcal{M}_1$ we have a spectral sequence
\begin{equation}
E_2^{p,q} = \operatorname{Ext}^p(L_q\operatorname{Alb}(X), N) \Rightarrow \operatorname{Ext}^{p+q}(L\operatorname{Alb}(X), N)
\end{equation}
yielding the following short exact sequence
\[
0 \to \operatorname{Ext}^1(L_{i-1}\operatorname{Alb}^Q(X), N) \to \operatorname{Ext}^i(L\operatorname{Alb}^Q(X), N) \to \operatorname{Hom}(L_i\operatorname{Alb}^Q(X), N) \to 0
\]
because of Proposition 1.2.1. By adjunction we also obtain
\[
\operatorname{Ext}^i(L\operatorname{Alb}^Q(X), N) = \operatorname{Hom}(L\operatorname{Alb}^Q(X), N[i]) \cong \operatorname{Hom}(M(X), \operatorname{Tot} N[i]).
\]
Now from [96, Thm. 3.2.6 and Cor. 3.2.7], for $X$ smooth we have
\[
\operatorname{Hom}(M(X), \operatorname{Tot} N[i]) \cong H^i_{\text{Zar}}(X, N)_\mathbb{Q}.
\]
If $k$ is of characteristic 0 and $X$ is arbitrary, we get the same isomorphism with cdh hypercohomology by [96, Thm. 4.1.10].

The proof for the second short exact sequence is similar. □

The following proposition follows readily by blow-up induction (Lemma 11.2.3) from Corollary 10.2.3 and the exact sequences (8.2):

11.3.2. Proposition. For any $X \in \text{Sch}(k)$ of dimension $d$, we have
a) $L_i\operatorname{Alb}(X) = 0$ if $i < 0$.
b) $L_0\operatorname{Alb}(X) = [\mathbb{Z}[\pi_0(X)] \to 0]$.
c) $L_i\operatorname{Alb}(X) = 0$ for $i > \max(2, d + 1)$.
d) $L_{d+1}\operatorname{Alb}(X)$ is a group of multiplicative type. □

11.4. The cohomological 1-motives $R^i\operatorname{Pic}(X)$. If $X \in \text{Sch}(k)$, we quote the following variant of Proposition 11.3.1:

11.4.1. Lemma. Let $N \in \mathcal{M}_1 \otimes \mathbb{Q}$ and $X \in \text{Sch}(k)$. We have a short exact sequence, for all $i \in \mathbb{Z}$
\[
0 \to \operatorname{Ext}(N, R^{i-1}\operatorname{Pic}(X)) \to \mathbb{H}^i_{\text{cdh}}(X, \pi^*(N^*))_\mathbb{Q} \to \operatorname{Hom}(N, R^i\operatorname{Pic}(X)) \to 0
\]
here $\pi : \text{Sch}(k)_{\text{cdh}} \to \text{Sch}(k)_{\text{Zar}}$ and $N^*$ is the Cartier dual.

Proof. The spectral sequence
\[
E_2^{p,q} = \operatorname{Ext}^p(N, R^q\operatorname{Pic}(X)) \Rightarrow \operatorname{Ext}^{p+q}(N, R\operatorname{Pic}(X))
\]
yields the following short exact sequence
\[
0 \to \operatorname{Ext}(N, R^{i-1}\operatorname{Pic}(X)) \to \operatorname{Ext}^i(N, R\operatorname{Pic}(X)) \to \operatorname{Hom}(N, R^i\operatorname{Pic}(X)) \to 0
\]
and by Cartier duality, the universal property and [96, Thm. 4.1.10] we obtain:

$$\text{Ext}^i(N, \text{RPic}(X)) = \text{Hom}(N, \text{RPic}(X)[i]) \cong \text{Hom}(\text{LAlb}(X), N^*[i]) = \text{Hom}(M(X), N^*[i]) \cong \mathbb{H}^i_{\text{cdh}}(X, \pi^*(N^*))_\mathbb{Q}. $$

On the other hand, here is a dual to Proposition 11.3.2:

11.4.2. **Proposition.** For any $X \in \text{Sch}(k)$ of dimension $d$, we have

a) $R^i\text{Pic}(X) = 0$ if $i < 0$.

b) $R^0\text{Pic}(X) = [0 \to \mathbb{Z}[\pi_0(X)]^*]$.

c) $R^i\text{Pic}(X) = 0$ for $i > \max(2, d + 1)$.

d) $R^{d+1}\text{Pic}(X)$ is discrete.

11.5. **Borel-Moore variants.**

11.5.1. **Definition.** For $X \in \text{Sch}(k)$, we denote by $\pi_0^c(X)$ the disjoint union of $\pi_0(Z_i)$ where $Z_i$ runs through the proper connected components of $X$: this is the proper scheme of constants.

11.5.2. **Proposition.** Let $X \in \text{Sch}(k)$ of dimension $d$. Then:

a) $L^i\text{Alb}^c(X) = 0$ if $i < 0$.

b) $L^0\text{Alb}^c(X) = [\mathbb{Z}[\pi_0^c(X)] \to 0]$. In particular, $L_0\text{Alb}^c(X) = 0$ if no connected component is proper.

c) $L^i\text{Alb}^c(X) = 0$ for $i > \max(2, d + 1)$.

d) $L_{d+1}\text{Alb}^c(X)$ is a group of multiplicative type.

**Proof.** If $X$ is proper, this is Proposition 11.3.2. In general, we may choose a compactification $\overline{X}$ of $X$; if $Z = \overline{X} - X$, with $\dim Z < \dim X$, the claim follows inductively by the long exact sequence (9.1).

We leave it to the reader to formulate the dual of this proposition for $\text{RPic}^c(X)$.

12. **1-MOTIVIC HOMOLOGY AND COHOMOLOGY OF CURVES**

12.1. **“Chow-Künneth” decomposition for a curve.** Note that for any curve $C$, the map $a_C$ is an isomorphism by Proposition 5.1.4. Moreover, since the category of 1-motives up to isogeny is of cohomological dimension 1 (see Prop. 1.2.1), the complex $\text{LAlb}(C)$ can be represented by a complex with zero differentials. Using Proposition 11.3.2 c), we then have:
12.1.1. **Corollary.** If $C$ is a curve then the motive $M(C)$ decomposes in $\text{DM}^\text{eff}_{\text{gm}} \otimes \mathbb{Q}$ as

$$M(C) = M_0(C) \oplus M_1(C) \oplus M_2(C)$$

where $M_i(C) := \text{Tot} \, L^i \text{Alb} \mathbb{Q}(C)[i]$.

12.2. **L}_i\text{Alb and } R^i\text{Pic of curves.** Here we shall complete the computation of Proposition 11.3.2 in the case of a curve $C$.

Let $\tilde{C}$ denote the normalisation of $C$. Let $\overline{C}$ be a smooth compactification of $\tilde{C}$ so that $F = \overline{C} - \tilde{C}$ is a finite set of closed points. Consider the following cartesian square

$$\begin{array}{ccc}
\tilde{S} & \longrightarrow & \tilde{C} \\
\downarrow & & \downarrow \\
S & \longrightarrow & C
\end{array}$$

where $S$ denote the singular locus. Let $\overline{S}$ denote $\tilde{S}$ regarded in $\overline{C}$. Note that $S = \pi_0(S)$, $\tilde{S} = \pi_0(\tilde{S})$ and $\pi_0(S) \twoheadrightarrow \pi_0(S)$ if $\tilde{C} \to C$ is radicial, yielding $M(\tilde{C}) \cong M(C)$ in this case. In general, we have the following.

12.2.1. **Theorem.** Let $C$, $\tilde{C}$, $\overline{C}$, $S$, $\tilde{S}$, $\overline{S}$ and $F$ as above. Then

$$L_i\text{Alb}(C) = \begin{cases} 
[Z[\pi_0(C)] \to 0] & \text{if } i = 0 \\
[\text{Div}^0_{\overline{S}/S}(\overline{C}, F) \twoheadrightarrow \text{Pic}^0(\overline{C}, F)] & \text{if } i = 1 \\
[0 \to \text{NS}^\ast_{C/k}] & \text{if } i = 2 \\
0 & \text{otherwise}
\end{cases}$$

where: $\text{Div}^0_{\tilde{S}/S}(\tilde{C}, F) = \text{Div}^0_{\overline{S}/S}(\overline{C})$ here is the free group of degree zero divisors generated by $\tilde{S}$ having trivial push-forward on $S$ and the map $u$ is the canonical map (cf. [11, Def. 2.2.1]); $\text{NS}^\ast_{C/k}$ is the sheaf associated to the free abelian group on the proper irreducible components of $\tilde{C}$. In particular, $L_1\text{Alb}(C) = \text{Pic}^0(C)$.

**Proof.** We use the long exact sequence (8.2)

$$\cdots \to L_i\text{Alb}(\tilde{S}) \to L_i\text{Alb}(\tilde{C}) \oplus L_i\text{Alb}(S) \to L_i\text{Alb}(C) \to L_{i-1}\text{Alb}(\tilde{S}) \to \cdots$$

Since $S$ and $\tilde{S}$ are 0-dimensional we have $L_i\text{Alb}(\tilde{S}) = L_i\text{Alb}(S) = 0$ for $i > 0$, therefore

$$L_i\text{Alb}(C) = L_i\text{Alb}(\tilde{C}) \text{ for } i \geq 2$$

and by 10.2.3 we get the claimed vanishing and description of $L_2\text{Alb}(C)$.

For $i = 0$ see Corollary 11.3.2. If $i = 1$ then $L_1\text{Alb}(C)$ is here represented as an element of $\text{Ext}([\Lambda \to 0], L_1\text{Alb}(\tilde{C}))$ where $\Lambda := \text{Ker}(Z[\pi_0(\tilde{S})])$.
→ \mathbb{Z}[\pi_0(\tilde{C})] \oplus \mathbb{Z}[\pi_0(S)]$. Recall, see 10.2.3, that $L_1 Alb(\tilde{C}) = [0 \to A^0_{C/k}]$ thus $\text{Ext}(\Lambda, L_1 Alb(\tilde{C})) = \text{Hom}_k(\Lambda, A^0_{C/k})$ and

$$L_1 Alb(C) = [\Lambda \xrightarrow{u} A^0_{C/k}].$$

Now $\Lambda = \text{Div}^0_{\overline{S}/S}(\overline{C}, F), \ A^0_{C/k} = \text{Pic}^0(\overline{C}, F)$ and the map $u$ is induced by the following canonical map.

Consider $\varphi_{\tilde{C}} : \tilde{C} \to \text{Pic}(\overline{C}, F)$ where $\varphi_{\tilde{C}}(P) := (\mathcal{O}_{\overline{C}}(P), 1)$ yielding $\mathcal{A}_{\overline{C}/k} = \text{Pic}(\overline{C}, F)$ and such that

$$0 \to \text{Div}^0_F(\overline{C})^* \to \text{Pic}^0(\overline{C}, F) \to \text{Pic}^0(\overline{C}) \to 0.$$

Thus $L_1 Alb(\tilde{C}) = [0 \to \text{Pic}^0(\overline{C}, F)]$. Note that $\mathbb{Z}[\pi_0(\tilde{S})] = \text{Div}_{\overline{S}}(\tilde{C}) = \text{Div}_{\overline{S}}(\overline{C}, F)$, the map $\mathbb{Z}[\pi_0(\tilde{S})] \to \mathbb{Z}[\pi_0(\tilde{C})]$ is the degree map and the following map $\mathbb{Z}[\pi_0(\tilde{S})] \to \mathbb{Z}[\pi_0(S)]$ is the proper push-forward of Weil divisors, i.e. $\Lambda = \text{Div}^0_{\overline{S}/S}(\overline{C}, F)$. The map $\varphi_{\tilde{C}}$ then induces the mapping $u \in \text{Hom}_k(\Lambda, \text{Pic}^0(\overline{C}, F))$ which also is the canonical lifting of the universal map $D \mapsto \mathcal{O}_{\overline{C}}(D)$ as the support of $D$ is disjoint from $F$ (cf. [11, Lemma 3.1.3]).

12.2.2. Remark. Note that $R^1 \text{Pic}(C) = L_1 Alb(C)^*$ is Deligne’s motivic cohomology $H^1_m(C)(1)$ of the singular curve $C$ by [11, Prop. 3.1.2]. In fact, $\text{Pic}^{-}(C)^* = \text{Alb}^+(C) \cong H^1_{\text{et}}(C)(1) \cong \text{Pic}^+(C) = \text{Alb}^-(C)^*$ for a curve $C$. Thus $L_1 Alb(C)$ also coincides with the homological Albanese 1-motive $\text{Alb}^-(C)$. The $L_i Alb(C)$ also coincide with Lichtenbaum-Deligne motivic homology $h_i(C)$ of the curve $C$, cf. [64].

12.2.3. Corollary. Let $C$ be a curve, $C'$ its seminormalisation, $\overline{C}'$ a compactification of $C'$, and $F = \overline{C}' - C'$. Let further $\tilde{C}$ denote the normalisation of $C$. Then

$$R^i \text{Pic}(C) = \begin{cases} [0 \to \mathbb{Z}^{\text{et}}[\pi_0(C)]] & \text{if } i = 0 \\ [\text{Div}^0_{F'}(\overline{C}') \to \text{Pic}^0(\overline{C}')] & \text{if } i = 1 \\ [\text{NS}(\overline{C}) \to 0] & \text{if } i = 2 \\ 0 & \text{otherwise} \end{cases}$$

where $\text{NS}(\overline{C}) = \mathbb{Z}[\pi_0^c(\overline{C})]$ and $\pi_0^c(\overline{C})$ is the scheme of proper constants. In particular, $R^1 \text{Pic}(C) \cong \text{Pic}^+(C)$.

12.3. Borel-Moore variants.

12.3.1. Theorem. Let $C$ be a smooth curve, $\overline{C}$ a smooth compactification of $C$ and $F = \overline{C} - C$ the finite set of closed points at infinity.
Then
\[
L_i \text{Alb}^c(C) = \begin{cases} 
[Z[\pi^0_0(C)] \to 0] & \text{if } i = 0 \\
[\text{Div}^0_F(C) \to \text{Pic}^0(C)] & \text{if } i = 1 \\
[0 \to \text{NS}^*[\overline{C}/k]] & \text{if } i = 2 \\
0 & \text{otherwise}
\end{cases}
\]
where \(\text{NS}(\overline{C}) = \mathbb{Z}[\pi_0(\overline{C})]\) and \(\pi^0_0(C)\) is the scheme of proper constants.

**Proof.** It follows from the distinguished triangle
\[
\begin{array}{ccc}
L \text{Alb}(F) & \longrightarrow & L \text{Alb}(\overline{C}) \\
& & \uparrow \\
& & L \text{Alb}^c(C)
\end{array}
\]
and Corollary 10.2.3, yielding the claimed description: \(L_0 \text{Alb}^c(C) = \text{Coker}(L_0 \text{Alb}(F) \to L_0 \text{Alb}(\overline{C}))\) moreover we have
\[
[\text{Div}^0_F(\overline{C}) \to 0] = \text{Ker}(L_0 \text{Alb}(F) \to L_0 \text{Alb}(\overline{C}))
\]
and the following extension
\[
0 \to L_1 \text{Alb}(\overline{C}) \to L_1 \text{Alb}^c(C) \to [\text{Div}^0_F(\overline{C}) \to 0] \to 0.
\]
Finally, \(L_i \text{Alb}(\overline{C}) = L_i \text{Alb}^c(C)\) for \(i \geq 2\). \(\Box\)

**12.3.2. Corollary.** Let \(C\) be a smooth curve, \(\overline{C}\) a smooth compactification of \(C\) and \(F = \overline{C} - C\) the finite set of closed points at infinity. Then
\[
R^i \text{Pic}^c(C) = \begin{cases} 
[0 \to \mathbb{G}_m[\pi^0_0(C)]] & \text{if } i = 0 \\
[0 \to \text{Pic}^0(\overline{C}, F)] & \text{if } i = 1 \\
[\text{NS}(\overline{C}) \to 0] & \text{if } i = 2 \\
0 & \text{otherwise}
\end{cases}
\]
where \(\text{NS}(\overline{C}) = \mathbb{Z}[\pi_0(\overline{C})]\) and \(\pi^0_0(C)\) is the scheme of proper constants.

Here we have that \(R^1 \text{Pic}^c(C) = R^1 \text{Pic}^*(C)\) is also the Albanese variety of the smooth curve.

Note that \(L_1 \text{Alb}^c(C) = \text{Pic}^+(C) = \text{Alb}^+(C)\) for curves, see [11]) coincide with Deligne’s motivic \(H^i_m(C)(1)\) of the smooth curve \(C\). This is due to the Poincaré duality isomorphism \(M^c(C) = M(C)^*(1)[2]\).

**13. Comparison with Pic\(^+, \text{Pic}^-, \text{Alb}^+, \text{Alb}^-\)**

In this section, \(k\) is of characteristic 0 since we mainly deal with singular schemes (but see beginning of Section 11). We want to study \(L_1 \text{Alb}(X)\) and its variants in more detail. In particular, we show in Proposition 13.6.3 c) that it is always a Deligne 1-motive, and show
in Corollaries 13.7.2 and 13.10.2 that, if $X$ is normal or proper, it is canonically isomorphic to the 1-motive $\text{Alb}^{-}(X)$ of [11]. Precise descriptions of $L_{1}\text{Alb}(X)$ are given in Proposition 13.6.5 and Corollary 13.6.6.

We also describe $L_{1}\text{Alb}^{\text{c}}(X)$ in Proposition 13.11.2; more precisely, we prove in Theorem 13.11.1 that its dual $R^{1}\text{Pic}^{\text{c}}(X)$ is canonically isomorphic to $\text{Pic}^{0}(\overline{X}, Z)/\mathcal{U}$, where $\overline{X}$ is a compactification of $X$ with complement $Z$ and $\mathcal{U}$ is the unipotent radical of the commutative algebraic group $\text{Pic}^{0}(X, Z)$. Finally, we prove in Theorem 13.12.6 that $L_{1}\text{Alb}^{*}(X)$ is abstractly isomorphic to the 1-motive $\text{Alb}^{+}(X)$ of [11].

We start with some comparison results between étale and étale cohomology for non smooth schemes.

Let $\varepsilon : \text{Sch}_{\text{et}} \to \text{Sch}_{\text{et}}$ be the obvious morphism of sites. If $\mathcal{F}$ is an étale sheaf on $\text{Sch}$, we denote by $\mathcal{F}_{\text{et}}$ its étale sheafification (that is, $\mathcal{F}_{\text{et}} = \varepsilon_{*}\varepsilon^{*}\mathcal{F}$). We shall abbreviate $H^{*}_{\text{et}}(X, \mathcal{F})$ to $H^{*}_{\text{et}}(X, \mathcal{F})$.

13.1. Torsion sheaves. The first basic result is a variant of [93, Cor. 7.8 and Th. 10.7]: it follows from Proposition 11.2.2 and Examples 11.2.4 via Lemma 11.2.3 b).

13.1.1. **Proposition.** Let $C$ be a bounded below complex of torsion sheaves on $(\text{Spec} k)_{\text{et}}$. Then, for any $X \in \text{Sch}$ and any $n \in \mathbb{Z}$,

$$H^{n}_{\text{et}}(X, C) \sim \to H^{n}_{\text{et}}(X, C).$$

(See [43, Th. 3.6] for a different proof.)

13.2. Discrete sheaves.

13.2.1. **Lemma.** If $\mathcal{F}$ is discrete, then

a) $\mathcal{F} \sim \to \mathcal{F}_{\text{et}}$. More precisely, for any $X \in \text{Sch}$, $\mathcal{F}(\pi_{0}(X)) \sim \to \mathcal{F}(X) \sim \to \mathcal{F}_{\text{et}}(X)$.

b) If $f : Y \to X$ is surjective with geometrically connected fibres, then $\mathcal{F}_{\text{et}} \sim \to f_{*}\mathcal{F}$.

**Proof.** a) We may assume $X$ reduced. Clearly it suffices to prove that $\mathcal{F}(\pi_{0}(X)) \sim \to \mathcal{F}_{\text{et}}(X)$ for any $X \in \text{Sch}$. In the situation of §8.1.e, we have a commutative diagram of exact sequences

$$
\begin{array}{cccc}
0 & \longrightarrow & \mathcal{F}_{\text{et}}(X) & \longrightarrow & \mathcal{F}_{\text{et}}(\overline{X}) \oplus \mathcal{F}_{\text{et}}(Z) & \longrightarrow & \mathcal{F}_{\text{et}}(\overline{Z}) \\
0 & \longrightarrow & \mathcal{F}(\pi_{0}(X)) & \longrightarrow & \mathcal{F}(\pi_{0}(\overline{X})) & \oplus & \mathcal{F}(\pi_{0}(Z)) & \longrightarrow & \mathcal{F}(\pi_{0}(\overline{Z})).
\end{array}
$$

The proof then goes exactly as the one of Proposition 13.1.1. b) follows from a).
It is well-known that $H^1_{\text{ét}}(X, \mathcal{F}) = 0$ for any geometrically unibranch scheme $X \in \text{Sch}$ if $\mathcal{F}$ is constant and torsion-free (cf. [SGA4, IX, Prop. 3.6 (ii)]). The following lemma shows that this is also true for the éh topology, at least if $X$ is normal.

13.2.2. Lemma (compare [70, Ex. 12.31 and 12.32]). Let $\mathcal{F}$ be a constant torsion-free sheaf on $\text{Sch}(k)$.

a) For any $X \in \text{Sch}$, $H^1_{\text{éh}}(X, \mathcal{F})$ is torsion-free. It is finitely generated if $\mathcal{F}$ is a lattice.

b) Let $f : \tilde{X} \to X$ be a surjective morphism. Then $H^1_{\text{éh}}(X, \mathcal{F}) \to H^1_{\text{éh}}(\tilde{X}, \mathcal{F})$ is injective in the following cases:
   (i) The geometric fibres of $f$ are connected.
   (ii) $f$ is finite and flat.

c) If $X$ is normal, $H^1_{\text{éh}}(X, \mathcal{F}) = 0$.

Proof. a) The first assertion follows immediately from Lemma 13.2.1 (consider the exact sequence of multiplication by $n$ on $\mathcal{F}$). The second assertion follows by blow-up induction from the fact that $H^1_{\text{éh}}(X, \mathcal{F}) = 0$ if $X$ is smooth, by Proposition 11.2.2.

b) In the first case, the Leray spectral sequence yields an injection

$$H^1_{\text{éh}}(X, f_* \mathcal{F}) \hookrightarrow H^1_{\text{éh}}(\tilde{X}, \mathcal{F})$$

and $f_* \mathcal{F} = \mathcal{F}$ by Lemma 13.2.1 b). In the second case, the theory of trace [SGA4, XVII, Th. 6.2.3] provides $\mathcal{F}$, hence $\mathcal{F}_{\text{éh}}$, with a morphism $Tr_f : f_* \mathcal{F} \to \mathcal{F}$ whose composition with the natural morphism is (on each connected component of $X$) multiplication by some nonzero integer. This shows that the kernel of $H^1_{\text{éh}}(X, \mathcal{F}) \to H^1_{\text{éh}}(X, f_* \mathcal{F})$ is torsion, hence 0 by a).

c) follows from b) with $\tilde{X}$ a desingularisation of $X$: by Proposition 13.1.1, $H^1_{\text{ét}}(\tilde{X}, \mathcal{F}) \overset{\sim}{\to} H^1_{\text{éh}}(\tilde{X}, \mathcal{F})$ and it is well-known that the first group is 0; on the other hand, the fibres of $f$ are geometrically connected by Zariski’s main theorem. □

The following is a version of [101, Lemma 5.6]:

13.2.3. Lemma. Let $f : \tilde{X} \to X$ be a finite birational morphism, $i : Z \hookrightarrow X$ a closed subset and $\tilde{Z} = p^{-1}(Z)$. Then, for any discrete sheaf, we have a long exact sequence:

$$\cdots \to H^i_{\text{ét}}(X, \mathcal{F}) \to H^i_{\text{ét}}(\tilde{X}, \mathcal{F}) \oplus H^i_{\text{ét}}(Z, \mathcal{F})$$

$$\to H^i_{\text{ét}}(\tilde{Z}, \mathcal{F}) \to H^{i+1}_{\text{ét}}(X, \mathcal{F}) \to \cdots$$
Proof. Let \( g : \tilde{Z} \to Z \) be the induced map. Then \( f_*, i_* \) and \( g_* \) are exact for the étale topology. Thus it suffices to show that the sequence of sheaves

\[
0 \to \mathcal{F} \to f^* f_* \mathcal{F} \oplus i^* i_* \mathcal{F} \to (ig)_* (igi)^* \mathcal{F} \to 0
\]

is exact. The assertion is local for the étale topology, hence we may assume that \( X \) is strictly local. Then \( Z, \tilde{X} \) and \( \tilde{Z} \) are strictly local as well, hence connected, thus the statement is obvious. \( \square \)

We can now prove:

13.2.4. Proposition. For any \( X \in \text{Sch}(k) \) and any discrete sheaf \( \mathcal{F} \), the map \( H^1_{\text{ét}}(X, \mathcal{F}) \to H^1_{\text{éh}}(X, \mathcal{F}) \) is an isomorphism.

Proof. Consider the exact sequence

\[
0 \to \mathcal{F}_{\text{tors}} \to \mathcal{F} \to \mathcal{F}/\mathcal{F}_{\text{tors}} \to 0
\]

where \( \mathcal{F}_{\text{tors}} \) is the torsion subsheaf of \( \mathcal{F} \). The 5 lemma, Lemma 13.2.1 and Proposition 13.1.1 reduce us to the case where \( \mathcal{F} \) is torsion-free. As a discrete étale sheaf over \( \text{Sch}(k) \), \( \mathcal{F} \) becomes constant over some finite Galois extension of \( k \): a Hochschild-Serre argument then reduces us to the case where \( \mathcal{F} \) is constant and torsion-free.

Let \( f : \tilde{X} \to X \) be the normalisation of \( X \), and take for \( Z \) the non-normal locus of \( X \) in Lemma 13.2.3. The result now follows from comparing the exact sequence of this lemma with the one for éh topology, and using Lemma 13.2.2 c).

13.2.5. Corollary. The exact sequence of Lemma 13.2.3 holds up to \( i = 1 \) for a general abstract blow-up. \( \square \)

13.3. Strictly reduced schemes. If \( G \) is a commutative \( k \)-group scheme, the associated presheaf \( G \) is an étale sheaf on reduced \( k \)-schemes of finite type. However, \( G(X) \to G_{\text{éh}}(X) \) is not an isomorphism in general if \( X \) is not smooth. Nevertheless we have some nice results in Lemma 13.3.4 below.

13.3.1. Definition. A separated \( k \)-scheme of finite type \( X \) is strictly reduced (a recursive definition) if it is reduced and

(i) If \( X \) is irreducible: \( X_{\text{sing}} \), considered with its reduced structure, is strictly reduced.

(ii) If \( Z_1, \ldots, Z_n \) are the irreducible components of \( X \): all \( Z_i \) are strictly reduced and the scheme-theoretic intersection \( Z_i \cap Z_j \) is reduced for any \( i \neq j \).

13.3.2. Examples. 1) If \( \dim X = 0 \), \( X \) is strictly reduced.

2) The union of a line and a tangent parabola is not strictly reduced.
3) If $X$ is normal and of dimension $\leq 2$, it is strictly reduced.

4) M. Ojanguren provided the following example of a normal 3-fold which is not strictly reduced: take the affine hypersurface with equation $uv = x^2(y^2 - x)^2$.

13.3.3. Lemma. Let $G$ be an affine group scheme and $f : Y \to X$ a proper surjective map with geometrically connected fibres. Then $\mathcal{G}(X) \to \mathcal{G}(Y)$, and $\mathcal{H}^0(Y, G) \to \mathcal{H}^0(Y, G)$ for any Grothendieck topology $\tau$ stronger than the Zariski topology.

Proof. The first statement is clear, and the second follows because the hypothesis on $f$ is stable under any base change. \hfill $\square$

13.3.4. Lemma. a) If $X$ is reduced, then the map

$$(13.1)\quad \mathcal{G}(X) \to \mathcal{G}_{\text{et}}(X)$$

is injective for any semi-abelian $k$-scheme $G$.

b) If $X$ is strictly reduced, (13.1) is an isomorphism.

c) If $X$ is proper and $G$ is a torus, the maps $\mathcal{G}(\pi_0(X)) \to \mathcal{G}_{\text{et}}(X) \to \mathcal{G}_{\text{et}}(X)$ are isomorphisms. If moreover $X$ is reduced, (13.1) is an isomorphism.

Proof. a) Let $Z_i$ be the irreducible components of $X$ (with their reduced structure), and for each $i$ let $p_i : \tilde{Z}_i \to Z_i$ be a resolution of singularities. We have a commutative diagram

$$\begin{array}{ccc}
\mathcal{G}_{\text{et}}(X) & \to & \bigoplus \mathcal{G}_{\text{et}}(Z_i) \\
\uparrow & & \uparrow \\
\mathcal{G}(X) & \to & \bigoplus \mathcal{G}(Z_i) \\
\end{array}$$

The bottom horizontal maps are injective; the right vertical map is an isomorphism by Proposition 11.2.2. The claim follows.

b) We argue by induction on $d = \dim X$. If $d = 0$ this is trivial. If $d > 0$, we first assume $X$ irreducible. Let $Z$ be its singular locus, and choose a desingularisation $p : \tilde{X} \to X$ with $p$ proper surjective, $\tilde{X}$ smooth, $\tilde{Z} = p^{-1}(Z)$ a divisor with normal crossings (in particular reduced) and $p|_{\tilde{X} - \tilde{Z}}$ an isomorphism. We now have a commutative diagram

$$\begin{array}{ccc}
0 & \to & \mathcal{G}_{\text{et}}(X) \\
\uparrow & & \uparrow \\
0 & \to & \mathcal{G}(X) \\
\end{array}$$

$$\begin{array}{ccc}
\mathcal{G}_{\text{et}}(Z) & \to & \mathcal{G}_{\text{et}}(\tilde{X}) \\
\uparrow & & \uparrow \\
\mathcal{G}(Z) & \to & \mathcal{G}(\tilde{X}) \\
\end{array}$$

$$\begin{array}{ccc}
\mathcal{G}_{\text{et}}(\tilde{Z}) & \to & \bigoplus \mathcal{G}(\tilde{Z}) \\
\uparrow & & \uparrow \\
\bigoplus \mathcal{G}(\tilde{Z}) & \to & \bigoplus \mathcal{G}(\tilde{Z}) \\
\end{array}$$
where the lower sequence is exact, the middle vertical map is bijective by induction on \(d\) and the smooth case (Proposition 11.2.2) and the right vertical map is injective by a). It follows that the left vertical map is surjective.

In general, write \(Z_1, \ldots, Z_n\) for the irreducible components of \(X\): by assumption, the two-fold intersections \(Z_{ij}\) are reduced. The commutative diagram

\[
\begin{array}{ccc}
0 & \rightarrow & G_{\text{et}}(X) \\
& & \uparrow \\
0 & \rightarrow & G(X)
\end{array}
\begin{array}{ccc}
\rightarrow & \oplus G_{\text{et}}(Z_i) & \rightarrow \oplus G_{\text{et}}(Z_{ij}) \\
& & \uparrow \\
\rightarrow & \oplus G(Z_i) & \rightarrow \oplus G(Z_{ij})
\end{array}
\]

then has the same formal properties as the previous one, and we conclude.

For c), same proof as for Lemma 13.2.1 a). (The second statement of c) is true because \(G(\pi_0(X)) \xrightarrow{\sim} G(X)\) if \(X\) is proper and reduced.) \(\square\)

13.4. **Normal schemes.** The main result of this subsection is:

13.4.1. **Theorem.** Let \(X\) be normal. Then, for any \(\mathcal{F} \in \text{Shv}\_1\), the map \(\mathcal{F}(X) \rightarrow \mathcal{F}_{\text{et}}(X)\) is bijective and the map \(H^1_{\text{et}}(X, \mathcal{F}) \rightarrow H^1_{\text{et}}(\mathcal{F}_{\text{et}})\) is injective (with torsion-free cokernel by Proposition 13.1.1).

**Proof.** In several steps:

*Step 1.* The first result implies the second for a given sheaf \(\mathcal{F}\): let \(\varepsilon : \text{Sch}(k)_{\text{et}} \rightarrow \text{Sch}(k)_{\text{et}}\) be the projection morphism. The associated Leray spectral sequence gives an injection

\[H^1_{\text{et}}(X, \varepsilon_\ast \mathcal{F}_{\text{et}}) \hookrightarrow H^1_{\text{et}}(\mathcal{F}_{\text{et}}).\]

But any scheme étale over \(X\) is normal [SGA1, Exp. I, Cor. 9.10], therefore \(\mathcal{F} \rightarrow \varepsilon_\ast \mathcal{F}_{\text{et}}\) is an isomorphism over the small étale site.

*Step 2.* Let \(0 \rightarrow \mathcal{F}' \rightarrow \mathcal{F} \rightarrow \mathcal{F}'' \rightarrow 0\) be a short exact sequence in \(\text{Shv}_1\). If the theorem is true for \(\mathcal{F}'\) and \(\mathcal{F}''\), it is true for \(\mathcal{F}\). This follows readily from *Step 1* and a diagram chase.

*Step 3.* Given the structure of 1-motivic sheaves, *Step 1 - 2* reduce us to prove that \(\mathcal{F}(X) \xrightarrow{\sim} \mathcal{F}_{\text{et}}(X)\) separately when \(\mathcal{F}\) is discrete, a torus or an abelian variety. The discrete case follows from Lemma 13.2.1 a).

*Step 4.* If \(G\) is a torus, let \(\pi : \widetilde{X} \rightarrow X\) be a desingularisation of \(X\). We have a commutative diagram

\[
\begin{array}{ccc}
G_{\text{et}}(X) & \rightarrow & G_{\text{et}}(\widetilde{X}) \\
\uparrow & & \uparrow \\
G(X) & \rightarrow & G(\widetilde{X}).
\end{array}
\]

Then the sequence is exact, and the commutative diagram

\[
\begin{array}{ccc}
0 & \rightarrow & G_{\text{et}}(X) \\
& & \uparrow \\
0 & \rightarrow & G(X)
\end{array}
\begin{array}{ccc}
\rightarrow & \oplus G_{\text{et}}(Z_i) & \rightarrow \oplus G(\widetilde{X}) \\
& & \uparrow \\
\rightarrow & \oplus G(Z_i) & \rightarrow \oplus G(\widetilde{X})
\end{array}
\]

then has the same formal properties as the previous one, and we conclude.
Here the right vertical map is an isomorphism because $\tilde{X}$ is smooth and the two horizontal maps are also isomorphisms by Lemma 13.3.3 applied to $\pi$ (Zariski’s main theorem). The result follows.

**Step 5.** Let finally $G$ be an abelian variety. This time, it is not true in general that $G(X) \xrightarrow{\sim} G(\tilde{X})$ for a smooth desingularisation $\tilde{X}$ of $X$. However, we get the result from Proposition 11.2.5 b) and the following general lemma. □

13.4.2. **Lemma.** Let $X \in \text{Sch}(k)$ be normal, $p : X_0 \to X$ a proper surjective map such that the restriction of $p$ to a suitable connected component $X'_0$ of $X_0$ is birational. Let $X_1 \xrightarrow{\psi} X_0$ be two morphisms such that $\psi_0 = p_1$ and that the induced map $\Psi : X_1 \to X_0 \times_X X_0$ is proper surjective. Let $Y \in \text{Sch}(k)$ and let $f : X_0 \to Y$ be such that $fp_0 = fp_1$.

![Diagram](attachment:diagram.png)

Then there exists a unique morphism $\overline{f} : X \to Y$ such that $f = \overline{f}p$.

**Proof.** We may assume $X$ connected. Since $\Psi$ is proper surjective, the hypothesis is true by replacing $X_1$ by $X_0 \times_X X_0$, which we shall assume henceforth. Let $x \in X$ and $K = k(x)$. Base-changing by the morphism $\text{Spec } K \to X$, we find (by faithful flatness) that $f$ is constant on $p^{-1}(x)$. Since $p$ is surjective, this defines $\overline{f}$ as a set-theoretic map, and this map is continuous for the Zariski topology because $p$ is also proper.

It remains to show that $\overline{f}$ is a map of locally ringed spaces. Let $x \in X$, $y = \overline{f}(x)$ and $x' \in p^{-1}(x) \cap X'_0$. Then $f^*O_{Y,y} \subseteq O_{X'_0,x'}$. Note that $X$ and $X'_0$ have the same function field $L$, and $O_{X,x} \subseteq O_{X'_0,x'} \subseteq L$. Now, since $X$ is normal, $O_{X,x}$ is the intersection of the valuation rings containing it.

Let $O$ be such a valuation ring, so that $x$ is the centre of $O$ on $X$. By the valuative criterion of properness, we may find $x' \in p^{-1}(x) \cap X'_0$ such that $O_{X'_0,x'} \subseteq O$. This shows that

$$O_{X,x} = \bigcap_{x' \in p^{-1}(x) \cap X'_0} O_{X'_0,x'}$$

and therefore that $f^*O_{Y,y} \subseteq O_{X,x}$. Moreover, the corresponding map $\overline{f}^* : O_{Y,y} \to O_{X,x}$ is local since $f^*$ is.
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(Alternatively, observe that $f$ and its topological factorisation induce a map
\[ f^\# : \mathcal{O}_Y \to f_*\mathcal{O}_{X_0} \simeq \mathcal{F}_p, \mathcal{O}_{X_0} = \mathcal{F}_s \mathcal{O}_X. \]

\[ \square \]

13.5. Some representability results.

13.5.1. Proposition. Let $\pi^X$ be the structural morphism of $X$ and $(\pi^X)^{\text{\acute{e}h}}$ the induced direct image morphism on the \text{\acute{e}h} sites. For any $F \in \text{HI}_{\text{\acute{e}h}}$, let us denote the restriction of $R^q(\pi^X)^{\text{\acute{e}h}}F_{\text{\acute{e}h}}$ to $\text{Sm}_{(k)}$ by $R^q\pi^X F_{\text{\acute{e}h}}$ (in other words, $R^q(\pi^X)^{\text{\acute{e}h}}F_{\text{\acute{e}h}}$ is the sheaf on $\text{Sm}_{(k)}$ associated to the presheaf $U \mapsto H^q(\mathcal{X} \times U, F_{\text{\acute{e}h}})$: it is an object of $\text{HI}_{\text{\acute{e}h}}$.

a) For any lattice $L$, $R^q\pi^X L$ is a ind-discrete sheaf for all $q \geq 0$; it is a lattice for $q = 0, 1$.

b) For any torus $T$, $R^q\pi^X T$ is 1-motivic for $q = 0, 1$.

Proof. We apply Lemma 11.2.3 a) in the following situation: $A = \text{HI}_{\text{\acute{e}h}}, B = \text{Shv}_{\text{0}}, H^i(X) = R^i\pi^X L$ in case a), $B = \text{Shv}_{1}, H^i(X) = R^i\pi^X T$ in case b). The smooth case is trivial in a) and the lattice assertions follow from lemmas 13.2.1 and 13.2.2 a). In b), the smooth case follows from Proposition 3.5.1. \(\square\)

13.6. $L_1 \text{Alb}(X)$ and the Albanese schemes. We now compute the 1-motive $L_1 \text{Alb}(X) = [L_1 \to G_1]$ in important special cases. This is done in the following three propositions: in particular, we shall show that it always “is” a Deligne 1-motive. Note that, by definition of a 1-motive with cotorsion, the pair $(L_1, G_1)$ is determined only up to a q.i.: the last sentence means that we may choose this pair such that $G_1$ is connected (and then it is uniquely determined).

13.6.1. Proposition. Let $X \in \text{Sch}(k)$. Then

a) $\mathcal{H}_i(\text{LAlb}(X)) = 0$ for $i < 0$.

b) Let $\mathcal{F}_X = \mathcal{H}_0(\text{Tot LAlb}(X))$. Then $\mathcal{F}_X$ corepresents the functor

\[ \text{Shv}_1 \to \text{Ab} \]

\[ \mathcal{F} \mapsto \mathcal{F}_{\text{\acute{e}h}}(X) \text{ (see Def. 11.2.1)} \]

via the composition

\[ \alpha^*M(X) \to \text{Tot LAlb}(X) \to \mathcal{F}_X[0]. \]

Moreover, we have an exact sequence, for any representative $[L_1 \to G_1]$ of $L_1 \text{Alb}(X)$:

\[ L_1 \to G_1 \to \mathcal{F}_X \to \mathbb{Z}\pi_0(X) \to 0. \]
c) Let $\mathcal{A}^\text{eh}_{X/k} := \Omega(\mathcal{F}_X)$ (cf. Proposition 3.7.5). Then $\mathcal{A}^\text{eh}_{X/k}$ corepresents the functor

$$\begin{align*}
^{t}\text{AbS} & \to \text{Ab} \\
G & \mapsto G^\text{eh}(X).
\end{align*}$$

Moreover we have an epimorphism

(13.3)

$$\mathcal{A}^\text{eh}_{X/k} \to \mathcal{A}_{X/\text{red}/k}.$$

d) If $X_{\text{red}}$ is strictly reduced (Def. 13.3.1) or normal, (13.3) is an isomorphism.

**Proof.** a) is proven as in Proposition 11.3.2 by blow-up induction (reduction to the smooth case). If $F \in \text{Shv}_1$, we have

$$\text{Hom}_{\text{DM}^\text{eff}_{\text{red}}} (\alpha^*M(X), \mathcal{F}) = \mathcal{F}_{\text{eh}}(X)$$

by Propositions 3.9.1, 11.2.2 and D.1.4. The latter group coincides with $\text{Hom}_{\text{Shv}_1} (\mathcal{F}_X, \mathcal{F})$ by (5.3) and a), hence b); the exact sequence follows from Proposition 3.12.2. The sheaf $\mathcal{A}^\text{eh}_{X/k}$ clearly corepresents the said functor; the map then comes from the obvious natural transformation in $G$: $G(X_{\text{red}}) \to G_{\text{eh}}(X)$ and its surjectivity follows from Lemma 13.3.4 a), hence c). d) follows from Lemma 13.3.4 b), Theorem 13.4.1 and the universal property of $\mathcal{A}_{X/k}$. □

13.6.2. **Remark.** One could christen $\mathcal{F}_X$ and $\mathcal{A}^\text{eh}_{X/k}$ the universal 1-motivic sheaf and the $\text{eh}$-Albanese scheme of $X$.

13.6.3. **Proposition.** a) The sheaves $\mathcal{F}_X$ and $\mathcal{A}^\text{eh}_{X/k}$ have $\pi_0$ equal to $\mathbb{Z}[\pi_0(X)]$; in particular, $\mathcal{A}^\text{eh}_{X/k} \in \text{AbS}$.

b) In (13.2), the composition $L_1 \xrightarrow{u} G_1 \to \pi_0(G_1)$ is surjective.

c) One may choose $L_1\text{Alb}(X) \simeq [L_1 \to G_1]$ with $G_1$ connected (in other words, $L_1\text{Alb}(X)$ is a Deligne 1-motive).

**Proof.** In a), it suffices to prove the first assertion for $\mathcal{F}_X$: then it follows from its universal property and Lemma 13.2.1 a). The second assertion of a) is obvious.

b) Let $0 \to L'_1 \to G'_1 \to \mathcal{F}_X \to \mathbb{Z}[\pi_0(X)] \to 0$ be the normalised presentation of $\mathcal{F}_X$ given by Proposition 3.3.3. We have a commutative
diagram

\[
\begin{array}{ccccccccc}
0 & \rightarrow & L' & \rightarrow & G' & \rightarrow & F_X & \rightarrow & \mathbb{Z}[\pi_0(X)] & \rightarrow & 0 \\
\downarrow & & \downarrow & & || & & || & & \downarrow & & \\
0 & \rightarrow & u_1(L_1) & \rightarrow & G_1 & \rightarrow & F_X & \rightarrow & \mathbb{Z}[\pi_0(X)] & \rightarrow & 0 \\
\uparrow & & \uparrow & & || & & || & & \uparrow & & \\
L_1 & \rightarrow & G_1 & \rightarrow & F_X & \rightarrow & \mathbb{Z}[\pi_0(X)] & \rightarrow & 0
\end{array}
\]

with \(\overline{u_1(L_1)} = u_1(L_1)/F\) and \(G_1 = G_1/F\), where \(F\) is the torsion subgroup of \(u_1(L_1)\). Indeed, \(\text{Ext}(G'_1, u_1(L_1)) = 0\) so we get the downwards vertical maps as in the proof of Proposition 3.3.3. By uniqueness of the normalised presentation, \(G'_1\) maps onto \(\overline{G'_1}\). A diagram chase then shows that the composition

\[
\overline{u_1(L_1)} \xrightarrow{\pi_1} G_1 \rightarrow \pi_0(G_1)
\]

is onto, and another diagram chase shows the same for \(u_1\).

c) The pull-back diagram

\[
\begin{array}{ccc}
L'_1 & \rightarrow & G'_1 \\
\downarrow & & \downarrow \\
L_1 & \rightarrow & G_1
\end{array}
\]

is a quasi-isomorphism in \(\mathcal{M}_{1}^{\text{eff}}\), thanks to b).

13.6.4. Lemma. Suppose that \(k\) is algebraically closed. Let \([L_1 \rightarrow G_1]\) be the Deligne 1-motive that lies in the q.i. class of \(L_1\text{Alb}(X)\), thanks to Proposition 13.6.3 c), and let \(L\) be a lattice.

a) We have an isomorphism

\[
\text{Hom}_{D^b(M_1)}(L\text{Alb}(X), L[1]) \sim \text{Hom}(L_1, L).
\]

b) The map

\[
\text{Hom}_{D^b(M_1)}(L\text{Alb}(X), L[j]) \rightarrow \text{Hom}_{D^b_{\text{eff}}(M_{\text{et}}(X), L[j]) = H^j_{\text{et}}(X, L)}
\]

induced by \(a_X\) (8.3) is an isomorphism for \(j = 0, 1\) (see Prop. 11.2.2 for the last equality).

Proof. a) From the spectral sequence (11.1), we get an exact sequence

\[
0 \rightarrow \text{Ext}^1(L_0\text{Alb}(X), L) \rightarrow \text{Hom}_{D^b(M_1)}(L\text{Alb}(X), L[1]) \rightarrow \text{Hom}(L_1\text{Alb}(X), L) \rightarrow \text{Ext}^2(L_0\text{Alb}(X), L).
\]
Since the two Ext are 0, the middle map is an isomorphism. Since \([L_1 \rightarrow G_1]\) is a Deligne 1-motive, \(\text{Hom}(L_1 \text{Alb}(X), L)\) is isomorphic to \(\text{Hom}(L_1, L)\).

b) By blow-up induction (Lemma 11.2.3) we reduce to \(X\) smooth. If \(j = 0\), the result is trivial; if \(j = 1\), it is also trivial because both sides are 0 (by a) and Corollary 10.2.3 for the left hand side). \(\square\)

13.6.5. **Proposition.** Keep the above notation \(L_1 \text{Alb}(X) = [L_1 \overset{u_1}{\rightarrow} G_1]\).

a) We have an isomorphism

\[ L_1 \simeq \mathcal{H}om \left( R^1 \pi_* \mathbb{Z}, \mathbb{Z} \right) \]

(cf. Proposition 13.5.1).

b) We have a canonical isomorphism

\[ G_1/(L_1)_{\text{Zar}} \xrightarrow{\sim} (\mathcal{A}^{\text{eh}}_{X/k})^0 \]

where \((L_1)_{\text{Zar}}\) is the Zariski closure of the image of \(L_1\) in \(G_1\) and \(\mathcal{A}^{\text{eh}}_{X/k}\) was defined in Proposition 13.6.1 \(((\mathcal{A}^{\text{eh}}_{X/k})^0 \text{ corepresents the functor} \ S_{\text{Ab}} \ni G \mapsto G^{\text{eh}}(X))\).

**Proof.** For the computations, we may assume \(k\) algebraically closed.

Let \(L\) be a lattice. By Lemma 13.6.4, we have an isomorphism

\[ H^1_{\text{et}}(X, L) \simeq \text{Hom}(L_1, L). \]

This gives a), since we obviously have \(H^1_{\text{et}}(X, L) = H^0_{\text{et}}(k, R^1 \pi_* L) = R^1 \pi_* \mathbb{Z} \otimes L\) by Proposition 13.5.1 a).

b) follows directly from the definition of \(\mathcal{A}^{\text{eh}}_{X/k}\). \(\square\)

13.6.6. **Corollary.** Let \(L_1 \text{Alb}(X) = [L_1 \rightarrow G_1]\), as a Deligne 1-motive.

a) If \(X\) is proper, then \(G_1\) is an abelian variety.

b) If \(X\) is normal, then \(L_1 \text{Alb}(X) = [0 \rightarrow \mathcal{A}^0_{X/k}]\).

c) If \(X\) is normal and proper then \(R^1 \text{Pic}(X) = [0 \rightarrow \text{Pic}^0_{X/k}]\) is an abelian variety with dual the Serre Albanese \(L_1 \text{Alb}(X) = [0 \rightarrow \mathcal{A}^0_{X/k}]\).

**Proof.** a) is seen easily by blow-up induction, by reducing to the smooth projective case (Corollary 10.2.3). b) follows from Proposition 13.6.5 a), b), Lemma 13.2.2 c) and Proposition 13.6.1 d). c) follows immediately from a) and b). \(\square\)

13.7. \(L_1 \text{Alb}(X)\) and \(\text{Alb}^{-}(X)\) for \(X\) normal. In 13.7.2, we prove that these two 1-motives are isomorphic. We begin with a slight improvement of Theorem 13.4.1 in the case of semi-abelian schemes:
13.7.1. **Lemma.** Let $X$ be normal, and let $X_\cdot$ be a smooth hyperenvelope (cf. Lemma 13.4.2). Then we have

$$
\mathcal{A}_{X/k} = \text{Coker}(\mathcal{A}_X \xrightarrow{(p_0)_*-(p_1)_*} \mathcal{A}_X^0)
$$

and

$$(\mathcal{A}_{X/k})^0 = \text{Coker}(\mathcal{A}_X^0 \xrightarrow{(p_0)_-(p_1)_*} \mathcal{A}_X^0).$$

**Proof.** The first isomorphism follows from Lemma 13.4.2 applied with $Y$ running through torsors under semi-abelian varieties. To deduce the second isomorphism, consider the short exact sequence of complexes

$$0 \to \mathcal{A}_X^0 \to \mathcal{A}_{X_\cdot/k} \to \mathcal{Z}[[\pi_0(X_\cdot)]] \to 0$$

and the resulting long exact sequence

$$(13.4) H_1(\mathcal{Z}[[\pi_0(X_\cdot)]]) \to H_0(\mathcal{A}_{X_\cdot/k}) \to H_0(\mathcal{A}_{X/k}) \to H_0(\mathcal{Z}[[\pi_0(X_\cdot)]]) \to 0.$$

For any $i \geq 0$, $\mathcal{Z}[[\pi_0(X_i)]]$ is $\mathcal{Z}$-dual to the Galois module $E_1^{i,0}$, where $E_1^{p,n} = H^{p,n}_{\text{ét}}(X_p \times_k \overline{k}, \mathcal{Z})$ is the $E_1$-term associated to the simplicial spectral sequence for $X_\cdot \times_k \overline{k}$. Since $H^{i}_{\text{ét}}(X_p \times_k \overline{k}, \mathcal{Z}) = 0$ for all $p \geq 0$, we get

$$H_i(\mathcal{Z}[[\pi_0(X_\cdot)]]) \simeq (H^i_{\text{ét}}(X_\cdot \times_k \overline{k}, \mathcal{Z}))^\vee$$

for $i = 0, 1$.

By Proposition 11.2.2, these étale cohomology groups may be replaced by éh cohomology groups. By Proposition 11.2.5, we then have

$$H^i_{\text{ét}}(X_\cdot \times_k \overline{k}, \mathcal{Z}) \simeq H^i_{\text{éh}}(X \times_k \overline{k}, \mathcal{Z}).$$

Now, by Lemma 13.2.1 a), $H^0_{\text{éh}}(X \times_k \overline{k}, \mathcal{Z})$ is $\mathcal{Z}$-dual to $\mathcal{Z}[[\pi_0(X)]]$, and by Lemma 13.2.2 c), $H^1_{\text{éh}}(X \times_k \overline{k}, \mathcal{Z}) = 0$ because $X$ is normal. Hence (13.4) yields a short exact sequence

$$0 \to H_0(\mathcal{A}_{X_\cdot/k}) \to \mathcal{A}_{X/k} \to \mathcal{Z}[[\pi_0(X)]] \to 0$$

which identifies $H_0(\mathcal{A}_{X_\cdot/k})$ with $\mathcal{A}_{X/k}^0$. \(\square\)

13.7.2. **Proposition.** If $X$ is normal, $R^1\text{Pic}(X)$ and $L_1\text{Alb}(X)$ are isomorphic, respectively, to the 1-motives $\text{Pic}^+(X)$ and $\text{Alb}^-(X)$ defined in [11, Ch. 4-5].

**Proof.** Let $\overline{X}$ be a normal compactification of $X$; choose a smooth hyperenvelope $X_\cdot$ of $X$ along with $\overline{X}$, a smooth compactification with normal crossing boundary $Y_\cdot$ such that $X_\cdot \to \overline{X}$ is an hyperenvelope.
Now we have, in the notation of [11, 4.2], a commutative diagram with exact rows

\[
0 \longrightarrow \text{Pic}^0_{X/k} \longrightarrow \text{Pic}^0_{X_0/k} \longrightarrow \text{Pic}^0_{X_1/k} \\
\uparrow \uparrow \uparrow \\
0 \longrightarrow \text{Div}^0_Y(\mathcal{X}_* \times \mathcal{X}_*) \longrightarrow \text{Div}^0_Y(\mathcal{X}_0) \longrightarrow \text{Div}^0_Y(\mathcal{X}_1)
\]

where \( \text{Pic}^+(X) = [\text{Div}^0_Y(\mathcal{X}_* \times \mathcal{X}_*) \to \text{Pic}^0_{X/k}] \) since \( X \) is normal. Taking Cartier duals we get an exact sequence of 1-motives

\[
[0 \to A^0_{X_1/k}] \overset{(p_0)_*)(p_1)_*}{\longrightarrow} [0 \to A^0_{X_0/k}] \to \text{Alb}^-(X) \to 0.
\]

Thus \( \text{Alb}^-(X) = [0 \to A^0_{X/k}] \) by Lemma 13.7.1. We conclude by Corollary 13.6.6 b) since \( X \) is normal and \( L^1\text{Alb}(X) = [0 \to A^0_{X/k}] \).

\[\Box\]

13.7.3. \textbf{Remarks.} 1) Note that, while \( L^0\text{Alb}(X) \) and \( L^1\text{Alb}(X) \) are Deligne 1-motives, the same is not true of \( L^2\text{Alb}(X) \) in general, already for \( X \) smooth projective (see Corollary 10.2.3).

2) One could make use of Proposition 11.3.1 to compute \( L^i\text{Alb}(X) \) for singular \( X \) and \( i > 1 \). However, \( H^i_{\text{et}}(X, \mathbb{G}_m)_\mathbb{Q} \) can be non-zero also for \( i \geq 2 \), therefore a precise computation for \( X \) singular and higher dimensional appears to be difficult. We did completely the case of curves in Sect. 12.

13.8. \textbf{RPic}(X) and \( H^*_{\text{et}}(X, \mathbb{G}_m) \). By definition of \( \text{RPic} \), we have a morphism in \( \text{DM}^{\text{eff}, \text{et}} \)

\[
\text{Tot } \text{RPic}(X) = \alpha^* \text{Hom}_{\text{Nis}}(M(X), \mathbb{Z}(1)) \\
\rightarrow \text{Hom}_{\text{et}}(M_{\text{et}}(X), \mathbb{Z}(1)) = R^1\pi^*_{\text{et}} \mathbb{G}_m[-1].
\]

This gives homomorphisms

\[
(13.5) \quad H^i(\text{Tot } \text{RPic}(X)) \to R^{i-1}\pi^*_{\text{et}} \mathbb{G}_m, \quad i \geq 0.
\]

13.8.1. \textbf{Proposition.} For \( i \leq 2 \), (13.5) is an isomorphism.

\textbf{Proof.} By blow-up induction, we reduce to the smooth case, where it follows from Hilbert’s theorem 90. \[\Box\]

13.9. \textbf{H}^1_{\text{et}}(X, \mathbb{G}_m) and \( H^1_{\text{et}}(X, \mathbb{G}_m) \). In this subsection, we assume \( \pi^X : X \to \text{Spec } k \) proper. Recall that, then, the étale sheaf associated to the presheaf

\[
U \mapsto \text{Pic}(X \times U)
\]

is representable by a \( k \)-group scheme \( \text{Pic}_{X/k} \) locally of finite type (Grothendieck-Murre [76]). Its connected component \( \text{Pic}^0_{X/k} \) is an extension
of a semi-abelian variety by a unipotent subgroup $U$. By homotopy
invariance of $\mathbb{R}^1\pi_*^X G_m$, we get a map
\begin{equation}
\text{Pic}_{X/k}/U \to \mathbb{R}^1\pi_*^X G_m.
\end{equation}

Recall that the right hand side is a 1-motivic sheaf by Proposition
13.5.1. We have:

13.9.1. Proposition. This map is injective with lattice cokernel.

Proof. Consider multiplication by an integer $n > 1$ on both sides. Using
the Kummer exact sequence, Proposition 13.1.1 and Lemma 13.3.4 c),
we find that (13.6) is an isomorphism on $n$-torsion and injective on
$n$-cotorsion. The conclusion then follows from Proposition 3.7.6. □

13.10. $\mathbb{R}^1\text{Pic}(X)$ and $\text{Pic}^+(X)$ for $X$ proper.

13.10.1. Theorem. For $X$ proper, the composition
\begin{equation}
\text{Pic}_{X/k}/U \to \mathbb{R}^1\pi_*^X G_m \to \mathcal{H}^2(\text{Tot } \mathbb{R}\text{Pic}(X))
\end{equation}
where the first map is (13.6) and the second one is the inverse of the
isomorphism (13.5), induces an isomorphism
\begin{equation}
\text{Pic}^+(X) \sim \mathbb{R}^1\text{Pic}(X)
\end{equation}
where $\text{Pic}^+(X)$ is the 1-motive defined in [11, Ch. 4].

Proof. Proposition 3.12.2 yields an exact sequence
\begin{equation}
L^1 \to G^1 \to \mathcal{H}^2(\text{Tot } \mathbb{R}\text{Pic}(X)) \to L^2
\end{equation}
where we write $\mathbb{R}^i\text{Pic}(X) = [L^i \to G^i]$. Propositions 13.8.1 and
13.9.1 then imply that the map of Theorem 13.10.1 induces an iso-
morphism $\text{Pic}^0_{X/k}/U \sim \sim G^1$. The conclusion follows, since on the one
hand $\text{Pic}^+(X) \simeq [0 \to \text{Pic}^0_{X/k}/U]$ by [11, Lemma 5.1.2 and Remark
5.1.3], and on the other hand the dual of Corollary 13.6.6 a) says that
$L^1 = 0$. □

13.10.2. Corollary. For $X$ proper there is a canonical isomorphism
\begin{equation}
L_1\text{Alb}(X) \sim \sim \text{Alb}^{-}(X).
\end{equation}

13.11. The Borel-Moore variant. Let $X \in \text{Sch}$ be provided with
a compactification $\overline{X}$ and closed complement $Z \hookrightarrow \overline{X}$. The relative
Picard functor is then representable by a $k$-group scheme locally of
finite type $\text{Pic}_{\overline{X},Z}$, and we shall informally denote by $U$ its unipotent
radical. Similarly to (13.5) and (13.6), we have two canonical maps
\begin{equation}
\mathcal{H}^2(\text{Tot } \mathbb{R}\text{Pic}^c(X)) \to \text{Pic}^c_{\overline{X},Z} \leftarrow \text{Pic}_{\overline{X},Z}/U
\end{equation}
where $\text{Pic}^{d\text{h}}_{X,Z}$ is by definition the $1$-motivic sheaf associated to the presheaf $U \mapsto H^1_{d\text{h}}(X \times U, (\mathbb{G}_m)_{X \times U} \to i_*(\mathbb{G}_m)_{Z \times U})$ (compare [11, 2.1]). Indeed, the latter group is canonically isomorphic to
\[
\text{Hom}_{\text{DM}_{\text{eff}}^-, \text{ét}}(\mathcal{M}_c(X \times U), \mathbb{Z}(1)[2])
\]
via the localisation exact triangle. From Theorem 13.10.1 and Proposition 11.4.2 b), we then deduce:

13.11.1. **Theorem.** The maps (13.7) induce an isomorphism
\[
R^1\text{Pic}^c(X) \simeq [0 \to \text{Pic}^0(X, Z)/U]. \quad \square
\]

The following is a sequel of Proposition 11.5.2:

13.11.2. **Corollary.** Let $X \in \text{Sch}(k)$ of dimension $d$. Then:

a) $L_1\text{Alb}^c(X) = [L_1 \to A_1]$, where $A_1$ is an abelian variety. In particular, $L_1\text{Alb}^c(X)$ is a Deligne 1-motive.

b) If $X$ is normal connected and not proper, let $\overline{X}$ be a normal compactification of $X$. Then $\text{rank } L_1 = \#\pi_0(\overline{X} - X) - 1$.

*Proof.* a) follows immediately from Theorem 13.11.1. For b), consider the complex of discrete parts associated to the exact sequence (9.1): we get with obvious notation an almost exact sequence
\[
L_1(\overline{X}) \to L_1(X) \to L_0(\overline{X} - X) \to L_0(\overline{X}) \to L_0(X)
\]
where “almost exact” means that its homology is finite. The last group is 0 and $L_0(\overline{X}) = \mathbb{Z}$; on the other hand, $L_1(\overline{X}) = 0$ by Corollary 13.6.6 b). Hence the claim. \quad \square

13.11.3. **Remarks** (on Corollary 11.3.2).

1) In fact, $A_1 = 0$ in a) if $X$ is smooth and quasi-affine of dimension > 1: see Corollary 14.6.2. This contrasts sharply with Theorem 12.2.3 for smooth curves.

2) As a consequence of the statement of b) we see that in b), the number of connected components of $\overline{X} - X$ only depends on $X$. Here is an elementary proof of this fact: let $\overline{X}'$ be another normal compactification and $\overline{X}''$ the closure of $X$ in $\overline{X} \times \overline{X}'$. Then the two maps $\overline{X}'' \to \overline{X}$ and $\overline{X}'' \to \overline{X}'$ have connected fibres by Zariski’s main theorem, thus $\overline{X} - X$ and $\overline{X}' - X$ have the same number of connected components as $\overline{X}'' - X$. (The second author is indebted to Marc Hindry for a discussion leading to this proof.)

We shall also need the following computation in the next subsection.
13.11.4. **Theorem.** Let $\overline{X}$ be smooth and proper, $Z \subset \overline{X}$ a divisor with normal crossings and $X = \overline{X} - Z$. Let $Z_1, \ldots, Z_r$ be the irreducible components of $Z$ and set

$$Z^{(p)} = \begin{cases} \overline{X} & \text{if } p = 0 \\ \prod_{i_1 < \cdots < i_p} Z_{i_1} \cap \cdots \cap Z_{i_p} & \text{if } p > 0. \end{cases}$$

Let $\text{NS}^{(p)}_c(X)$ (resp. $\text{Pic}^{(p)}_c(X)$, $\text{T}^{(p)}_c(X)$) be the cohomology (resp. the connected component of the cohomology) in degree $p$ of the complex

$$\cdots \to \text{NS}(Z^{(p-1)}) \to \text{NS}(Z^{(p)}) \to \text{NS}(Z^{(p+1)}) \to \cdots$$

(resp.

$$\cdots \to \text{Pic}^0(Z^{(p-1)}) \to \text{Pic}^0(Z^{(p)}) \to \text{Pic}^0(Z^{(p+1)}) \to \cdots$$

$$\cdots \to \mathbb{R}_{\pi_0(Z^{(p-1)})/k}\mathbb{G}_m \to \mathbb{R}_{\pi_0(Z^{(p)})/k}\mathbb{G}_m \to \mathbb{R}_{\pi_0(Z^{(p+1)})/k}\mathbb{G}_m \to \cdots \right).$$

Then, for all $n \geq 0$, $\mathbb{R}^n\text{Pic}^c(X)$ is of the form $[\text{NS}^{(n-2)}_c(X) \xrightarrow{\eta^n} \text{G}^{(n)}_c]$, where $\text{G}^{(n)}_c$ is an extension of $\text{Pic}^{(n-1)}_c(X)$ by $\text{T}^{(n)}_c(X)$.

**Proof.** A standard argument (compare e.g. [40, 3.3]) yields a spectral sequence of cohomological type in $^{1}M_1$:

$$E_1^{p,q} = \mathbb{R}^q\text{Pic}^c(Z^{(p)}) \Rightarrow \mathbb{R}^{p+q}\text{Pic}^c(X).$$

By Corollary 10.6.1, we have $E_2^{2,0} = [\text{NS}^{(p)}_c(X) \to 0]$, $E_2^{2,1} = [0 \to \text{Pic}^{(p)}_c(X)]$ and $E_2^{2,0} = [0 \to \text{T}^{(p)}_c(X)]$. By Proposition C.9.1, all $d_2$ differentials are 0, hence the theorem. \hfill \square

13.11.5. **Corollary.** With notation as in Theorem 13.11.4, the complex $\mathbb{R}\text{Pic}(M^c(X)(1)[2])$ is q.i. to

$$\cdots \to [\mathbb{Z}_{\pi_0(Z^{(p-2)})} \to 0] \to \cdots$$

In particular, $\mathbb{R}^0\text{Pic}(M^c(X)(1)[2]) = \mathbb{R}^1\text{Pic}(M^c(X)(1)[2]) = 0$ and $\mathbb{R}^2\text{Pic}(M^c(X)(1)[2]) = [\mathbb{Z}_{\pi_0}^{(p)} \to 0]$ (see Definition 11.5.1).

**Proof.** This follows from Theorem 13.11.4 via the formula $M^c(X \times \mathbb{P}^1) = M^c(X) \oplus M^c(X)(1)[2]$, noting that $\overline{X} \times \mathbb{P}^1$ is a smooth compactification of $X \times \mathbb{P}^1$ with $\overline{X} \times \mathbb{P}^1 - X \times \mathbb{P}^1$ a divisor with normal crossings with components $Z_i \times \mathbb{P}^1$, and

$$\text{NS}(Z^{(p)} \times \mathbb{P}^1) = \text{NS}(Z^{(p)}) \oplus \mathbb{Z}_{\pi_0}^{(p)}(Z^{(p)})$$

$$\text{Pic}^0(Z^{(p)} \times \mathbb{P}^1) = \text{Pic}^0(Z^{(p)})$$

$$\pi_0(Z^{(p)} \times \mathbb{P}^1) = \pi_0(Z^{(p)}).$$

\hfill \square
13.11.6. **Remark.** Let $X$ be arbitrary, and filter it by its successive singular loci, i.e.

$$X = X^{(0)} \supset X^{(1)} \supset \ldots$$

where $X^{(i+1)} = X^{(i)}_{\text{sing}}$. Then we have a spectral sequence of cohomological type in $\mathcal{M}_1$

$$E_2^{p,q} = R^{p+q}\text{Pic}^c(X^{(q)} - X^{(q+1)}) \Rightarrow R^{p+q}\text{Pic}^c(X)$$

in which the $E_2$-terms involve smooth varieties. This qualitatively reduces the computation of $R^\ast \text{Pic}^c(X)$ to the case of smooth varieties, but the actual computation may be complicated; we leave this to the interested reader.

13.12. **$L_1\text{Alb}^\ast$ and $\text{Alb}^+$**.

13.12.1. **Lemma.** Let $n > 0$ and $Z \in \text{Sch}$ of dimension $< n$; then

$$R^i\text{Pic}(M(Z)^\ast(n)[2n]) = 0 \text{ for } i \leq 1$$

$$R^2\text{Pic}(M(Z)^\ast(n)[2n]) = [Z^{n-1}] \to 0$$

where $Z^{n-1}$ is the disjoint union of the irreducible components of $Z$ of dimension $n - 1$.

**Proof.** Let

$$\begin{array}{ccc}
\tilde{T} & \longrightarrow & \tilde{Z} \\
\downarrow & & \downarrow \\
T & \longrightarrow & Z
\end{array}$$

be an abstract blow-up square, with $\tilde{Z}$ smooth and $\dim T, \dim \tilde{T} < \dim Z$. By Lemma 9.2.1, $M(T)^\ast(n-2)[2n-4]$ and $M(\tilde{T})^\ast(n-2)[2n-4]$ are effective, so by Proposition 8.1.3, the exact triangle

$$R\text{Pic}(M(\tilde{T})^\ast(n)[2n]) \to R\text{Pic}(M(\tilde{Z})^\ast(n)[2n]) \oplus R\text{Pic}(M(T)^\ast(n)[2n])$$

$$\to R\text{Pic}(M(Z)^\ast(n)[2n]) \xrightarrow{\pm 1}$$

degenerates into an isomorphism

$$R\text{Pic}(M(\tilde{Z})^\ast(n)[2n]) \xrightarrow{\sim} R\text{Pic}(M(Z)^\ast(n)[2n]).$$

The lemma now follows from Corollary 13.11.5 by taking for $\tilde{Z}$ a desingularisation of $Z^{n-1}$ and for $T$ the union of the singular locus of $Z$ and its irreducible components of dimension $< n - 1$ (note that $M(\tilde{Z})^\ast(n)[2n] \simeq M^c(\tilde{Z})(1)[2]$). \qed
13.12.2. **Lemma.** Let $\overline{X}$ a proper smooth scheme with a pair $Y$ and $Z$ of disjoint closed (reduced) subschemes of pure codimension 1 in $\overline{X}$. We then have

$$R^1\text{Pic}({\overline{X}} - Z, Y) \cong \text{Pic}^+({\overline{X}} - Z, Y)$$

(see [11, 2.2.1] for the definition of relative $\text{Pic}^+$).

**Proof.** The following exact sequence provides the weight filtration

$$0 \rightarrow R^1\text{Pic}(\overline{X}, Y) \rightarrow R^1\text{Pic}(\overline{X} - Z, Y) \rightarrow R^2\text{Pic}_Z(\overline{X}, Y)$$

where $R^1\text{Pic}(\overline{X}, Y) \cong R^1\text{Pic}^c(\overline{X} - Y) \cong [0 \rightarrow \text{Pic}^0(\overline{X}, Y)]$ by Theorem 13.11.1 (here $U = 0$ since $\overline{X}$ is smooth). Also $R^2\text{Pic}_Z(\overline{X}, Y) \cong R^2\text{Pic}_Z(\overline{X}) = [\text{Div}_Z(\overline{X}) \rightarrow 0]$ from 8.2.2: thus the discrete part of $R^1\text{Pic}(\overline{X} - Z, Y)$ is given by a subgroup $D$ of $\text{Div}_Z(\overline{X}) = \text{Div}_Z(\overline{X}, Y)$.

It remains to identify the map $u : D \rightarrow \text{Pic}^0(\overline{X}, Y)$. Using now the exact sequence

$$R^0\text{Pic}(Y) \rightarrow R^1\text{Pic}(\overline{X} - Z, Y) \rightarrow R^1\text{Pic}(\overline{X} - Y) \rightarrow R^1\text{Pic}(Y)$$

where $R^i\text{Pic}(Y)$ is of weight $< 0$ for $i \leq 1$ (11.3.2 and 13.6.6), we get that $u$ is the canonical lifting of the map of the 1-motive $R^1\text{Pic}(\overline{X} - Z)$ described in 10.6.1. Thus $D = \text{Div}_Z^0(\overline{X}, Y)$ and the claimed isomorphism is clear. \qed

This proof also gives:

13.12.3. **Corollary.** We have

$$[\text{Div}_Z^0(\overline{X}, Y) \rightarrow 0] = \ker(R^2\text{Pic}_Z(\overline{X}, Y) \rightarrow R^2\text{Pic}(\overline{X}, Y)).$$

We shall need:

13.12.4. **Theorem (Relative duality).** Let $\overline{X}$, $Y$ and $Z$ be as above and further assume that $\overline{X}$ is $n$-dimensional. Then

$$M(\overline{X} - Z, Y)^*(n)[2n] \cong M(\overline{X} - Y, Z)$$

and therefore

$$R\text{Pic}^*(\overline{X} - Z, Y) \cong R\text{Pic}(\overline{X} - Y, Z)$$

and dually for $L\text{Alb}$. **Proof.** See [9]. \qed
13.12.5. **Corollary.** Let \( Z \) be a divisor in \( \overline{X} \) such that \( Z \cap Y = \emptyset \). There exists a “cycle class” map \( \eta \) fitting in the following commutative diagram

\[
\begin{array}{ccc}
R^2\text{Pic}(M(Z)^*(n)[2n]) & \longrightarrow & R^2\text{Pic}^c(\overline{X} - Y) \\
\| & & \| \\
R^2\text{Pic}_Z(\overline{X}, Y) & \longrightarrow & R^2\text{Pic}(\overline{X}, Y)
\end{array}
\]

Writing \( Z = \bigcup Z_i \) as union of its irreducible components we have that \( \eta \) on \( Z_i \) is the “fundamental class” of \( Z_i \) in \( \overline{X} \) modulo algebraic equivalence.

**Proof.** We have a map \( M(Z) \to M(\overline{X} - Y) \), and the vertical isomorphisms in the following commutative square

\[
\begin{array}{ccc}
M(\overline{X} - Y)^*(n)[2n] & \longrightarrow & M(Z)^*(n)[2n] \\
\| & & \| \\
M(\overline{X}, Y) & \longrightarrow & M^Z(\overline{X}, Y)
\end{array}
\]

are given by relative duality. \( \square \)

13.12.6. **Theorem.** For \( X \in \text{Sch} \) we have

\[ R^1\text{Pic}^*(X) \cong \text{Pic}^-(X). \]

**Proof.** We are left to consider \( X \in \text{Sch} \) purely of dimension \( n \) with the following associated set of data and conditions.

For the irreducible components \( X_1, \ldots, X_r \) of \( X \) we let \( \tilde{X} \) be a desingularisation of \( \bigsqcup X_i, S := X_{\text{sing}} \cup \bigcup_{i \neq j} S_i \cap S_j \) and \( \tilde{S} \) the inverse image of \( S \) in \( \tilde{X} \). We let \( \overline{X} \) be a smooth proper compactification with normal crossing divisor \( Y \). Let \( \overline{S} \) denote the Zariski closure of \( S \) in \( \overline{X} \). Assume that \( Y + \overline{S} \) is a reduced normal crossing divisor in \( \overline{X} \). Finally denote by \( Z \) the union of all compact components of divisors in \( \tilde{S} \) (cf. [11, 2.2]).

We have an exact sequence coming from the abstract blow-up square associated to the above picture:

\[
\cdots \to R^1\text{Pic}^*(\tilde{X}) \oplus R^1\text{Pic}(M(S)^*(n)[2n]) \to R^1\text{Pic}^*(X) \\
\to R^2\text{Pic}(M(\tilde{S})^*(n)[2n]) \to R^2\text{Pic}^*(\tilde{X}) \oplus R^2\text{Pic}(M(S)^*(n)[2n])
\]

Now:

- the first map is injective (Lemma 13.12.1),
- \( R^1\text{Pic}^*(\tilde{X}) = R^1\text{Pic}^c(\tilde{X}) = [0 \to \text{Pic}^0(\overline{X}, Y)] \) since \( \tilde{X} \) is smooth (Theorem 13.11.1; note that \( U = 0 \) by the smoothness of \( \tilde{X} \)).
• $R^1\text{Pic}(M(S)^* (n)[2n]) = 0$ (Lemma 13.12.1),

• $R^2\text{Pic}(M(S)^* (n)[2n]) = [\mathbb{Z}^{\pi_0(S+1)}_n] = [\text{Div}_S(\mathcal{X}, Y) \to 0]$ (Lemma 13.12.1),

• $R^2\text{Pic}^*(\tilde{X}) = R^2\text{Pic}^c(\tilde{X}) = R^2\text{Pic}(\mathcal{X}, Y) = [\text{NS}^0(\tilde{X}) \xrightarrow{u^2} G_c^{(2)}]$ (Theorem 13.11.4),

• $R^2\text{Pic}(M(S)^* (n)[2n]) = [\mathbb{Z}^{\pi_0(S+1)}_n] = [\text{Div}_S(\mathcal{X}, Y) \to 0]$ (Lemma 13.12.1).

We may therefore rewrite the above exact sequence as follows:

$$0 \to [0 \to \text{Pic}^0(\mathcal{X}, Y)] \to R^1\text{Pic}^*(X) \to [\text{Div}_S(\mathcal{X}, Y) \to 0] \xrightarrow{\alpha} [\text{NS}^0(\tilde{X}) \xrightarrow{u^2} G_c^{(2)}] \oplus [\text{Div}_S(\mathcal{X}, Y) \to 0].$$

The map $\text{Div}_S(\mathcal{X}, Y) \to \text{Div}_S(\mathcal{X})$ induced from $M(\tilde{S}) \to M(S)$ is clearly the proper push-forward of Weil divisors. The map

$$[\text{Div}_S(\mathcal{X}, Y) \to 0] \to [\text{NS}^0(\tilde{X}) \xrightarrow{u^2} G_c^{(2)}]$$

is the cycle class map described in Corollary 13.12.5. By Corollary 13.12.3 we then get

$$\text{Ker } \alpha = [\text{Div}^0_{S/S}(\mathcal{X}, Y) \to 0]$$

where the lattice $\text{Div}^0_{S/S}(\mathcal{X}, Y)$ is from the definition of Pic$^-$ (see [11, 2.2.1]). In other terms, we have

$$R^1\text{Pic}^*(X) = [\text{Div}^0_{S/S}(\mathcal{X}, Y) \xrightarrow{u} \text{Pic}^0(\mathcal{X}, Y)]$$

and we are left to check that the mapping $u$ is the one described in [11]. Just observe that, by Lemma 13.12.1 and Theorem 13.12.4,

$$R^1\text{Pic}^*(X) \hookrightarrow R^1\text{Pic}^*(X, S) \cong R^1\text{Pic}^*(\tilde{X}, \tilde{S}) \cong R^1\text{Pic}^*(\tilde{X}, Z) \cong R^1\text{Pic}^*(\mathcal{X} - Y, Z) \cong R^1\text{Pic}^+(\mathcal{X} - Z, Y)$$

and the latter is isomorphic to Pic$^+(\mathcal{X} - Z, Y)$ by 13.12.2. Since, by construction, Pic$^-(\mathcal{X})$ is a sub-1-motive of Pic$^+(\mathcal{X} - Z, Y)$ the isomorphism of 13.12.2 restricts to the claimed one. □

14. Generalisations of Roikhman’s theorem

In this section, we give a unified treatment of Roikhman’s theorem on torsion 0-cycles on a smooth projective variety and its various generalisations.
14.1. Motivic and classical Albanese. Let $X \in \text{Sch}(k)$; we assume $X$ smooth if $p > 1$ and $X$ semi-normal (in particular reduced) if $p = 1$, see Lemma 9.4.1. Recall that Suslin’s algebraic singular homology is

$$H_j(X) := \text{Hom}_{\text{DM}^{\text{eff}}}(\mathbb{Z}[j], M(X)) = \mathbb{H}^{-j}_{\text{Nis}}(k, C_*(X))$$

for any scheme $p : X \to k$. On the other hand, we may define

$$H^\text{ét}_j(X) := \text{Hom}_{\text{DM}^{\text{eff}}}(\mathbb{Z}[j], M_\text{ét}(X)) = \mathbb{H}^{-j}_\text{ét}(k, \alpha^*C_*(X)).$$

We also have versions with coefficients in an abelian group $A$:

$$H^\text{ét}_j(X, A) = \text{Hom}_{\text{DM}^{\text{eff}}}(\mathbb{Z}[j], M_\text{ét}(X) \otimes A).$$

We shall also use the following notation throughout:

14.1.1. Notation. For any $M \in \text{DM}^{\text{eff}}$ and any abelian group $A$, we write $H_j^{(1)}(M, A)$ for the abelian group

$$\text{Hom}_{\text{DM}^{\text{eff}}}(\mathbb{Z}[j], \text{Tot } L\text{Alb}(M) \otimes A) \simeq \mathbb{H}^{-j}_{\text{éti}}(k, \text{Tot } L\text{Alb}(M) \otimes A).$$

This is Suslin 1-motivic homology of $M$ with coefficients in $A$. If $M = M(X)$, we write $H_j^{(1)}(X, A)$ for $H_j^{(1)}(M, A)$. We drop $A$ in the case where $A = \mathbb{Z}$.

We also write $H_j^\text{ét}(M, A) = \text{Hom}_{\text{DM}^{\text{eff}}}(\mathbb{Z}[j], M \otimes A)$ and $H_j^\text{ét}(M) = H_j^\text{ét}(M, \mathbb{Z})$.

The motivic Albanese map (5.2) then gives maps

(14.1) $H_j^\text{ét}(M, A) \to H_j^{(1)}(M, A)$

for any abelian group $A$.

14.1.2. Proposition. If $X$ is a smooth curve (or any curve in characteristic 0), the map (14.1) (for $M = M(X)$) is an isomorphism for any $A, j$.

Proof. This follows immediately from Proposition 5.1.4. □

Note that if $X = \overline{X} - Y$ is a smooth curve obtained by removing a finite set of closed points from a projective smooth curve $\overline{X}$ then $\mathcal{A}_{X/k} = \text{Pic}(\overline{X}, Y)_{/k}$ is the relative Picard scheme (see [11] for its representability) and the Albanese map just sends a point $P \in X$ to $(\mathcal{O}_{\overline{X}}(P), 1)$ where 1 is the tautological section, trivialising $\mathcal{O}_{\overline{X}}(P)$ on $X$. We then have the following result (cf. [70, Lect. 7, Th. 7.16]).

14.1.3. Corollary. If $X = \overline{X} - Y$ is a smooth curve,

$$H_0^\text{ét}(X) \to \text{Pic}(\overline{X}, Y)[1/p]$$

is an isomorphism.
Now let \( A_{X/k}^{\text{et}} \) be as in Proposition 13.6.1 and Remark 13.6.2. The map \( \text{Tot} \mathcal{L}_{\text{Alb}}(X) \to A_{X/k}^{\text{et}}(k)[1/p] \) of loc. cit. induces a homomorphism
\[
(14.2) \quad H^0_{(1)}(X) \to A_{X/k}^{\text{et}}(k)[1/p]
\]
which is not an isomorphism in general (but see Lemma 14.4.2). Composing (14.2), (14.1) (for \( A = \mathbb{Z} \)) and the obvious map \( H^0(X)[1/p] \to H^0(X) \), we get a map
\[
(14.3) \quad H^0(X)[1/p] \to A_{X/k}^{\text{et}}(k)[1/p].
\]
We may further restrict to parts of degree 0, getting a map
\[
(14.4) \quad H^0_{(0)}(X)[1/p] \to (A_{X/k}^{\text{et}})^{0}(k)[1/p].
\]
Recall that \( A_{X/k}^{\text{et}} = A_{X/k} \) if \( X \) is normal or strictly reduced (Proposition 13.6.1 d)). In this case, the above map becomes
\[
(14.5) \quad H^0_{(0)}(X)[1/p] \to (A_{X/k}^{\text{et}})^{0}(k)[1/p].
\]
If \( X \) is smooth, (14.5) is the \( \mathbb{Z}[1/p] \)-localisation of the generalised Albanese map of Spieß-Szamuely [91, (2)].

Dually to Lemma C.6.2, the functor
\[
D^b(M_1[1/p]) \to D_{\text{eff}}^\text{gm} \to \text{et}
\]
\[
s \mapsto \text{Tot}(s) \otimes (\mathbb{Q}/\mathbb{Z})'
\]
is exact with respect to the \( t \mathcal{M}_1 \) \( t \)-structure on the left and the homotopy \( t \)-structure on the right; here, as usual, \( (\mathbb{Q}/\mathbb{Z})' = \bigoplus_{\ell \neq p} \mathbb{Q}_\ell/\mathbb{Z}_\ell \). In other words:

14.1.4. **Lemma.** For any \( C \in D^b(M_1[1/p]) \), there are canonical isomorphisms of sheaves
\[
\mathcal{H}^j_{t}(\text{Tot}(C) \otimes (\mathbb{Q}/\mathbb{Z})') \simeq \text{Tot}(\mathcal{H}^j_{t}(C)) \otimes (\mathbb{Q}/\mathbb{Z})'
\]
(note that the right hand side is a single sheaf!) In particular, for \( C = \mathcal{L}_{\text{Alb}}(M) \) and \( k \) algebraically closed:
\[
H^0_{(1)}(M, (\mathbb{Q}/\mathbb{Z})') \simeq \Gamma(k, \text{Tot}(L_j \mathcal{L}_{\text{Alb}}(M)) \otimes (\mathbb{Q}/\mathbb{Z})').
\]

14.2. A variant of the Suslin-Voevodsky theorem. We now assume that \( k \) is algebraically closed until the end of this section.

Let \( n \) be invertible in \( k \). For \( M \in D_{\text{eff}}^\text{gm, et} \), we have the composition pairing
\[
(14.5) \quad \text{Hom}(\mathbb{Z}/n, M) \times \text{Hom}(M, \mathbb{Z}/n) \to \text{Hom}(\mathbb{Z}/n, \mathbb{Z}/n) = \mathbb{Z}/n.
\]

14.2.1. **Theorem.** For any \( M \in D_{\text{eff}}^\text{gm, et} \), the pairing (14.5) is a perfect duality of finite \( \mathbb{Z}/n \)-modules.
Proof. The statement is stable under exact triangles and direct summands, thus it is enough to check it for $M = M(X)[-j]$, $X$ smooth, $j \in \mathbb{Z}$. Then the statement amounts to the duality between the group $\text{Hom}(M(X), \mathbb{Z}/n[j])$ and algebraic singular homology $H^j_{\text{sing}}(X, \mathbb{Z}/n) = \text{Hom}(\mathbb{Z}/n[j], M(X))$, which is the contents of [70, Th. 10.9]. □

14.3. Change of topology and motivic Albanese map. We have the change of topology functor

$$\alpha^* : \text{DM}_{\text{gm}}^{\text{eff}} \to \text{DM}_{\text{gm, ét}}^{\text{eff}}.$$ 

Recall the functor $d_{\leq 1}$ of (5.1) and the motivic Albanese map $a_M$ of (5.2). Note that $a_{\mathbb{Z}/n(1)} : \alpha^* \mathbb{Z}/n(1) \to d_{\leq 1} \mathbb{Z}/n(1)$ is an isomorphism by Proposition 5.1.4. This gives a meaning to:

14.3.1. Proposition. Let $M \in \text{DM}_{\text{gm, ét}}^{\text{eff}}$. Then:

a) The diagram

$$\begin{array}{ccc}
\text{Hom}_{\text{DM}_{\text{gm, ét}}^{\text{eff}}}(M, \mathbb{Z}/n(1)) & \xrightarrow{d_{\leq 1}} & \text{Hom}_{\text{DM}_{\text{gm, ét}}^{\text{eff}}}(d_{\leq 1} M, \alpha^* \mathbb{Z}/n(1)) \\
\downarrow_{\alpha^*} & & \downarrow_{(a_M)^*} \\
\text{Hom}_{\text{DM}_{\text{gm, ét}}^{\text{eff}}}(\alpha^* M, \alpha^* \mathbb{Z}/n(1))
\end{array}$$

commutes.

b) In this diagram, $d_{\leq 1}$ is an isomorphism.

Proof. Let $N \in \text{DM}_{\text{gm, ét}}^{\text{eff}}$. By the naturality of the motivic Albanese map, the diagram

$$\begin{array}{ccc}
\text{Hom}_{\text{Nis}}(M, N) & \xrightarrow{d_{\leq 1}} & \text{Hom}_{\text{ét}}(d_{\leq 1} M, d_{\leq 1} N) \\
\downarrow_{\alpha^*} & & \downarrow_{(a_M)^*} \\
\text{Hom}_{\text{ét}}(\alpha^* M, \alpha^* N) & \xrightarrow{(a_N)^*} & \text{Hom}_{\text{ét}}(\alpha^* M, d_{\leq 1} N)
\end{array}$$

commutes. Taking $N = \mathbb{Z}/n(1)$, we get a).

For b), we write $d_{\leq 1}$ as a composition $D_{\leq 1}^{\text{ét}} \circ \alpha^* \circ D_{\leq 1}^{\text{Nis}}$. We shall show that each of these three functors induces an isomorphism on the corresponding Hom groups.

For $D_{\leq 1}^{\text{Nis}}$, this is because the map

$$D_{\leq 1}^{\text{Nis}} : \text{Hom}_{\text{Nis}}(M, \mathbb{Z}/n(1)) \to \text{Hom}_{\text{Nis}}(\mathbb{Z}/n, D_{\leq 1}^{\text{Nis}}(M))$$

coincides with the adjunction isomorphism for $\text{Hom}_{\text{Nis}}$. For $\alpha^*$, this is because $k$ is algebraically closed, so that étale cohomology of $\text{Spec } k$ coincides with Nisnevich cohomology. Finally, for $D_{\leq 1}^{\text{ét}}$, this is because
$\mathbb{Z}/n$ and $\alpha^*D_{\leq 1}^{\text{et}}(M)$ are in $d_{\leq 1} \text{DM}_{\text{gm,et}}^{\text{eff}}$ (Lemma 5.1.2), and $D_{\leq 1}^{\text{et}}$ restricts to a perfect duality on this subcategory (Prop. 4.5.1). □

14.4. A proof of Roitman’s and Spieß-Szamuely’s theorems. In this subsection, we only deal with smooth schemes and the characteristic is arbitrary: we shall show how the results of Section 10 allow us to recover the classical theorem of Roitman on torsion 0-cycles up to $p$-torsion, as well as its generalisation to smooth varieties by Spieß-Szamuely [91]. The reader should compare our argument with theirs (loc. cit., §5).

Since $k$ is algebraically closed, Corollary D.1.6 implies

14.4.1. Lemma. For any $j \in \mathbb{Z}$, $H^1_{\text{et}}(X) = H_j(X)[1/p]$; similarly with finite or divisible coefficients. □

Moreover, it is easy to evaluate $H^{(1)}_j(X) = \mathcal{H}_j(\text{Tot LAlb}(X))(k)$ out of Theorem 10.2.2: if $L_n\text{Alb}(X) = [L_n \to G_n]$, we have a long exact sequence coming from Proposition 3.12.2

\[
L_{j+1}(k)[1/p] \to G_{j+1}(k)[1/p] \to H^{(1)}_j(X) \\
\to L_j(k)[1/p] \to G_j(k)[1/p] \to \ldots
\]

Thus:

14.4.2. Lemma. For $X$ smooth, (14.2) is an isomorphism and we have

\[
H^{(1)}_1(X) \simeq \text{NS}^*_X(k)[1/p] \\
H^{(1)}_j(X) = 0 \text{ if } j \neq 0, 1.
\]

Here is now the main lemma:

14.4.3. Lemma. Let $M = M(X)$ with $X$ smooth, and let $A = \mathbb{Z}/n$ with $(n, p) = 1$. Then the map (14.1) is an isomorphism for $j = 0, 1$ and surjective for $j = 2$.

Proof. By theorem 14.2.1, the statement is equivalent to the following: the motivic Albanese map

\[
(a_X)^* : \text{Hom}_{\text{et}}(d_{\leq 1}M(X), \alpha^*\mathbb{Z}/n(1)[j]) \to \text{Hom}_{\text{et}}(\alpha^*M(X), \alpha^*\mathbb{Z}/n(1)[j])
\]

induced by (8.3) is bijective for $j = 0, 1$ and injective for $j = 2$. (Here we also use the fact that $\alpha^*\mathbb{Z}/n(1) = \mu_n$ and that $k$ is algebraically closed.)
By Proposition 14.3.1, we may replace the above map by the change of topology map

\[ \alpha^* : H^j_{\text{Nis}}(X, \mathbb{Z}/n(1)) = \text{Hom}_{\text{Nis}}(M(X), \mathbb{Z}/n(1)[j]) \]

\[ \rightarrow \text{Hom}(\alpha^* M(X), \alpha^* \mathbb{Z}/n(1)[j]) = H^j_{\text{et}}(X, \mathbb{Z}/n(1)). \]

Then the result follows from Hilbert’s theorem 90 (aka Beilinson-Lichtenbaum in weight 1).

\[ \square \]

From this and Lemma 14.1.4 we deduce:

14.4.4. Corollary. The homomorphism (14.1)

\[ H_j(X, (\mathbb{Q}/\mathbb{Z})') \rightarrow H_j^{(1)}(X, (\mathbb{Q}/\mathbb{Z})') \]

(see Lemma 14.4.1) is bijective for \( j = 0, 1 \) and surjective for \( j = 2 \).

The following theorem extends in particular [91, Th. 1.1] to all smooth varieties\(^\text{12}\).

14.4.5. Theorem. a) The maps (14.3) and (14.4) are isomorphisms on torsion.

b) \( H_1(X) \otimes (\mathbb{Q}/\mathbb{Z})' = 0 \).

c) The map (14.1) for \( A = \mathbb{Z} \) yields a surjection

\[ H_1(X)\{p'\} \rightarrow NS^*_{X/k}(k)\{p'\} \]

where \( M\{p'\} \) denotes the torsion prime to \( p \) in an abelian group \( M \).

Proof. Lemmas 14.4.1 and 14.4.2 reduce us to show that (14.1) is an isomorphism on torsion for \( A = \mathbb{Z}, j = 0 \). We have commutative diagrams with exact rows:

\[ \begin{array}{c}
0 \rightarrow H_j(X) \otimes (\mathbb{Q}/\mathbb{Z})' \rightarrow H_j(X, (\mathbb{Q}/\mathbb{Z})') \rightarrow H_{j-1}(X)\{p'\} \rightarrow 0 \\
\downarrow \quad \downarrow \quad \downarrow \\
0 \rightarrow H_j^{(1)}(X) \otimes (\mathbb{Q}/\mathbb{Z})' \rightarrow H_j^{(1)}(X, (\mathbb{Q}/\mathbb{Z})') \rightarrow H_{j-1}^{(1)}(X)\{p'\} \rightarrow 0
\end{array} \] (14.8)

For \( j = 1 \), the middle vertical map is an isomorphism by Lemma 14.4.3 or Corollary 14.4.4 and \( H_1^{(1)}(X) \otimes \mathbb{Q}/\mathbb{Z} = 0 \) by (14.7), which gives a) and b). For \( j = 2 \), the middle map is surjective by the same lemma and corollary, which gives c). The proof is complete.

\[ \square \]

\(^{12}\text{In loc. cit., } X \text{ is supposed to admit an open embedding into a smooth projective variety.}\]
14.4.6. **Remark.** If $X$ is smooth projective of dimension $n$, $H_j(X)$ is isomorphic to the higher Chow group $CH^n(X, j)$. In (14.8) for $j = 2$, the lower left term is 0 by Lemma 14.4.2. The composite map
\[ H_2(X, (\mathbb{Q}/\mathbb{Z})') \to H_1(X)\{p'\} \to H_1^{(1)}(X)\{p'\} = NS_{X/k}(k)\{p'\} \]
is “dual” to the map
\[ NS(X) \otimes (\mathbb{Q}/\mathbb{Z})' \to H^2_{\text{ét}}(X, \mathbb{Q}/\mathbb{Z}(1)) \]
whose cokernel is $Br(X)\{p'\}$. Let
\[ Br(X)^D = \lim_{\to (n,p)=1} \text{Hom}(n.Br(X), \mu_n) : \]
a diagram chase in (14.8) for $j = 2$ then yields an exact sequence
\[ 0 \to CH^n(X, 2) \otimes (\mathbb{Q}/\mathbb{Z})' \to Br(X)^D \]
\[ \to CH^n(X, 1)\{p'\} \to NS_{X/k}(k)\{p'\} \to 0. \]
Together with $CH^n(X, 1) \otimes (\mathbb{Q}/\mathbb{Z})' = 0$, this should be considered as a natural complement to Rojtman’s theorem.

14.5. **Generalisation to singular schemes.** We now assume char $k = 0$ (but see beginning of Section 11), and show how the results of Section 11 allow us to extend the results of the previous subsection to singular schemes. By blow-up induction and the 5 lemma, we get:

14.5.1. **Proposition.** The isomorphisms and surjection of Lemma 14.4.3 and Corollary 14.4.4 extend to all $X \in \text{Sch}$. \qed

Let $L_1\text{Alb}(X) = [L_1 \to G_1]$. Proposition 14.5.1, the exact sequence (14.6) and the snake chase in the proof of Theorem 14.4.5 give:

14.5.2. **Corollary.** For $X \in \text{Sch}$, we have exact sequences
\[ 0 \to H_1(X) \otimes \mathbb{Q}/\mathbb{Z} \to \text{Ker}(u_1) \otimes \mathbb{Q}/\mathbb{Z} \to H_0(X)_{\text{tors}} \to \text{Coker}(u_1)_{\text{tors}} \to 0 \]
\[ 0 \to H_1(X) \otimes \mathbb{Q}/\mathbb{Z} \to H_1^{(1)}(X, \mathbb{Q}/\mathbb{Z}) \to H_0(X)_{\text{tors}} \to 0. \]

The second exact sequence is more intrinsic than the first, but note that it does not give information on $H_1(X) \otimes \mathbb{Q}/\mathbb{Z}$.

14.5.3. **Corollary.** If $X$ is normal, $H_1(X) \otimes \mathbb{Q}/\mathbb{Z} = 0$ and there is an isomorphism
\[ A_{X/k}(k)_{\text{tors}} \sim H_0(X)_{\text{tors}}. \]

**Proof.** This follows from the previous corollary and Corollary 13.6.6 c). \qed
14.5.4. **Remark.** Theorem 13.10.1 shows that the second isomorphism of Proposition 14.5.1 coincides with the one of Geisser in [44, Th. 6.2] when $X$ is proper. When $X$ is further normal, the isomorphism of Corollary 14.5.3 also coincides with the one of his Theorem 6.1.

14.5.5. **Remarks.** Note that the reformulation of “Roitman’s theorem” involving $\text{Ker}\, u_1$ is the best possible!

1) Let $X$ be a proper scheme such that $\text{Pic}^0(X)/\mathcal{U} = G_m^r$ is a torus (more likely such that $\text{Alb}(X_0) = 0$ where $X_0 \to X$ is a resolution, according with the description in [11, p. 68]). Then $R^1\text{Pic}(X)^* = L_1\text{Alb}(X) = [Z^r \to 0]$ is the character group (cf. [11, 5.1.4]). For example, take a nodal projective curve $X$ with resolution $X_0 \to X$. In this case the map (14.1) for $A = Z$ is an isomorphism for all $j$ and thus $\text{Ker}(u_1) \otimes \mathbb{Q}/\mathbb{Z} = H^1(X) \otimes \mathbb{Q}/\mathbb{Z} = (\mathbb{Q}/\mathbb{Z})^r$.

2) For Borel-Moore and $L_1\text{Alb}^c(X) = L_1\text{Alb}^*(X)$ for $X$ smooth open is Cartier dual of $\text{Pic}^0(X,Y)$ then (cf. [11, p. 47]) $\text{Ker}\, u_1^c$ can be non-zero: take $X = \mathbb{P}^1$ and $Y$ = a finite number of points.

14.6. **Borel-Moore Roitman.** Recall that the Borel-Moore motivic homology group

$$H^c_j(X,\mathbb{Z}) := \text{Hom}(\mathbb{Z}[j], M^c(X))$$

is canonically isomorphic to Bloch’s higher Chow group $CH_0(X, j)$. Similarly to the previous sections, we have maps

$$H^c_j(X,\mathbb{Z}) \to H^{c,(1)}_j(M^c(X)) =: H^{c,(1)}_j(X)$$

$$H^c_j(X,\mathbb{Q}/\mathbb{Z}) \to H^{c,(1)}_j(M^c(X),\mathbb{Q}/\mathbb{Z}) =: H^{c,(1)}_j(X,\mathbb{Q}/\mathbb{Z})$$

and

14.6.1. **Proposition.** The second map is an isomorphism for $j = 0, 1$ and surjective for $j = 2$.

Proof. By localisation induction, reduce to $X$ proper and use Proposition 14.5.1.

14.6.2. **Corollary.** For $X \in \text{Sch}$, we have exact sequences

$$0 \to CH_0(X, 1) \otimes \mathbb{Q}/\mathbb{Z} \to \text{Ker}(u^c_1) \otimes \mathbb{Q}/\mathbb{Z} \to CH_0(X)_{\text{tors}} \to \text{Coker}(u^c_1)_{\text{tors}} \to 0$$

$$0 \to CH_0(X, 1) \otimes \mathbb{Q}/\mathbb{Z} \to H^{c,(1)}_j(X,\mathbb{Q}/\mathbb{Z}) \to CH_0(X)_{\text{tors}} \to 0$$

where we write $L_1\text{Alb}^c(X) = [L_1^c \xrightarrow{u_1^c} G_1^c]$. In particular, if $X$ is smooth quasi-affine of dimension $> 1$, $G_1^c = 0$. 

Proof. Only the last assertion needs a proof: if $X$ is smooth affine of dimension $> 1$ then $CH_0(X)_{\text{tors}} = 0$ [30, Th. 4.1 (iii)], hence $\text{Coker}(u_1)_{\text{tors}} = 0$; this forces the semi-abelian variety $G^1_c$ to be 0. We may then pass from affine to quasi-affine by using the localisation exact sequence and the description of $L_0\text{Alb}^c$ in Proposition 11.5.2 b). □

14.7. “Cohomological” Roitman.

14.7.1. **Lemma.** Let $0 < r < n$. Then for any $Z \in \text{Sch}$ of dimension $\leq n - r$ and any $i > 2(n-r)$, we have $H^i_{\text{cdh}}(Z, \mathbb{Q}/\mathbb{Z}(n)) = 0$.

**Proof.** By blow-up induction we reduce to the case where $Z$ is smooth of pure dimension $n - r$; then $H^i_{\text{cdh}}(Z, \mathbb{Q}/\mathbb{Z}(n)) = H^i_{\text{Nis}}(Z, \mathbb{Q}/\mathbb{Z}(n))$. Since $k$ is algebraically closed, and $n \geq \dim Z$, $H^i_{\text{Nis}}(Z, \mathbb{Q}/\mathbb{Z}(n)) \simeq H^i_{\text{et}}(Z, \mathbb{Q}/\mathbb{Z}(n))$ by Suslin’s theorem [92] and the vanishing follows from the known bound for étale cohomological dimension. □

Now consider the 1-motive $L_1\text{Alb}^*(X)$ for $X$ of dimension $n$. This time, we have maps

$$H^{2n-j}_{\text{cdh}}(X, \mathbb{Z}(n)) \to H^j_{(1)}(M(X)^*(n)[2n]) = H^{2n-j}_{(1)}(X, \mathbb{Z}(n))$$

(14.9)

$$H^{2n-j}_{\text{cdh}}(X, \mathbb{Q}/\mathbb{Z}(n)) \to H^j_{(1)}(M(X)^*(n)[2n], \mathbb{Q}/\mathbb{Z}) = H^{2n-j}_{(1)}(X, \mathbb{Q}/\mathbb{Z}(n)).$$

14.7.2. **Lemma.** Let $Z \in \text{Sch}$ be of dimension $< n$. Then the map

$$H^{2n-2}_{\text{cdh}}(Z, \mathbb{Q}/\mathbb{Z}(n)) \to H^2_{(1)}(M(Z)^*(n)[2n], \mathbb{Q}/\mathbb{Z})$$

is an isomorphism.

**Proof.** For notational simplicity, write $H^*(Y, n)$ for $H^*_{\text{cdh}}(Y, \mathbb{Q}/\mathbb{Z}(n))$ and $F_j(Y)$ for $H^j_{(1)}(M(Y)^*(n)[2n], \mathbb{Q}/\mathbb{Z}))$, where $Y$ is a scheme of dimension $\leq n$. Let $\tilde{Z}, \tilde{T}, \tilde{T}$ be as in the proof of Lemma 13.12.1. Then Lemma 14.7.1 and proposition 8.1.3 yield a commutative diagram

$$\begin{array}{ccc}
H^{2n-2}_{(1)}(Z, n) & \longrightarrow & H^{2n-2}_{(1)}(\tilde{Z}, n) \\
\downarrow & & \downarrow \\
F_2(Z) & \longrightarrow & F_2(\tilde{Z})
\end{array}$$

in which both horizontal maps are isomorphisms. Therefore, it suffices to prove the lemma when $Z$ is smooth quasiprojective of dimension $n - 1$.

The motive $R^2\text{Pic}(M(Z)^*(n)[2n]) \simeq R^2\text{Pic}(M^c(Z)(1)[2])$ was computed in Corollary 13.11.5: it is $[\pi^c_5(Z) \to 0]$. Therefore, we get

$$F_2(Z) \simeq \mathbb{Q}/\mathbb{Z}(1)[\pi^c_5(Z)].$$
On the other hand, the trace map defines an isomorphism
\[ H^{2n-2}(Z, n) \xrightarrow{\sim} \mathbb{Q}/\mathbb{Z} \langle \pi_0^*(Z) \rangle \]
and the issue is to prove that the vertical map in the diagram is this isomorphism. For this, we first may reduce to \( Z \) projective and connected. Now we propose the following argument: take a chain of smooth closed subvarieties \( Z \supset Z_2 \supset \cdots \supset Z_n \), with \( Z_i \) of dimension \( n - i \) and connected (take multiple hyperplane sections up to \( Z_{n-1} \) and then a single point of \( Z_{n-1} \) for \( Z_n \). The Gysin exact triangles give commutative diagrams
\[
\begin{array}{ccc}
H^{2n-2i-2}(Z_{i+1}, n-i) & \longrightarrow & H^{2n-2i}(Z_i, n-i+1) \\
\downarrow & & \downarrow \\
F_2(Z_{i+1}) & \longrightarrow & F_2(Z_i)
\end{array}
\]
in which both horizontal maps are isomorphisms: thus we are reduced to the case \( \dim Z = 0 \), where it follows from Proposition 14.1.2 applied to \( X = \mathbb{P}^1 \).

14.7.3. Theorem. The map (14.9) is an isomorphism for \( j = 0, 1 \).

Proof. This is easy and left to the reader for \( j = 0 \). For \( j = 1 \), we argue as usual by blowup induction. In the situation of 8.1.e, we then have a commutative diagram of exact sequences
\[
\begin{array}{cccc}
H^{2n-2}(\tilde{X}, n) & \oplus & H^{2n-2}(Z, n) & \rightarrow & H^{2n-1}(\tilde{Z}, n) \\
\downarrow & & \downarrow & & \downarrow \\
F_2(\tilde{X}) & \oplus & F_2(Z) & \rightarrow & F_1(\tilde{X}) & \oplus & F_1(Z).
\end{array}
\]

In this diagram, we have \( F_1(Z) = 0 \) by Lemma 13.12.1 and \( H^{2n-1}(Z, n) = 0 \) by Lemma 14.7.1, and the same lemmas imply that both rightmost horizontal maps are surjective. The rightmost vertical map is now an isomorphism by Proposition 14.6.1, which also gives the surjectivity of \( H^{2n-2}(\tilde{X}, n) \rightarrow F_2(\tilde{X}) \). Finally, Lemma 14.7.2 implies that \( H^{2n-2}(\tilde{Z}, n) \rightarrow F_2(\tilde{Z}) \) and \( H^{2n-2}(Z, n) \rightarrow F_2(Z) \) are isomorphisms, and the conclusion follows from the 5 lemma.

14.7.4. Corollary. For \( X \in \text{Sch} \) of dimension \( n \), we have exact sequences
\[
0 \rightarrow H^{2n-1}(X, Z(n)) \otimes \mathbb{Q}/\mathbb{Z} \rightarrow \text{Ker}(u_1^*) \otimes \mathbb{Q}/\mathbb{Z} \\
\rightarrow H^{2n}(X, Z(n))_{\text{tors}} \rightarrow \text{Coker}(u_1^*)_{\text{tors}} \rightarrow 0
\]
\[ 0 \to H^{2n-1}(X, \mathbb{Z}(n)) \otimes \mathbb{Q}/\mathbb{Z} \to H^{2n-1}_{(1)}(X, \mathbb{Q}/\mathbb{Z}(n)) \]
\[ \to H^{2n}(X, \mathbb{Z}(n))_{\text{tors}} \to 0 \]

where \( u_1^* \) is the map involved in the 1-motive \( L_1 \text{ Alb}^*(X) \) (which is isomorphic to \( \text{ Alb}^+(X) \) by the dual of Theorem 13.12.6).

14.7.5. **Corollary.** If \( X \) is a proper scheme of dimension \( n \) we then get \( H^{2n-1}(X, \mathbb{Z}(n)) \otimes \mathbb{Q}/\mathbb{Z} = 0 \) and an isomorphism

\[ \text{ Alb}^+(X)(k)_{\text{tors}} \xrightarrow{\sim} H^{2n}(X, \mathbb{Z}(n))_{\text{tors}}. \]

**Proof.** If \( X \) is proper then \( L_1 \text{ Alb}^*(X) \cong \text{ Alb}^+(X) \) is semiabelian and the claim follows from the previous corollary. \( \square \)

14.7.6. **Remark.** Marc Levine outlined us how to construct a “cycle map” \( c_\ell^{\text{cdh}} \) from \( CH^n_{\text{LW}}(X) \) to \( H^{2n}_{\text{cdh}}(X, \mathbb{Z}(n)) \), where \( CH^n_{\text{LW}}(X) \) is the Levine-Weibel cohomological Chow group of zero cycles. This gives a map

\[ c_\ell^{\text{cdh}}_{\text{tors}} : CH^n_{\text{LW}}(X)_{\text{tors}} \to H^{2n}_{\text{cdh}}(X, \mathbb{Z}(n))_{\text{tors}} \]

which most likely fits in a commutative diagram (for \( X \) projective)

\[ \begin{array}{ccc}
CH^n_{\text{LW}}(X)_{\text{tors}} & \xrightarrow{c_\ell^{\text{cdh}}_{\text{tors}}} & H^{2n}_{\text{cdh}}(X, \mathbb{Z}(n))_{\text{tors}} \\
\downarrow^{a^+_{\text{tors}}} & & \downarrow^{i} \\
\text{ Alb}^+(X)(k)_{\text{tors}} & \xrightarrow{\sim} & L_1 \text{ Alb}^*(X)(k)_{\text{tors}}
\end{array} \]

where: the horizontal bottom isomorphism is that induced by Theorem 13.12.6 and the right vertical one comes from the previous Corollary 14.7.4; the left vertical map is the one induced, on torsion, by the universal regular homomorphism \( a^+ : CH^n_{\text{LW}}(X)_{\deg 0} \to \text{ Alb}^+(X)(k) \) constructed in [11, 6.4.1]. This would imply that

\[ c_\ell^{\text{cdh}}_{\text{tors}} \text{ is an isomorphism} \iff a^+_{\text{tors}} \text{ is an isomorphism.} \]

If \( X \) is normal and \( k = \overline{k} \) or for any \( X \) projective if \( k = \mathbb{C} \) then \( a^+_{\text{tors}} \) is known to be an isomorphism, see [62]. For \( X \) projective over any algebraically closed field, see Mallick [66].

We expect that Levine’s “cycle map” \( c_\ell^{\text{cdh}} \) is surjective with uniquely divisible kernel (probably representable by a unipotent group).
Part 4. Realisations

15. An axiomatic version of Deligne’s conjecture

Let $k$ be a perfect field. We shall drop the reference to $k$ from the notation for categories of motives associated to $k$.

15.1. A review of base change. Suppose given a diagram of categories and functors

$$
\begin{array}{ccc}
T_1 & \xrightarrow{T} & T \\
\downarrow{R_1} & & \downarrow{R} \\
D_1 & \xrightarrow{S} & D \\
\end{array}
$$

where $A$ is left adjoint to $T$ and $B$ is left adjoint to $S$, plus a natural transformation $\varphi : RS \Rightarrow TR_1$. Then we get a natural transformation $\psi : AR \Rightarrow R_1B$ as the adjoint of the composition $R \Rightarrow RSB \Rightarrow TR_1B$ where the first natural transformation is given by the unit $Id_D \Rightarrow SB$ and the second one is induced by $\varphi$.

Suppose now that all categories and functors are triangulated. To prove that $\psi$ is an isomorphism of functors, it suffices to check it on generators of $D$.

15.2. A weight filtration on $\mathcal{M}_1 \otimes \mathbb{Q}$. In this subsection, we prove that the weight filtration on 1-motives defines a weight filtration on $\mathcal{M}_1 \otimes \mathbb{Q}$ in the sense of Definition E.7.2.

For $w \in \mathbb{Z}$, let $(\mathcal{M}_1 \otimes \mathbb{Q})_{\leq w}$ be the full subcategory consisting of 1-motives of weight $\leq w$ (cf. [32, (10.1.4)] and §C.11). Then $(\mathcal{M}_1 \otimes \mathbb{Q})_{\leq w} = 0$ for $w < -2$ and $(\mathcal{M}_1 \otimes \mathbb{Q})_{\leq w} = \mathcal{M}_1 \otimes \mathbb{Q}$ for $w \geq 0$.

15.2.1. Proposition. The inclusion functors

$$
\iota_w : (\mathcal{M}_1 \otimes \mathbb{Q})_{\leq w} \hookrightarrow (\mathcal{M}_1 \otimes \mathbb{Q})_{\leq w+1}
$$

define a weight filtration on $\mathcal{M}_1 \otimes \mathbb{Q}$.

Proof. By Remark E.7.8, it suffices to check that the weight filtration on 1-motives verifies the conditions in [53, p. 83, Def. 6.3 a)]. The only point is its exactness, which is clear.
15.3. **A left adjoint in the category of realisations.** Let \( K \) be a field and \( \mathcal{T} \) be a \( K \)-linear triangulated category. We assume that \( \mathcal{T} \) is provided with a \( K \)-linear \( t \)-structure, with heart \( \mathcal{B} \) with a weight filtration \( \mathcal{B}_{\leq n} \) (in the sense of Definition E.7.2). For convenience, we assume that \( \mathcal{B}_{\leq 0} = \mathcal{B} \).

Let us consider a thick \( K \)-subcategory \( \mathcal{B}_L \) of \( \mathcal{B}_{\geq -2} \) whose objects are called the **Lefschetz objects**. We assume \( \mathcal{B}_L \) semi-simple.

15.3.1. **Definition.** An object \( H \in \mathcal{B} \) is of level \( \leq 1 \) if

(i) The weights of \( H \) belong to \( \{-2, -1, 0\} \);

(ii) \( H_{-2} \) is a Lefschetz object.

We write \( \mathcal{B}(1) \) for the full subcategory of \( \mathcal{B} \) consisting of objects of level \( \leq 1 \).

15.3.2. **Proposition.**

(1) \( \mathcal{B}(1) \) is a thick abelian subcategory of \( \mathcal{B} \).

(2) If \( \mathcal{B}_{\geq -2} \) is semi-simple, the inclusion functor \( \mathcal{B}(1) \hookrightarrow \mathcal{B} \) has an exact left adjoint \( H \mapsto \text{Alb}^B(H) \).

**Proof.**

(1) By semi-simplicity of \( \mathcal{B}_L \) the assertion is clear.

(2) We shall construct \( \text{Alb}^B \) as the composition of two exact functors:

- The first functor sends an object \( H \) to \( H_{> -3} \).
- Suppose that \( H_{\leq -3} = 0 \), and consider \( H_{-2} \). By semi-simplicity, we may write \( H_{-2} = H' \oplus H'' \) with \( H' \) a Lefschetz object and with \( \text{Hom}_B(L, H'') = \text{Hom}_B(H'', L) = 0 \) for any Lefschetz object \( L \). Then the second functor sends \( H \) to \( H/H'' \).

The fact that this indeed defines a left adjoint is readily checked. \( \square \)

15.3.3. **Remark.** Let \( \mathcal{B}'_{\leq -2} = \{ B \in \mathcal{B}_{\leq -2} \mid \text{Hom}(B, \mathcal{B}_L) = 0 \} \). If \( \mathcal{B}_{\leq -2} \) is semi-simple, every object \( H \in \mathcal{B}_{\leq -2} \) has a unique decomposition \( H = H_L \oplus H'' \) with \( H_L \in \mathcal{B}_L \) and \( H'' \in \mathcal{B}'_{\leq -2} \). Let now

\[
\mathcal{B}'_{\leq -2} = \{ H \in \mathcal{B}_{\leq -2} \mid (H_{-2})_{-2} = 0 \}.
\]

Then Proposition 15.3.2 yields a split exact sequence

\[
0 \to \mathcal{B}'_{\leq -2} \to \mathcal{B} \xrightarrow{\text{Alb}^B} \mathcal{B}(1) \to 0
\]

in which the right adjoint of \( \text{Alb}^B \) is the natural inclusion.

15.3.4. **Proposition.** Let \( \mathcal{T}(1) \) be the full subcategory of \( \mathcal{T} \) consisting of objects \( T \) such that \( H^i(T) \in \mathcal{B}(1) \) for all \( i \in \mathbb{Z} \). Then:

(1) \( \mathcal{T}(1) \) is a thick subcategory of \( \mathcal{T} \), and the \( t \)-structure of \( \mathcal{T} \) induces a \( t \)-structure on \( \mathcal{T}(1) \).
If the $t$-structure is bounded and $\mathcal{B}_{-2}$ is semi-simple, the inclusion functor $T_{(1)} \hookrightarrow T$ has a $t$-exact left adjoint $\text{LAlb}^T$.

**Proof.** (1) follows from Proposition 15.3.2 (1) and (2), since $\mathcal{B}_{(1)}$ is thick in $\mathcal{B}$ by Proposition 15.3.2 (1). For (2), the exact sequence (15.2) of Remark 15.3.3 yields an exact sequence of triangulated categories

$$0 \to T'_{\leq -2} \to T \xrightarrow{\pi} T/T'_{\leq -2} \to 0$$

where $T'_{\leq -2} = \{C \in T \mid H^*(C) \in \mathcal{B}'_{\leq -2}\}$. The claim now follows from Proposition E.20.1 (3). More precisely, this proposition shows that $\pi$ has a right adjoint $j$ such that $j(T/T'_{\leq -2}) = T_{(1)}$; then $\pi$ gets identified with the desired functor $\text{LAlb}^T$. □

15.4. Realisation functor. Let $K, \mathcal{T}, \mathcal{B}$ be as in 15.3. For $T \in \mathcal{T}$, we denote by $H^T_R(X)$ the homology objects of $T$ (with values in $\mathcal{B}$) with respect to the $t$-structure of $T$.

We give ourselves a (covariant) triangulated functor $R : \text{DM}^\text{eff}_{gm} \otimes \mathbb{Q} \to T$. (Note: this implies that $K$ is of characteristic zero.)

Let $X \in \text{Sm}$: for $i \in \mathbb{Z}$, we write $H^R_i(X) := H^T_i(R(M(X)))$. We assume:

15.4.1. **Hypothesis.** If $X$ is smooth projective of dimension $d \leq 1$, we have

1. $RM(X) \in \mathcal{T}_{[-2d,0]}$ (in particular, $H^R_i(X) = 0$ for $i \notin [-2d,0]$).
2. If $d = 1$ and $E$ is the field of constants of $X$, the map $H^R_0(X) \to H^R_0(\text{Spec } E)$ is an isomorphism.
3. If $d = 1$, $E$ is the field of constants of $X$ and $f : X \to \mathbb{P}^1_E$ is a nonconstant rational function, the map $f_* : H^R_2(X) \to H^R_2(\mathbb{P}^1_E)$ is an isomorphism.

15.4.2. **Proposition.** Under Hypothesis 15.4.1, the composition

$$\mathcal{M}_1 \otimes \mathbb{Q} \to \text{Db}(\mathcal{M}_1) \otimes \mathbb{Q} \xrightarrow{\text{Tot}} \text{DM}^\text{eff}_{gm} \otimes \mathbb{Q} \xrightarrow{R} \mathcal{T}$$

has image in the heart $\mathcal{B}$ of $\mathcal{T}$. The corresponding functor

$$R_1 : \mathcal{M}_1 \otimes \mathbb{Q} \to \mathcal{B}$$

is exact. If moreover

(W) $H^R_i(X) \in \mathcal{B}_{-i}$ for all $i \in \mathbb{N}$

for $X$ smooth projective with $\dim X \leq 1$, then $R_1$ respects the splittings of $\mathcal{M}_1 \otimes \mathbb{Q}$ and $\mathcal{B}$ in the sense of Definition E.9.1 (2).

**Proof.** By definition of a $t$-structure, the first assertion will hold provided $R \circ \text{Tot}(N) \in \mathcal{B}$ for any 1-motive $N$ of pure weight. We are then left with lattices ($[L \to 0]$), tori ($[0 \to T]$) and abelian varieties...
([0 \to A]). Moreover, since we work with rational coefficients, we may assume that $L = R_{E/k}\mathbb{Z}$ and $T = R_{E/k}\mathbb{G}_m$ for a finite separable extension $E/k$.

We have $\text{Tot}([L \to 0]) = M(\text{Spec } E)$ and $\text{Tot}([0 \to T]) = M(\text{Spec } E)(1)$; hence $R\text{Tot}([L \to 0]) = RM(\text{Spec } E) = H^R_0(\text{Spec } E)[0] \in \mathcal{B}$ by Hypothesis 15.4.1 (1). On the other hand, since the only idempotents in $\text{End}(M(\mathbb{P}^1_E))$ are the Künneth idempotents, yielding the decomposition $M(\mathbb{P}^1_E) = M(\text{Spec } E) \oplus M(\text{Spec } E)(1)$, we get $R\text{Tot}([0 \to T]) = H^R_2(\mathbb{P}^1_E) \in \mathcal{B}$, and also $H^R_1(\mathbb{P}^1_E) = 0$, by Hypothesis 15.4.1 (2).

For abelian varieties, we may reduce to the case of Jacobians of curves. Recall Voevodsky’s functor [98, 2.1.4] (15.3) $\Phi : \text{Chow}_{\text{eff}} \otimes \mathbb{Q} \to \text{DM}_{\text{eff}} \otimes \mathbb{Q}$ such that $\Phi(h(X)) = M(X)$ for any smooth projective $X$: this is a full embedding by the cancellation theorem of [97].

Let $C$ be a smooth projective geometrically connected $k$-curve: the choice of a closed point $c \in C$ determines a Chow-Künneth decomposition. Also, $\text{Tot}([0 \to J(C)]) \simeq \Phi(h_1(C))[-1]$ as a Chow-Künneth direct summand of $M(C)[-1]$ (see 2.6.a). This already shows that $R\text{Tot}([0 \to J(C)]) \in \mathcal{T}_{-1,1}$, by Hypothesis 15.4.1 (1).

Choose a nonconstant rational function $f : C \to \mathbb{P}^1$, and let $x = f(c) \in \mathbb{P}^1$. If $\pi^i$ and $\pi^{i*}$ are the corresponding Chow-Künneth projectors, we clearly have $f_*\pi^0 = \pi^0f_*$. Hence the matrix of $f_*$ on the decompositions $h(C) = h_0(C) \oplus h_1(C) \oplus h_2(C)$ and $h(\mathbb{P}^1) = h_0(\mathbb{P}^1) \oplus h_2(\mathbb{P}^1)$ is of the form

$$f_* = \begin{pmatrix} 1 & 0 & * \\ 0 & 0 & 1 \end{pmatrix}$$

if we identify $h_0(\mathbb{P}^1)$ with $1$ and $h_2(\mathbb{P}^1)$ with $\mathbb{L}$. (One can compute that $*$ equals $\pm (f^{-1}(f(c)) - \deg f \cdot c)$, as an element of $J(C)(k) \otimes \mathbb{Q}$.) Thus we have an exact triangle in $\text{DM}_{\text{eff}} \otimes \mathbb{Q}$:

$$\text{Tot}([0 \to J(C)][1]) \to M(C) \xrightarrow{f_*} M(\mathbb{P}^1) \xrightarrow{+1}$$

hence a long exact sequence in $\mathcal{B}$:

$$\cdots \to H^R_{i+1}(\mathbb{P}^1) \to H^T_i(\text{Tot}([0 \to J(C)])) \to H^R_i(C) \xrightarrow{f_*} H^R_i(\mathbb{P}^1) \to \cdots$$

Using now the computation of $H^R_*(\mathbb{P}^1)$ and Hypothesis 15.4.1 (3), we find:

$$H^T_i(\text{Tot}([0 \to J(C)][1]))) = \begin{cases} 0 & i \neq 1 \\ H^R_1(C) & i = 1. \end{cases}$$
This shows that $R \operatorname{Tot}([0 \to J(C)]) \in \mathcal{B}$, hence the functor $R_1 : \mathcal{M}_1 \otimes \mathbb{Q} \to \mathcal{B}$. By Lemma E.19.1, the composition

$$D^b(\mathcal{M}_1) \otimes \mathbb{Q} \xrightarrow{\operatorname{Tot}} \operatorname{DM}_{\text{eff}}^\text{gm} \otimes \mathbb{Q} \xrightarrow{R} \mathcal{T}$$

is $t$-exact relatively the canonical $t$-structure on $D^b(\mathcal{M}_1) \otimes \mathbb{Q}$ (the motivic one, with heart $\mathcal{M}_1 \otimes \mathbb{Q}$), and its restriction $R_1$ to the hearts is exact.

If Condition (W) is verified, the proof shows that $R_1$ respects the splittings of $\mathcal{M}_1 \otimes \mathbb{Q}$ and $\mathcal{B}$ in the sense of Definition E.9.1 (2). □

15.5. The base change theorem. Let $K, \mathcal{B}, \mathcal{T}, R$ be as in 15.4. If $X$ is a smooth projective $k$-variety, we set as before $H^R_i(X) := H^i_T(R(M(X)))$

where $H^*_T$ denotes the homology functors with values in $\mathcal{B}$ defined by the $t$-structure on $\mathcal{T}$.

15.5.1. Remark. Let $X$ be smooth projective and $x \in X$ be a closed point. Let $E = k(x)$ be the residue field of $X$. We have an Albanese map $a_x : X_E \to (\mathcal{A}^0_{X/k})_E$, hence a map in $\operatorname{DM}_{\text{eff}}^\text{gm} \otimes \mathbb{Q}$:

$$\alpha_x : M(X) \xrightarrow{{}^t M(p)} M(X_E) \xrightarrow{M(a_x)} M((\mathcal{A}^0_{X/k})_E) \xrightarrow{d^{-1} M(q)} M(\mathcal{A}^0_{X/k})$$

where $d = [E : k]$, $p : X_E \to X$ and $q : (\mathcal{A}^0_{X/k})_E \to \mathcal{A}^0_{X/k}$ are the projections and $^t M(p)$ is the transpose of the graph of (the finite surjective morphism) $p$. This map depends on the choice of $x$, but two choices differ by a translation on $\mathcal{A}^0_{X/k}$.

Thus we get maps

$$(\alpha_x)_* : H^R_i(X) \to H^R_i(\mathcal{A}^0_{X/k}).$$

If the (duals of the) $H^R_i$ define a “classical” Weil cohomology theory in the sense of [1, 3.4], then $(\alpha_x)_*$ does not depend on the choice of $x$ for $i > 0$. We won’t need this fact, but merely the fact that for two choices of $x$, the corresponding $(\alpha_x)_*$ differ by an isomorphism.

15.5.2. Hypothesis. We assume Hypothesis 15.4.1, and moreover:

1. The $t$-structure on $\mathcal{T}$ is bounded.
2. The restriction of $R_1$ to $(\mathcal{M}_1 \otimes \mathbb{Q})_{-2}$ induces an equivalence of categories $(\mathcal{M}_1 \otimes K)_{-2} \xrightarrow{\sim} \mathcal{B}_L$.
3. For any $X$ smooth projective:
   (i) $H^R_i(X) := H_i(R(M(X)) = 0$ for $i < 0$.
   (ii) $H^R_i(X) \in \mathcal{B}_{-i}$ for $i \geq 0$.
   (iii) $H^R_0(X) \xrightarrow{\sim} H^R_0(\pi_0(X)).$
(iv) The choice of a closed point of $X$ induces an isomorphism 
$(\alpha_x)_* : H^1_1(X) \sim H^1_1(A^0_{X/k})$. (This does not depend on 
the choice of $x$: see Remark 15.5.1.)

Let $R_1 := R_{\text{Tot}}$. Using Proposition 15.3.4 and Section 15.1, we get
from this equality a base change morphism
\begin{equation}
(15.4) \quad v : \text{LAlb}^T R \Rightarrow R_1 \text{LAlb}^Q.
\end{equation}

15.5.3. Lemma. Under 15.5.2, we have a commutative diagram

\[
\begin{array}{ccc}
\text{Hom}_{\text{DM}_{\text{gm}} \otimes \Q}((M(X), \Z(1))[2]) & \xrightarrow{R} & \text{Hom}_T(R(X), R(\Z(1))[2]) \\
\downarrow{\alpha} & & \downarrow{\beta} \\
\text{Hom}_{\mathcal{B}}(R_1 \text{L}_2 \text{Alb}^Q(X), \Lambda) & \xrightarrow{v^*} & \text{Hom}_{\mathcal{B}}(\text{Alb}^T H^2_1(X), \Lambda)
\end{array}
\]

for any smooth projective variety $X$, where $\Lambda := R^1([0 \to \G_m])$.

Proof. Playing with the adjunctions and $t$-structures, we have chains of maps
\begin{equation}
(15.5) \quad (\text{DM}_{\text{gm}} \otimes \Q)(M(X), \Z(1)[2]) \simeq (D^b(\mathcal{M}_1) \otimes \Q)(\text{LAlb}^Q(X), [0 \to \G_m][2])
\end{equation}

\[
\xrightarrow{\iota H^2} (\mathcal{M}_1 \otimes \Q)(\text{L}_2 \text{Alb}^Q(X), [0 \to \G_m]) \xrightarrow{R_1} \mathcal{B}(R_1 \text{L}_2 \text{Alb}^Q(X), \Lambda)
\]

and
\begin{equation}
(15.6) \quad T(R(X), R(\Z(1))[2]) \simeq T(R(X), \Lambda[2])
\end{equation}

\[
\xrightarrow{H^2_{\text{R}}} \mathcal{B}(H^2_1(X), \Lambda) \simeq \mathcal{B}(\text{Alb}^T H^2_1(X), \Lambda).
\]

This defines respectively $\alpha$ and $\beta$. By following the various adjunc-
tion isomorphisms, the diagram is commutative as claimed. \qed

15.5.4. Remark. Note that $\text{Hom}_{\mathcal{B}}(R_1 \text{L}_2 \text{Alb}^Q(X), \Lambda) = \text{NS}(X)^{G_E} \otimes K$
bym Corollary 10.2.3 and Hypothesis 15.5.2 (2). Also, we have an injec-
tion $\text{Hom}_{\mathcal{B}}(\text{Alb}^T H^2_1(X), \Lambda) \hookrightarrow \text{Hom}_{\mathcal{B}}(H^2_1(X), \Lambda)$ by (the proof of)
Proposition 15.3.4 (2). If $\mathcal{B}$ sits in a larger “non-effective” category $\mathcal{B}'$
which carries a duality, the latter group may be interpreted as
$\text{Hom}_{\mathcal{B}'}(K_{\mathcal{B}'}, H^2_1(X)(1))$, with $K_{\mathcal{B}'} := R_1(\Z)$. Finally, the composition
$\beta R$ in the diagram of Lemma 15.5.3, followed by the latter inclusion,
is easily checked to be the cycle class map in the classical cases. So
the bottom row of this diagram contains an abstract argument that
algebraic equivalence is weaker than homological equivalence in codi-
mension 1.

On the other hand, it is known that algebraic and numerical equiva-
lences coincide rationally in codimension 1. Thus, if $H^2_{\text{R}}$ defines an
adequate equivalence relation on algebraic cycles, we automatically get that \( v^* \) is injective in the diagram of Lemma 15.5.3. This will be the case if \( H^*_R \) defines a Weil cohomology theory, which will follow if \( B \) and \( T \) can be extended to categories satisfying natural extra axioms (tensor structure, duality), cf. Cisinski-Déglise [28].

15.5.5. **Theorem.** Under 15.5.2,

1. The base change morphism \( v \) is an isomorphism in weights 0 and \(-1\).
2. Let \( (\text{DM}^{\text{eff}}_{gm})' \) be the thick subcategory of \( \text{DM}^{\text{eff}}_{gm} \otimes \mathbb{Q} \) generated by the \( M(X) \) where \( X \) is a smooth projective variety such that, for any finite extension \( E/k \), the map \( v^* \) of Lemma 15.5.3 is injective for \( X_E \) (see Remark 15.5.4) and the “geometric cycle class map”

\[
\text{Pic}(X_E) \otimes K = \text{Hom}_{\text{DM}^{\text{eff}}_{gm} \otimes \mathbb{Q}}(M(X_E), \mathbb{Z}(1)[2]) \otimes K
\]

\[
\xrightarrow{R} \text{Hom}_T(R(X_E), R(\mathbb{Z}(1))[2]) \xrightarrow{H^*_R} \text{Hom}_S(H^*_R(X_E), R(\mathbb{Z}(1)))
\]

is surjective. Then the restriction of \( v \) to \( (\text{DM}^{\text{eff}}_{gm})' \) is an isomorphism.

**Proof.** (1) By de Jong’s theorem, it suffices to prove the statement for \( M = M(X), X \) smooth projective. Thus we have to prove that, for all \( i \in \mathbb{Z} \), the map

\[
\text{Alb}^T H^i_R(X) \simeq H^i_T(\text{LAlb}^T R(X)) \to R_1 \text{L}_i \text{Alb}^Q(X)
\]

defined by \( v_{M(X)} \) is an isomorphism in weights 0 and \(-1\). Here we used the \( t \)-exactness of \( \text{LAlb}^T \), cf. Proposition 15.3.4 (2).

For \( i < 0 \) (resp. \( i > 2 \)), both sides are 0 by Corollary 10.2.3 and 15.5.2 (3) (i) (resp. (ii)). For \( i = 0, 1 \), (iii) and (iv) imply that the map is an isomorphism. Finally, 15.5.2 (3) (ii) implies that \( H^2_R(X) \) is pure of weight \(-2\) and so is \( \text{L}_2 \text{Alb}^Q(X) \), hence the statement is still true in this case.

(2) It is sufficient to show that, for any smooth projective \( X \) verifying the condition of (2), the morphism \( \text{Alb}^T H^2_R(X) \to R_1 \text{L}_2 \text{Alb}^Q(X) \) is an isomorphism. Note that both sides are Lefschetz objects: hence, by Yoneda’s lemma, it suffices to show that for any Lefschetz object \( \Theta \), the map

\[
\text{Hom}(R_1 \text{L}_2 \text{Alb}^Q(X), \Theta) \to \text{Hom}(\text{Alb}^T H^2_R(X), \Theta)
\]

is an isomorphism.
Without loss of generality, we may assume that $\Theta = R_1([0 \to T])$ with $T = R_{E/k}^* \mathbb{G}_m = M(\text{Spec } E) \otimes \mathbb{Z}(1)[1]$. In the commutative diagram of Lemma 15.5.3 for $X_E$, the composition of $\beta$ and $R$ is surjective by the surjectivity of (15.7). Therefore (15.8) is surjective. By assumption, (15.8) is also injective. This concludes the proof. □

16. Comparing realisations

Let $K, T, B$ be as in 15.3 and $R$ be as in 15.4. We now give ourselves

- a $t$-exact functor $D^b(B) \to T$ which is the identity on $B$
- an exact functor $\mathbb{T} : \mathcal{M}_1 \otimes \mathbb{Q} \to B$.

We suppose that $\mathbb{T}$ respects the splittings of $\mathcal{M}_1 \otimes \mathbb{Q}$ and $B$ in the sense of Definition E.9.1 (see Proposition 15.2.1 for the weight filtration on $\mathcal{M}_1 \otimes \mathbb{Q}$). We still write $\mathbb{T}$ for its trivial extension

$$D^b(\mathcal{M}_1) \otimes \mathbb{Q} \xrightarrow{\mathbb{T}} D^b(B) \to T.$$ 

We would like to compare $\mathbb{T}$ with $R_1 = R_{\text{Tot}}$. The aim of this section is to discuss the existence and uniqueness of a natural isomorphism between these two functors.

16.1. A full embedding. Let Chow be the category of Chow motives over $k$, Chow $\boxtimes \mathbb{Q}$ the category of Chow motives with rational coefficients and Chow$^{\text{eff}} \boxtimes \mathbb{Q}$ the full subcategory of effective Chow motives. We take the covariant convention for composition of correspondences: the functor

$$X \mapsto h(X)$$

from smooth projective varieties to Chow$^{\text{eff}} \boxtimes \mathbb{Q}$ is covariant.

16.1.1. Lemma. Let $d_{\leq 1}$ Chow$^{\text{eff}} \boxtimes \mathbb{Q}$ be the thick subcategory of Chow$^{\text{eff}} \boxtimes \mathbb{Q}$ generated by motives of curves. Then

1. $d_{\leq 1}$ Chow$^{\text{eff}} \boxtimes \mathbb{Q}$ consists of those objects that may be written as a direct sum of Chow motives of the following type:
   - an Artin motive;
   - a motive of the form $h_1(A)$ for $A$ an abelian variety;
   - a motive of the form $M \otimes \mathbb{L}$, where $M$ is an Artin motive and $\mathbb{L}$ is the Lefschetz motive.
2. The composition

$$d_{\leq 1} \text{Chow}^{\text{eff}} \boxtimes \mathbb{Q} \xrightarrow{\cdot 1} \text{Chow}^{\text{eff}} \boxtimes \mathbb{Q} \xrightarrow{\cdot \Phi} \text{DM}^{\text{eff}} \boxtimes \mathbb{Q} \xrightarrow{\text{LAlb}^Q} D^b(\mathcal{M}_1 \otimes \mathbb{Q})$$
is fully faithful, where $\Phi$ is as in (15.3). It yields a naturally commutative diagram of full embeddings:

$$
\begin{array}{ccc}
d_{\leq 1} \text{Chow}^{\text{eff}} \boxtimes \mathbb{Q} & \xrightarrow{\Phi(1)} & D^b(M_1 \otimes \mathbb{Q}) \\
\downarrow & & \downarrow \text{Tot}^Q \\
\text{Chow}^{\text{eff}} \boxtimes \mathbb{Q} & \xrightarrow{\Phi} & D\text{M}_{\text{eff}}^{\text{gm}} \boxtimes \mathbb{Q}
\end{array}
$$

with $\Phi(1) = \text{LAlb}^Q \circ \Phi \circ \iota$.

Proof. (1) is clear by the Chow-Künneth decomposition for motives of curves and the fact that any abelian variety is a direct summand of the Jacobian of a curve, up to isogeny.

(2) We have a naturally commutative diagram

$$
\begin{array}{ccc}
d_{\leq 1} \text{Chow}^{\text{eff}} \boxtimes \mathbb{Q} & \xrightarrow{\Phi} & d_{\leq 1} D\text{M}_{\text{eff}}^{\text{gm}} \boxtimes \mathbb{Q} \\
\downarrow & & \downarrow \\
\text{Chow}^{\text{eff}} \boxtimes \mathbb{Q} & \xrightarrow{\Phi} & D\text{M}_{\text{eff}}^{\text{gm}} \boxtimes \mathbb{Q} \xrightarrow{\text{LAlb}} D^b(M_1 \otimes \mathbb{Q})
\end{array}
$$

where the vertical functors are full embeddings. The lemma now boils down to the fact that the restriction of $\text{LAlb}^Q$ to $d_{\leq 1} D\text{M}_{\text{eff}}^{\text{gm}} \boxtimes \mathbb{Q}$ is quasi-inverse to $\text{Tot}$ (Corollary 6.2.2). □

16.1.2. Remark. Of course, we can now define the full embedding $\Phi(1)$ of Lemma 16.1.1 without reference to $D\text{M}_{\text{eff}}^{\text{gm}}$ or $\text{LAlb}^Q$: this functor sends

1. An Artin motive $M$ to the 1-motive $[L \to 0]$, where $L$ is the permutation Galois-module associated to $M$.
2. If $A$ is an abelian variety, $h_1(A)$ to $[0 \to A][1]$.
3. A Lefschetz motive $M \otimes \mathbb{L}$ to $[0 \to L \otimes \mathbb{G}_m][2]$, where $L$ is as in (1).

16.2. Extending a natural isomorphism.

16.2.1. Hypothesis. We assume given, for every smooth projective curve $C$, an isomorphism $v_C : R(M(C)) \xrightarrow{\sim} \mathbb{T}(\Phi(1)h(C))$ with the following two properties:

(i) If $C'$ is another such curve, then for any Chow correspondence $\alpha \in CH^1(C \times C') \otimes \mathbb{Q}$, the diagram

$$
\begin{array}{ccc}
R(M(C)) & \xrightarrow{\alpha_*} & R(M(C')) \\
\downarrow v_C & & \downarrow v_{C'} \\
\mathbb{T}(\Phi(1)h(C)) & \xrightarrow{\alpha_*} & \mathbb{T}(\Phi(1)h(C'))
\end{array}
$$


commutes.

Let $E/k$ be a finite extension, and let $h(E) := h(Spec E)$, $Z_E := M(Spec E) = \Phi h(E)$, $[Z_E \to 0] := [Z[G_k/G_E] \to 0] = \text{LAlb}(Z_E)$.

For $C = \mathbb{P}^1_E$ with $M(\mathbb{P}^1_E) = Z_E \oplus Z_E(1)[2]$, $v_{\mathbb{P}^1_E}$ and the commutation of (16.1) for Chow correspondences from $\mathbb{P}^1_E$ to itself yield two isomorphisms $v_{h(E)} : R(Z_E) \sim \rightarrow \mathcal{T}([Z_E \to 0])$ and $v_{L \otimes h(E)} : R(Z_E(1)[2]) \sim \rightarrow \mathcal{T}([0 \to Z_E \otimes \mathbb{G}_m][1])$. The second property we require is:

(ii) For any $E/k, E'/k$ and any $\beta \in \text{Hom}_{DM}(Z_E, Z_{E'}(1)[1]) = (E \otimes_k E')^* \otimes \mathbb{Q}$, the diagram

\[
\begin{array}{ccc}
R(Z_E) & \xrightarrow{\beta} & R(Z_{E'}(1)[1]) \\
v_{h(E)}\downarrow & & v_{L \otimes h(E)}[\cdot - 1]\downarrow \\
\mathcal{T}([Z_E \to 0]) & \xrightarrow{\beta} & \mathcal{T}([0 \to Z_{E'} \otimes \mathbb{G}_m])
\end{array}
\]

commutes.

The aim of this subsection is to prove the following

16.2.2. Theorem. Let as before $R_1 = R \text{Tot}$. Under Hypotheses 15.4.1 and 16.2.1, there exists at most one natural isomorphism $u : R_1 \Rightarrow \mathcal{T}$ such that, for every smooth projective curve $C$, $v_C = u_{\Phi(h(C))}$. This isomorphism exists if and only if a certain obstruction (see (5) in the proof below) vanishes.

Proof. Recall first that, under Hypothesis 15.4.1, $R_1(M_1 \otimes \mathcal{Q}) \subseteq B$ (Proposition 15.4.2). If $u : R_1 \Rightarrow \mathcal{T}$ is a natural transformation, then it is determined by its restriction $u_1$ to $M_1 \otimes \mathcal{Q}$ by Lemma E.22.1; moreover, $u$ is an isomorphism if and only if $u_1$ is (ibid.). Therefore, we only need to discuss the existence and uniqueness of $u_1$.

The commutativity of the diagrams (16.1) means that $v$ defines a natural transformation on the category of smooth projective curves provided with Chow correspondences. We proceed in several steps:

(1) Extend $v$ to $d_{\leq 1} \text{Chow}^{\text{eff}} \otimes \mathcal{Q}$, yielding natural isomorphisms

$v_h : R\Phi(h) \sim \rightarrow \mathcal{T}(\Phi(1)(h)),$

$h \in d_{\leq 1} \text{Chow}^{\text{eff}} \otimes \mathcal{Q}$

and diagrams like (16.2) with $Z_E$ (resp. $Z_{E'}(1)[1]$) replaced by $\Phi(h)$ (resp. by $\Phi(h' \otimes \mathbb{L})[-1]$ for any Artin motives $h, h'$. Here $\mathbb{L}$ is the Lefschetz motive.

(2) Define $u$ on 1-motives of pure weight.

(3) Extend $u$ to 1-motives of weights $\in \{-2, -1\}$ and $\in \{-1, 0\}$.

(4) Extend $u$ to 1-motives of weights $\in \{-2, 0\}$.

(5) Get the obstruction to extend $u$ to all 1-motives.
(1) is formal.

(2) Let \( N \) be of pure weight \(-w\). Then \( \Phi(h) = \text{Tot} N[w] \) for a unique \( h \in d_{<1} \text{Chow}^{\text{eff}} \otimes \mathbb{Q} \) of weight \(-w\). Conversely, we have \( \Phi(h) = \text{Tot} N[w] \). Define \( u_N = u_h[w] \): this indeed defines a natural transformation thanks to Lemma 16.1.1 (2).

(3) Start with the case of weights \( \in \{-2, -1\} \). By Theorem E.10.2 (2), we have to show that given a 1-motive \([0 \to G]\), with \( G \) extension of \( A \) by \( T \), the diagram

\[
\begin{array}{ccc}
T'(\mathcal{H}) & \xrightarrow{\Phi(\mathcal{H})} & T'(\mathcal{H})[1] \\
\downarrow u_{[0\to A]} & & \downarrow u_{[0\to T][1]} \\
\mathcal{T}([0 \to A]) & \xrightarrow{\Phi(\mathcal{T})} & \mathcal{T}([0 \to T])[1]
\end{array}
\]

commutes.

We may write \([0 \to A] = \Phi([A])[-1]\) and \([0 \to T] = \Phi([T])[-2]\), where \( A = h_1(A) \) and \( T = L \otimes \text{Hom}(\mathbb{G}_m, T) \) (\( L \) the Lefschetz motive). Then the map

\([0 \to A] \to [0 \to T][1]\)

corresponding to the extension \([0 \to G]\) comes from a map \( A \to T \) by Lemma 16.1.1. By (1), the diagram

\[
\begin{array}{ccc}
R(\Phi A) & \longrightarrow & R(\Phi T) \\
\downarrow v_{\Phi A} & & \downarrow v_{\Phi T} \\
\mathcal{T}(\Phi(A)) & \longrightarrow & \mathcal{T}(\Phi(T))
\end{array}
\]

commutes. This is equivalent to the fact we request.

In the case of weights \( \in \{-1, 0\} \), given a 1-motive \([L \to A]\) we have similarly to check that the diagram

\[
\begin{array}{ccc}
R(\Phi(L \otimes 1)) & \longrightarrow & R(\Phi A) \\
\downarrow v_{\Phi(L \otimes 1)} & & \downarrow v_{\Phi A} \\
\mathcal{T}(\Phi(L \otimes 1)) & \longrightarrow & \mathcal{T}(\Phi(A))
\end{array}
\]

commutes, which also follows from (1).
(4) We have to prove that, given a 1-motive \( N = [L \to T] \) with \( T \) a torus, the diagram
\[
\begin{array}{ccc}
\mathbf{T}'([0 \to T]) & \xrightarrow{[T(N)]} & \mathbf{T}'([L \to 0])[1] \\
\downarrow_{u_{[0 \to T]}} & & \downarrow_{u_{[L \to 0][1]}} \\
\mathbf{T}([0 \to T]) & \xrightarrow{[T(N)]} & \mathbf{T}([L \to 0])[1]
\end{array}
\]
commutes. As in (5), this is a translation of (1).

(5) By Theorem E.12.1 (3), we now get an obstruction to glueing of the following form: for any 1-motive \( [L \to G] \), a bilinear map
\[
\text{Ext}^1_{\mathcal{M}_1 \otimes \mathbb{Q}}([L \to 0], [0 \to A]) \times \text{Ext}^1_{\mathcal{M}_1 \otimes \mathbb{Q}}([0 \to A], [0 \to T]) \\
\to \text{Ext}^1_{\mathcal{G}}(\mathbf{T}'([L \to 0]), \mathbf{T}'([0 \to T])).
\]

In case \( L = \mathbb{Z} \) and \( T = \mathbb{G}_m \), we may rewrite this as
\[
A(k) \otimes \mathbb{Q} \times A'(k) \otimes \mathbb{Q} \to \text{Ext}^1_{\mathcal{G}}(R\mathbb{Z}, R\mathbb{Z}(1)).
\]

\[\Box\]

16.2.3. Remark. If we assume that the natural map
\[
\text{DM}_{\text{gm}}^{\text{eff}} \otimes \mathbb{Q}(\mathbb{Z}, \mathbb{Z}(1)[1]) \otimes K \xrightarrow{R} \mathbf{T}(R\mathbb{Z}, R\mathbb{Z}(1)[1]) = \text{Ext}^1_{\mathcal{G}}(R\mathbb{Z}, R\mathbb{Z}(1))
\]
is bijective, then the pairing in part (5) of the proof of Theorem 16.2.2 may be reformulated as a \( K \)-pairing
\[(16.3) \quad A(k) \otimes K \times A'(k) \otimes K \to k^* \otimes K.
\]

Suppose that we have the above picture functorially over a base \( S \), where \( S \) runs through smooth \( k \)-schemes essentially of finite type. By Proposition C.12.3, the category of smooth 1-motives \( \mathcal{M}_1(\mathcal{O}_{S,s}^{\text{sh}}) \otimes \mathbb{Q} \) [32, 10.1.10] is of cohomological dimension \( \leq 1 \) for any point \( s \in S \). Hence the pairing (16.3) extends to a pairing of étale sheaves
\[
A \otimes K \times A' \otimes K \to \mathbb{G}_m \otimes K.
\]
by Theorem E.12.1 (3). So we get in particular a homomorphism
\[
\varphi_S : A(S) \otimes K \to \text{Hom}(A'(k) \otimes K, \Gamma(S, \mathbb{G}_m) \otimes K)
\]
natural in \( S \).

For \( S = A \), the right hand side is reduced to \( \text{Hom}(A'(k) \otimes K, k^* \otimes K) \), hence Yoneda’s lemma implies that \( \varphi_S \) is constant, and therefore 0.
17. The Hodge realisation

Let MHS denote the abelian category of (graded polarizable, \(\mathbb{Q}\)-linear) mixed Hodge structures. We take for \(\mathcal{B}\) the full subcategory \(\text{MHS}^{\text{eff}}\) of MHS consisting of objects whose Hodge numbers are of type \((i,j)\) with \(i \leq 0\) and \(j \leq 0\). For \(\mathcal{T}\) we take \(D^b(\mathcal{B})\). The weight filtration provides \(\mathcal{B}\) with a weight filtration in the sense of Definition E.7.2. We take for \(\mathcal{B}_L\) the Hodge structures purely of type \((-1,-1)\). With the notation of §15.3, \(\mathcal{B}_{(1)} = \text{MHS}_{(1)}\) is the full subcategory of \(\text{MHS}^{\text{eff}}\) given by mixed Hodge structures with possibly non zero Hodge numbers in the set \{\((0,0),(0,-1),(-1,0),(-1,-1)\)\}.

17.1. \(\text{LAlb}^\mathcal{T}\) for mixed Hodge structures. Note that \(\text{MHS}^{-2}\) is semi-simple since pure polarizable Hodge structures are. As a special case of Proposition 15.3.4, we therefore have:

17.1.1. Proposition. The full embeddings \(\iota : \text{MHS}_{(1)} \hookrightarrow \text{MHS}^{\text{eff}}\) and \(\iota : D^b(\text{MHS}_{(1)}) \hookrightarrow D^b(\text{MHS}^{\text{eff}})\) have left adjoints \(\text{Alb}^\text{MHS}\) and \(\text{LAlb}^\text{MHS}\).

17.1.2. Notation. For \(H \in \text{MHS}^{\text{eff}}\) we shall write \(H \leq 1\) for \(\text{Alb}^\text{MHS}(H)\). If \(H\) has Hodge numbers \(\geq 0\) then the dual \(\text{Hom}(H, \mathbb{Q}) \in \text{MHS}^{\text{eff}}\) is effective and we denote

\[H \leq 1 := \text{Hom}(\text{Hom}(H, \mathbb{Q}) \leq 1, \mathbb{Q}(1))\]

Denoting \(\text{Pic}^\text{MHS}\) the Cartier dual of \(\text{Alb}^\text{MHS}\) the latter \(H \leq 1\) translates in \(\text{Pic}^\text{MHS}(\text{Hom}(H, \mathbb{Q}))\).

17.1.3. Remark. In Deligne’s notation [32, 10.4.1], for \(H \in \text{MHS}\) we have:

- \(\Pi_n(H)_\mathbb{Q} = H(n) \leq 1\) if the Hodge numbers of \(H\) are \(\leq n\)
- \(\Pi(H)_\mathbb{Q} = H \leq 1\) if the Hodge numbers of \(H\) are \(\geq 0\).

Note that \(H \mapsto H \leq 1\) is actually right adjoint to the (full embedding) functor \(H \mapsto H(-1)\) from \(\text{MHS}_{(1)}\) to the full subcategory \(\text{MHS}^{\text{eff}}\) of MHS consisting of objects whose Hodge numbers are \(\geq 0\).

17.2. Huber’s Hodge realisation functor. We have A. Huber’s realisation functor [49]

\[R_{\text{Hodge}} : \text{DM}_{\text{gm}}^\text{eff}(\mathbb{C}) \otimes \mathbb{Q} \to D^b(\text{MHS}^{\text{eff}})\]

For \(X\) a smooth variety, we have \(R_{\text{Hodge}}(M(X)) = R\Gamma(X, \mathbb{Q})\), and in particular its Hodge numbers are \(\geq 0\). This functor is contravariant. To get a covariant functor we compose it with the (exact) duality of \(D^b(\text{MHS})\) sending \(H\) to \(\text{Hom}(H, \mathbb{Q})\). Thus we get a functor

\[R^\text{Hodge} : \text{DM}_{\text{gm}}^\text{eff}(\mathbb{C}) \otimes \mathbb{Q} \to D^b(\text{MHS}^{\text{eff}})\]
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Since $\mathcal{R}_{\text{Hodge}} \Phi : \text{Chow}^{\text{eff}} \otimes \mathbb{Q} \to D^b(\text{MHS}_{\text{eff}})$ is by construction isomorphic to the functor $X \mapsto R\Gamma(X, \mathbb{Q})$, the conditions of Hypothesis 15.4.1 are verified, as well as Condition (W) of Proposition 15.4.2. This proposition then shows that $\mathcal{R}_{\text{Hodge}} \text{Tot}$ defines an exact functor
\[
\mathcal{R}_{\text{Hodge}}^1 : \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q} \to \text{MHS}_{(1)}.
\]

Although this is irrelevant for our purpose, it is nice to know:

17.2.1. **Theorem.** The functor $\mathcal{R}_{\text{Hodge}}^1$ is an equivalence of categories.

**Proof.** Note that $\mathcal{R}_{\text{Hodge}}^1$ respects the splittings of $\mathcal{M}_1 \otimes \mathbb{Q}$ and $\text{MHS}_{(1)}$, by Proposition 15.4.2. Therefore we are in a position to apply Theorem E.14.1.

Let $W_i \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q}$ and $W_i(\text{MHS}_{(1)})$ denote the full subcategories of objects pure of weight $i$ ($i = 0, -1, -2$). We first check that $\mathcal{R}_1$ induces equivalences of categories $W_i \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q} \sim W_i(\text{MHS}_{(1)})$. Note that these three categories are semi-simple. The cases $i = 0$ and $i = -2$ are obvious. For $i = -1$, it is known (e.g. from Deligne’s equivalence of categories [32, 10.1.3]) that any $H \in W_{-1}(\text{MHS}_{(1)})$ is a direct summand of some $H_1(C)$: this proves essential surjectivity. For the full faithfulness, we reduce to proving that, given two connected smooth projective curves, the map
\[
\text{Hom}(J(C), J(C')) \to \text{Hom}(H_1(C), H_1(C'))
\]
given by $\mathcal{R}_{\text{Hodge}}^1$ is the usual action of divisorial correspondences, which follows from the construction of $\mathcal{R}_{\text{Hodge}}$.

(Note that these arguments provide natural isomorphisms of the restrictions of $\mathcal{R}_{\text{Hodge}}^1$ to $W_i \mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q}$ with Deligne’s realisation functor.)

We are left to check the conditions of Theorem E.14.1 on isomorphisms of Hom and Ext groups. Note that the condition on Hom groups in (2) is empty because they are identically 0. For the Ext groups, since $\text{Ext}_{\text{MHS}}^2$ is identically 0, we reduce by (4) to prove that, for $N_m, N_n \in \mathcal{M}_1 \otimes \mathbb{Q}$ of pure weights $m < n$, the map
\[
\text{Ext}_{\mathcal{M}_1 \otimes \mathbb{Q}}^1(N_n, N_m) \to \text{Ext}_{\text{MHS}}^1(\mathcal{R}_{\text{Hodge}}^1(N_n), \mathcal{R}_{\text{Hodge}}^1(N_m))
\]
is bijective.

Since $\text{Tot} : D^b(\mathcal{M}_1 \otimes \mathbb{Q}) \to \text{DM}_{\text{gm}}^{\text{eff}} \otimes \mathbb{Q}$ is fully faithful, it suffices to prove that the map
\[
\text{Hom}_{\text{DM}_{\text{gm}}^{\text{eff}} \otimes \mathbb{Q}}(\text{Tot}(N_n), \text{Tot}(N_m)[1])
\rightarrow \text{Hom}_{D^b(\text{MHS})}(\mathcal{R}_{\text{Hodge}} \text{Tot}(N_n), \mathcal{R}_{\text{Hodge}} \text{Tot}(N_m)[1])
\]
is bijective. We distinguish 3 cases:
(i) \((m,n) = (-1,0)\). Without loss of generality, we may assume 
\(N_0 = [Z \to 0], \ N_{-1} = [0 \to J_C]\) for a smooth projective curve 
\(C\). Then \(\text{Tot}(N_{-1}) = \Phi h_1(C)[-1], \ R^{\text{Hodge}} \text{Tot}(N_{-1}) = H_1(C)\) 
and we are looking at the map
\[\text{Hom}_{DM}(\mathbb{Q}, \Phi h_1(C)) \to \text{Hom}_{D^b(MHS)}(\mathbb{Z}, H_1(C)[1]).\]

By Poincaré duality, this map is equivalent to the map
\[J_C(C) \otimes \mathbb{Q} = \text{Hom}_{DM}(\Phi h_1(C), \mathbb{Z}(1)[2]) \to \text{Hom}_{D^b(MHS)}(H^1(C), \mathbb{Z}(1)[1]) = \text{Ext}_{MHS}^1(H^1(C), \mathbb{Z}(1)),\]

which coincides with the Abel-Jacobi map\(^{13}\), hence is bijective.

(ii) \((m,n) = (-2,-1)\). Without loss of generality, we may assume 
\(N_{-2} = [0 \to \mathbb{G}_m], \ N_{-1} = [0 \to J_C]\) for a smooth projective 
curve \(C\). Then \(\text{Tot}(N_{-1}) = \Phi h_1(C)[-1], \ R^{\text{Hodge}} \text{Tot}(N_{-1}) = H^1(C)\) 
and we are looking at the map
\[\text{Hom}_{DM}(\Phi h_1(C)\mathbb{Z}(1)[2]) \to \text{Hom}_{D^b(MHS)}(H^1(C), \mathbb{Z}(1)[1])\]

which is the Abel-Jacobi map as in (ii).

(iii) \((m,n) = (-2,0)\). Without loss of generality, we may assume 
\(N_{-2} = [0 \to \mathbb{G}_m], \ N_0 = [\mathbb{Z} \to 0]\). We are now looking at the map
\[\mathbb{C}^* \otimes \mathbb{Q} = \text{Hom}_{DM}(\mathbb{Z}, \mathbb{Z}(1)[1]) \to \text{Hom}_{D^b(MHS)}(\mathbb{Z}, \mathbb{Z}(1)[1]) = \text{Ext}_{MHS}^1(\mathbb{Z}, \mathbb{Z}(1)),\]

which is again the usual isomorphism, by definition of Huber’s 
realisation functor.

17.3. **Deligne’s conjecture.** From Theorem 17.2.1 and (15.4) we get, 
for any \(M \in \text{DM}_{gm}(\mathbb{C}) \otimes \mathbb{Q}\), a natural map
\[R^{\text{Hodge}}(M)_{\leq 1} \to R^{\text{Hodge}}_1 L\text{Alb}(M).\]

Taking homology of both sides, we get comparison maps
\[H_i(R^{\text{Hodge}}(M))_{\leq 1} \to R_i^{\text{Hodge}} L_i \text{Alb}(M)\]

for all \(i \in \mathbb{Z}\). From Theorem 15.5.5 and the Lefschetz 1-1 theorem, we now get:

17.3.1. **Theorem.** The maps (17.1) and (17.2) are isomorphisms for 
all motives \(M\) .

\(^{13}\) Because, by construction, the restriction of Huber’s functor to pure motives is 
the “usual” Hodge realisation functor.
This theorem recovers the results of [10], with rational coefficients.

The isomorphisms (17.2) may be applied to geometric motives like $M(X)$, $X$ any $\mathbb{C}$-scheme of finite type (yielding $\text{LAlb}(X)$), but also $M(X)^*(n)[2n]$ and $M^*(X)$ yielding $\text{LAlb}^*(X)$ and $\text{LAlb}^c(X)$ respectively. We thus get the following corollary, overlapping Deligne’s conjecture (see 17.1.2 and 17.1.3 for the notation):

17.3.2. Corollary. Let $X$ be an $n$-dimensional complex algebraic variety. The mixed Hodge structures $H^i(X, \mathbb{Q})_{\leq 1}$, $H^{2n-i}(X, \mathbb{Q}(n))_{\leq 1}$ and $H^c_i(X, \mathbb{Q})_{\leq 1}$ induced by the Betti cohomology mixed Hodge structure and the Borel-Moore homology mixed Hodge structure admit a purely algebraic construction provided by the previously explained isomorphisms

$$R^1_{\text{Hodge}}(R^1\text{Pic}(X)) \xrightarrow{\sim} H^i(X, \mathbb{Q})_{\leq 1}$$

$$H^{2n-i}(X, \mathbb{Q}(n))_{\leq 1} \xrightarrow{\sim} R^1_{\text{Hodge}}(\text{LAlb}^*(X))$$

$$H^c_i(X, \mathbb{Q})_{\leq 1} \xrightarrow{\sim} R^1_{\text{Hodge}}(\text{LAlb}^c(X))$$

of mixed Hodge structures.

17.3.3. Remark. Deligne’s conjecture [32, (10.4.1)] concerns three types of Hodge structures of level $\leq 1$ for $X$ of dimension $\leq N$: $I(H^n(X, \mathbb{Z}))$, $II_n(H^n(X, \mathbb{Z}))$ ($n \leq N$) and $II_N(H^n(X, \mathbb{Z}))$ ($n \geq N$). Corollary 17.3.2 covers the first and last (compare Remark 17.1.3), but not the second in general. The issue for $II_n$ and $II_N$ is that the motive $M(X)^*(n)[2n]$ is effective for $n \geq \dim X$ by Lemma 9.2.1, but not for $n < \dim X$ in general. Indeed, if $M(X)^*(n)[2n]$ is effective, then it is isomorphic in $\text{DM}^\text{eff} \otimes \mathbb{Q}$ to $\text{Hom}_\text{eff}(M(X), \mathbb{Z}(n)[2n])$ for formal reasons, and therefore the latter is a geometric motive. But this is false e.g. for $n = 2$ and $X$ a suitable smooth projective 3-fold, see [2].

Suppose that the motivic $t$-structure exists on $\text{DM}^\text{eff} \otimes \mathbb{Q}$. By a recent result of Beilinson [13], this implies Grothendieck’s standard conjecture B. For any $X$, let us then write $M_i(X)$ for the $i$-th $t$-homology of $M(X)$. If $X$ is smooth projective, by Poincaré duality and Conjecture B we find that

$$\text{Hom}_\text{eff}(M_n(X), \mathbb{Z}(n)) \simeq M_n(X)$$

is geometric. By blow-up induction, this then implies that the motive $\text{Hom}_\text{eff}(M_n(X), \mathbb{Z}(n))$ is geometric for any $X$ of finite type, and we obtain the remaining part of Deligne’s conjecture.

A less expensive approach could be to use the extension of $\text{LAlb}^\mathbb{Q}$ to $\text{DM}^\text{eff} \otimes \mathbb{Q}$ constructed in [7], provided one can similarly extend the Hodge realisation functor to $\text{DM}^\text{eff} \otimes \mathbb{Q}$.
17.4. **Deligne’s Hodge realisation functor.** In Deligne’s construction, the *integrally defined* Hodge realization

\[ T^{\text{Hodge}}(M) := (T^*_Z(M), W_*, F^*) \]

of a 1-motive (with torsion) \( M \) over \( k = \mathbb{C} \) (see [10, §1] and [32, 10.1.3]) is obtained as follows. The finitely generated abelian group \( T^*_Z(M) \) is given by the pull-back of \( u : L \to G \) along \( \exp : \text{Lie}(G) \to G \), \( W_* \) is the weight filtration

\[
W_i T(M) := \begin{cases} 
T^*_Z(M) \otimes \mathbb{Q} & i \geq 0 \\
H_1(G, \mathbb{Q}) & i = -1 \\
H_1(T, \mathbb{Q}) & i = -2 \\
0 & i \leq -3
\end{cases}
\]

and \( F^* \) is defined by \( F^0(T^*_Z(M) \otimes \mathbb{C}) := \text{Ker}(T^*_Z(M) \otimes \mathbb{C} \to \text{Lie}(G)) \).

We have that \( T^*_Z(M), W_* \) and \( F^0 \) are independent of the representative of \( M \). Thus \( T^{\text{Hodge}}(M) \) is a mixed \( \mathbb{Z} \)-Hodge structure such that \( \text{gr}^W_i \) is polarizable. We have \( \text{gr}^W_0 T^{\text{Hodge}}(M) \cong L \otimes \mathbb{Q} \), \( \text{gr}^W_{-1} T^{\text{Hodge}}(M) \cong H_1(A, \mathbb{Q}) \) and \( \text{gr}^W_{-2} T^{\text{Hodge}}(M) \cong H_1(T, \mathbb{Q}) \) as pure polarizable \( \mathbb{Q} \)-Hodge structures.

Let \( \text{MHS}^Z_1 \) be the category of mixed \( \mathbb{Z} \)-Hodge structure with possibly non zero Hodge numbers in the set \( \{(0,0), (0,-1), (-1,0), (-1,-1)\} \) such that \( \text{gr}^W_0 \) is polarizable. We have \( \text{MHS}^Z_1 \otimes \mathbb{Q} = \text{MHS}^Z(1) \).

The functor \( T^{\text{Hodge}} \) is the *covariant* Deligne’s Hodge realization

\[ T^{\text{Hodge}} : t\mathcal{M}(\mathbb{C}) \xrightarrow{\cong} \text{MHS}^Z_1 \]

which is an equivalence of abelian categories by [10, Prop. 1.5]. It induces an equivalence

\[ T^{\text{Hodge}}_Q : D^b(t\mathcal{M}(\mathbb{C}) \otimes \mathbb{Q}) \xrightarrow{\cong} D^b(\text{MHS}(1)). \]

17.4.1. **Remark.** We don’t prove here that the functor \( R^{\text{Hodge}}_1 \) of Theorem 17.2.1 is isomorphic to \( T^{\text{Hodge}}_Q \). By Theorem 16.2.2, there exists at most one such natural isomorphism. Its existence would follow from a validation of Remark 16.2.3 in the Hodge context; V. Vologodsky actually gives an explicit construction of it in [99]. In fact, such an isomorphism along with its uniqueness is a simple consequence of the fact that 1-motives with torsion is a universal abelian category in the sense of Nori for an explicit diagram of curves: see [6] for details in the more natural and general framework that applies to mixed realisations.
This is reproving Theorem 17.2.1 (using [32, 10.1.3]) and yield a naturally commutative diagram

\[ \begin{array}{c}
D^b(\text{MHS}_{(1)}) \xrightarrow{T^\text{Hodge}_Q} D^b(\text{MHS}^\text{eff}) \\
\downarrow (-)_{\leq 1} & \downarrow R^\text{Hodge} \\
D^b(\mathcal{M}_1(\mathbb{C}) \otimes \mathbb{Q}) \xrightarrow{\text{Tot}_{\text{LAlb}}} \text{DM}^\text{eff}_{\text{gm}}(\mathbb{C}) \otimes \mathbb{Q}.
\end{array} \]

18. The mixed realisation

We consider here the other part of Deligne’s conjecture:

Les morphismes

\[ T_\ell(I(H^n(X, \mathbb{Z}))) \to (H^n(X, \mathbb{Z}_\ell)/\text{torsion})(1) \]
\[ T_\ell(IH_n(H^n(X, \mathbb{Z}))) \leftarrow H^n(X, \mathbb{Z}_\ell)(n) \text{ (pour } n \leq N) \]
\[ T_\ell(IH_N(H^n(X, \mathbb{Z}))) \leftarrow H^n(X, \mathbb{Z}_\ell)(N) \text{ (pour } n \geq N) \]

et leurs analogues en cohomologie de De Rham devraient aussi admettre une définition purement algébrique.

Huber’s Hodge realisation is only a part of her construction of a functor from \( \text{DM}_{\text{gm}}(k, \mathbb{Q}) \) \((k \text{ a finitely generated field over } \mathbb{Q})\) to her category of mixed realisations. We exploit this much richer structure to give a proof of the above conjecture, rationally and excluding the second case (see Remark 17.3.3 for the latter).

18.1. \text{LAlb}^T \text{ for mixed realisations.} Let \( k \) be a finitely generated extension of \( \mathbb{Q} \). Recall from [47, Def. 11.1.1] Huber’s category \( \mathcal{M}_\mathcal{R} \) of mixed realisations. An object \( A \in \mathcal{M}_\mathcal{R} \) is a collection

\[ (A_{\text{DR}}, A_\ell, A_{\sigma, \ell}, A_\sigma, A_{\sigma, C}; I_{\text{DR}, \sigma}, I_{\sigma, C}, I_{\pi, \ell}, I_{\ell, \sigma})_{\ell \in \mathcal{P}, \sigma \in S} \]

where \( \mathcal{P} \) is the set of prime numbers, \( S \) is the set of embeddings \( k \hookrightarrow \mathbb{C} \) and

- \( A_{\text{DR}} \) is a [finite dimensional] bifiltered \( k \)-vector space.
- \( A_\ell \) is a filtered \( \mathbb{Q}_\ell \)-adic representation of \( G_k := \text{Gal}(\overline{k}/k) \); it is assumed to be constructible \( i.e. \) unramified over some model of finite type of \( k/\mathbb{Z} \) and that the filtration is a weight filtration.
- \( A_{\sigma, \ell} \) is a filtered \( \mathbb{Q}_\ell \)-vector space.
- \( A_{\sigma} \) is a filtered \( \mathbb{Q} \)-vector space.
- \( A_{\sigma, C} \) is a filtered \( \mathbb{C} \)-vector space.
- \( I_{\text{DR}, \sigma} : A_{\text{DR}} \otimes_\sigma \mathbb{C} \to A_{\sigma, C} \) is a filtered isomorphism.
- \( I_{\sigma, C} : A_{\sigma} \otimes_\mathbb{Q} \mathbb{C} \to A_{\sigma, C} \) is a filtered isomorphism.
- \( I_{\pi, \ell} : A_{\sigma} \otimes_\mathbb{Q} \mathbb{Q}_\ell \to A_{\sigma, \ell} \) is a filtered isomorphism.
- \( I_{\ell, \sigma} : A_\ell \to A_{\sigma, \ell} \) is a filtered isomorphism.
Additionally, it is required that the systems \((A_\sigma, A_{\text{DR}}, A_{\sigma,C}, I_{\text{DR},\sigma}, I_{\sigma,C})\) define mixed Hodge structures.

Morphisms in \(\mathcal{MR}\) are defined in the obvious way.

This is a refinement of the category defined by Jannsen [53, Ch. 1] and Deligne [35]: the refinement is that on the \(\ell\)-adic components of an object, the filtration is required to be a weight filtration. Huber also defined a triangulated \(t\)-category \(D_{\mathcal{MR}}\), with heart \(\mathcal{MR}\) (loc. cit. Def. 11.1.3); it comes with a canonical functor (loc. cit. p. 94)

\[ D^b(\mathcal{MR}) \to D_{\mathcal{MR}} \]

which is the identity on the hearts.

These categories are not sufficient for our purposes: instead, we shall use the categories \(\mathcal{MR}^P\) and \(D_{\mathcal{MR}^P}\) of [47, Def. 21.1.1 and 21.1.3], which restrict the Hodge components to polarizable mixed Hodge structures: by definition, \(\mathcal{MR}^P\) is a full subcategory of \(\mathcal{MR}\). There is the same formalism as above (loc. cit. Prop. 21.1.4), which maps to the previous one.

We need an “effective” full subcategory \(\mathcal{MR}^{P,\text{eff}} \subset \mathcal{MR}^P\), and a corresponding effective triangulated category \(D_{\mathcal{MR}^P}^{\text{eff}} \subset D_{\mathcal{MR}^P}\).

18.1.1. Definition. a) An object \(X \in \mathcal{MR}^P\) is in \(\mathcal{MR}^{P,\text{eff}}\) if

1. The de Rham component \(X_{\text{DR}}\) verifies \(F^{0,0}X_{\text{DR}} = X_{\text{DR}}\) (non-positive Hodge numbers).
2. The eigenvalues of (arithmetic) Frobenius acting on the \(\ell\)-adic components \(X_\ell\) are algebraic integers.

b) An object \(C \in D_{\mathcal{MR}^P}\) is in \(D_{\mathcal{MR}^P}^{\text{eff}}\) if \(H^i_t(C) \in \mathcal{MR}^{P,\text{eff}}\) for all \(i \in \mathbb{Z}\), where \(H^i_t\) is the homology respective to the canonical \(t\)-structure of \(D_{\mathcal{MR}^P}\).

In this way, the above functor refines to

\[ D^b(\mathcal{MR}^{P,\text{eff}}) \to D_{\mathcal{MR}^P}^{\text{eff}}. \]

By Remark E.21.3 and [47, Prop. 11.1.5] (adapted to \(\mathcal{MR}^P\)), \(\mathcal{MR}^P\) and \(D_{\mathcal{MR}^P}\) enjoy weights filtrations in the sense of Definitions E.7.2 and E.17.1, which are compatible in the sense of Proposition E.21.2. Moreover, the categories of pure weights \(\mathcal{MR}^P_n\) are semi-simple [47, Prop. 21.1.2], which is the main point of passing from \(\mathcal{MR}\) to \(\mathcal{MR}^P\). These weight filtrations induce compatible weight filtrations on \(\mathcal{B} = \mathcal{MR}^{P,\text{eff}}\) and \(\mathcal{T} = D_{\mathcal{MR}^P}^{\text{eff}}\). We take for \(\mathcal{B}_L\) the full subcategory of \(\mathcal{MR}^P\) consisting of objects of the form \(R_{\mathcal{MR}^P}(A \otimes \mathbf{T})\), where \(A\) is a (pure) Artin motive and \(\mathbf{T}\) is the Tate motive. Here \(R_{\mathcal{MR}^P}\) is the
functor defined in [47, Th. 20.2.3] on Chow motives: in *loc. cit.* it takes values in \( \mathcal{MR} \) but its essential image actually lands into \( \mathcal{MR}^P \).

With the notation of §15.3, \( \mathcal{B}_{(1)} = \mathcal{MR}^P_{(1)} \) is the full subcategory of \( \mathcal{MR}^P_{\text{eff}} \) of objects \( X \) such that the possibly non zero Hodge numbers of \( X_{\text{DR}} \) are in the set \( \{(0,0), (0,-1), (-1,0), (-1,-1)\} \). (Indeed, this condition forces the relevant conditions on the \( \ell \)-adic components.)

We have seen that the full subcategory \( \mathcal{MR}^P_{-2} \) of pure objects of weight \(-2\) is semi-simple. As a special case of Proposition 15.3.4, we therefore have:

18.1.2. **Proposition.** The full embeddings \( \iota : \mathcal{MR}^P_{(1)} \to \mathcal{MR}^P_{\text{eff}} \) and \( \iota : (D^\text{eff}_{\mathcal{MR}^P})_{(1)} \to D^\text{eff}_{\mathcal{MR}^P} \) have left adjoints \( \text{Alb}^\mathcal{MR}^P \) and \( \text{LAlb}^\mathcal{MR}^P \). \( \square \)

18.1.3. **Notation.** For simplicity we shall write \( (\_ \leq 1) \) for \( \text{Alb}^\mathcal{MR}^P \).

We shall need the following lemma:

18.1.4. **Lemma.** Let \( X \) be smooth projective over \( k \). Then the map

\[
\text{Pic}(X) \otimes \mathbb{Q} \to \text{Hom}_{\mathcal{MR}^P}(\mathbb{Q}, H^2_{\mathcal{MR}^P}(X)(1))
\]

given by the realisation functor \( R_{\mathcal{MR}^P} \) induces an isomorphism

\[
\text{NS}(X) \otimes \mathbb{Q} \sim \text{Hom}_{\mathcal{MR}^P}(\mathbb{Q}, H^2_{\mathcal{MR}^P}(X)(1)).
\]

**Proof.** Clearly the given map factors through \( \text{NS}(X) \otimes \mathbb{Q} \), since all its components do, and the resulting map is injective because its Betti components are. To prove surjectivity, choose an embedding \( \sigma : \overline{k} \to \mathbb{C} \). For any finite extension \( E/k \) we have a commutative diagram

\[
\begin{array}{ccc}
\text{NS}(X_E) \otimes \mathbb{Q} & \longrightarrow & \text{Hom}_{\mathcal{MR}^P(E)}(\mathbb{Q}, H^2_{\mathcal{MR}^P(E)}(X_E)(1)) \\
\downarrow & & \downarrow \sigma_{|E} \\
\text{NS}(\overline{X}) \otimes \mathbb{Q} & \longrightarrow & H^2_{\text{Hodge}}(X_{\mathbb{C}}, \mathbb{Q}(1))^{(1,1)}
\end{array}
\]

in which all maps are injective \( (\overline{X} = X \otimes_k \overline{k}) \). The bottom row is an isomorphism by the \((1,1)\) theorem and the isomorphism \( \text{NS}(X) \otimes \mathbb{Q} \sim \text{NS}(X_{\mathbb{C}}) \otimes \mathbb{Q} \). Passing to the limit, we get a commutative diagram

\[
\begin{array}{ccc}
\text{NS}(\overline{X}) \otimes \mathbb{Q} & \longrightarrow & \varinjlim_{E} \text{Hom}_{\mathcal{MR}^P(E)}(\mathbb{Q}, H^2_{\mathcal{MR}^P(E)}(X_E)(1)) \\
\| & & \| \\
\text{NS}(\overline{X}) \otimes \mathbb{Q} & \sim & H^2_{\text{Hodge}}(X_{\mathbb{C}}, \mathbb{Q}(1))^{(1,1)}
\end{array}
\]
of injections, which forces the top horizontal map to be bijective. To conclude, we use the commutative diagram

\[
\begin{array}{ccc}
\text{NS}(X) \otimes \mathbb{Q} & \longrightarrow & \text{Hom}_{\mathcal{MR}^P}(\mathbb{Q}, H^2_{\mathcal{MR}^P}(X)(1)) \\
\downarrow i & & \downarrow i \\
(\text{NS}(X) \otimes \mathbb{Q})^{G_k} & \longrightarrow & \lim_{\rightarrow E} \text{Hom}_{\mathcal{MR}^P(E)}(\mathbb{Q}, H^2_{\mathcal{MR}^P(E)}(X_E)(1))^{G_k}
\end{array}
\]

where the vertical maps are isomorphisms by the usual transfer argument. □

18.2. Huber’s mixed realisation functor. In [49, Th. 2.3.3 and following remark], Annette Huber defines a (contravariant) realisation functor:

\[ R_{\mathcal{MR}^P} : \text{DM}_{\text{gm}}(k, \mathbb{Q})^{\text{op}} \rightarrow \text{D}_{\mathcal{MR}^P}. \]

The categories \( \mathcal{MR}^P \) and \( \text{D}_{\mathcal{MR}^P} \) carry a duality. As in the previous section, we define a covariant realisation functor

\[ R^{\mathcal{MR}^P} : \text{DM}_{\text{gm}}(k, \mathbb{Q}) \rightarrow \text{D}_{\mathcal{MR}^P} \]

as the composite of \( R_{\mathcal{MR}^P} \) with this duality. This induces a functor

\[ R^{\mathcal{MR}^P} : \text{DM}_{\text{eff}}^{\text{gm}}(k, \mathbb{Q}) \rightarrow \text{D}_{\text{eff}}^{\mathcal{MR}^P}. \]

Since \( R_{\mathcal{MR}^P} \Phi : \text{Chow}_{\text{eff}} \otimes \mathbb{Q} \rightarrow \text{D}_{\mathcal{MR}^P} \) is by construction isomorphic to the mixed realisation fonctor \( X \mapsto R_{\mathcal{MR}^P}(X) \) collecting all individual realisations of \( X \) with their comparison isomorphisms [47, Th. 20.2.3], the conditions of Hypothesis 15.4.1 are verified, as well as Condition (W) of Proposition 15.4.2. This proposition then shows that \( R^{\mathcal{MR}^P} \) Tot defines an exact functor

\[ R^{\mathcal{MR}^P}_{1} : \mathcal{M}_1(k) \otimes \mathbb{Q} \rightarrow \mathcal{MR}^P_{(1)}. \]

18.3. Deligne’s conjecture. From Theorem 17.2.1 and (15.4) we get, for any \( M \in \text{DM}_{\text{gm}}^{\text{eff}}(k) \otimes \mathbb{Q} \), a natural map

\[ R^{\mathcal{MR}^P}(M)_{\leq 1} \rightarrow R^{\mathcal{MR}^P}_{1} \text{LAlb}(M). \]

Taking homology of both sides, we get comparison maps

\[ H_i(R^{\mathcal{MR}^P}(M))_{\leq 1} \rightarrow R^{\mathcal{MR}^P}_{1} \text{L}_{i}\text{Alb}(M) \]

for all \( i \in \mathbb{Z} \). From Theorem 15.5.5 and Lemma 18.1.4, we now get:

18.3.1. Theorem. The maps (18.1) and (18.2) are isomorphisms for all motives \( M \). □
Let us develop this theorem in view of the definition of $\mathcal{MR}^P$. For this, we shall write $R^\ell$, $R^{DR}$, $R^\sigma$ for the $\ell$-adic, de Rham and (relative to $\sigma$) Betti components of $R^{\mathcal{MR}^P}$, and similarly $R^1\%$, $H^i\% = H_i \circ R^1\%$ ($\% \in \{DR, \ell, \sigma\}$).

18.3.2. Corollary. Let $M \in \text{DM}_\text{eff}^\text{gm}(k, \mathbb{Q})$. Then:

a) One has isomorphisms

\[
H^\ell_i(M) \leq 1 \xrightarrow{\sim} R^\ell_1 L_i \text{Alb}(M) \\
H^{DR}_i(M) \leq 1 \xrightarrow{\sim} R^{DR}_1 L_i \text{Alb}(M) \\
H^\sigma_i(M) \leq 1 \xrightarrow{\sim} R^\sigma_1 L_i \text{Alb}(M).
\]

The last two isomorphisms yield the isomorphism of Hodge structures from Theorem 17.3.1, and the first one is an isomorphism of constructible Galois representations with weight filtrations.

b) The diagrams

\[
\begin{array}{cc}
H^\ell_i(M) \leq 1 \otimes \mathbb{Q}_\ell & \xrightarrow{\sim} R^\ell_1 L_i \text{Alb}(M) \otimes \mathbb{Q}_\ell \\
\downarrow \scriptstyle I_{\ell, \sigma}^{-1} \circ I_{\sigma, \ell} & \downarrow \scriptstyle I_{\ell, \sigma}^{-1} \circ I_{\sigma, \ell} \\
H^{DR}_i(M) \leq 1 \otimes \mathbb{C} & \xrightarrow{\sim} R^{DR}_1 L_i \text{Alb}(M) \otimes \mathbb{C} \\
\downarrow \scriptstyle I_{DR, \sigma}^{-1} \circ I_{\sigma, \ell} & \downarrow \scriptstyle I_{DR, \sigma}^{-1} \circ I_{\sigma, \ell} \\
H^\sigma_i(M) \leq 1 \otimes_k \mathbb{C} & \xrightarrow{\sim} R^\sigma_1 L_i \text{Alb}(M) \otimes_k \mathbb{C}
\end{array}
\]

commute.

Corollary 18.3.2 partly extends to $\text{DM}_\text{gm}^\text{eff}(\mathbb{C}, \mathbb{Q})$. On the one hand, one has

\[
2 - \lim_{\mathbb{Q}_f.g.} \text{DM}_\text{gm}^\text{eff}(k, \mathbb{Q}) \xrightarrow{\sim} \text{DM}_\text{gm}^\text{eff}(\mathbb{C}, \mathbb{Q})
\]

by [51, Prop. 4.16]. On the other hand, de Rham cohomology commutes with base change and $\ell$-adic cohomology is invariant under algebraically closed extensions. This yields:

18.3.3. Corollary. Let $M \in \text{DM}_\text{gm}^\text{eff}(\mathbb{C}, \mathbb{Q})$. Then:

a) The comparison isomorphisms extend to comparison isomorphisms of realisations:

\[
R^B(M) \otimes \mathbb{Q}_\ell \xrightarrow{I_{\ell}} R^\ell(M) \\
R^B(M) \otimes \mathbb{C} \xrightarrow{I_{DR}} R^{DR}(M).
\]
b) There exist vector spaces

\[ H^\ell_i(M)_{\leq 1}, H^{\text{DR}}_i(M)_{\leq 1}, H^B_i(M)_{\leq 1} \]

quotients of the \( \ell \)-adic, de Rham and Betti realisations of \( M \), and functorially attached to \( M \).

c) One has isomorphisms

\[
H^\ell_i(M)_{\leq 1} \sim \to R^\ell_1 L_i \text{Alb}(M) \\
H^{\text{DR}}_i(M)_{\leq 1} \sim \to R^{\text{DR}}_1 L_i \text{Alb}(M) \\
H^B_i(M)_{\leq 1} \sim \to R^\sigma_1 L_i \text{Alb}(M).
\]

The last two isomorphisms yield the isomorphism of Hodge structures from Theorem 17.3.1.

d) The diagrams

\[
H^B_i(M)_{\leq 1} \otimes_{\mathbb{Q}} \mathbb{Q}_\ell \sim \to R^B_1 L_i \text{Alb}(M) \otimes_{\mathbb{Q}} \mathbb{Q}_\ell \\
\downarrow \quad \quad \downarrow
\]

\[
H^\ell_i(M)_{\leq 1} \sim \to R^\ell_1 L_i \text{Alb}(M) \\
\downarrow \quad \quad \downarrow
\]

\[
H^{\text{DR}}_i(M)_{\leq 1} \otimes_{\mathbb{Q}} \mathbb{C} \sim \to R^{\text{DR}}_1 L_i \text{Alb}(M) \otimes_{\mathbb{Q}} \mathbb{C} \\
\downarrow \quad \quad \downarrow
\]

\[
H^{\text{DR}}_i(M)_{\leq 1} \sim \to R^{\text{DR}}_1 L_i \text{Alb}(M)
\]

commute.

Applied to geometric motives like \( M(X) \) or \( M(X)^*(n)[2n] \), this gives a reasonable interpretation of the second part of Deligne’s conjecture.

19. THE \( \ell \)-ADIC REALISATION IN POSITIVE CHARACTERISTIC

In this section, \( k \) is a finitely generated field and \( \ell \) is a prime number different from \( \text{char } k \). From §19.3 onwards, we shall assume \( \text{char } k > 0 \) and \( \ell \neq 2 \).

19.1. The tame derived category of \( \ell \)-adic sheaves. We shall use an analogue of the categories considered by Huber [48]. Namely,

19.1.1. Definition. Let

\[
\widetilde{D}(k, \mathbb{Z}_\ell) := 2 - \lim D(S, \mathbb{Z}_\ell)
\]

where \( S \) runs through the regular models of \( k \), of finite type over \( \text{Spec } \mathbb{Z} \), and for such \( S \), \( D(S, \mathbb{Z}_\ell) \) is the category defined by Ekedahl in [39], for the étale topos of \( S \). Let

\[
\widetilde{D}^b_c(k, \mathbb{Z}_\ell) := 2 - \lim D^b_c(S, \mathbb{Z}_\ell)
\]
where $D^b_c(S, \mathbb{Z}_\ell)$ is the thick subcategory of $D(S, \mathbb{Z}_\ell)$ consisting of those complexes whose cohomology sheaves are constructible. Finally, 

$$\tilde{D}^b_m(k, \mathbb{Q}_\ell) := 2 - \lim_{\rightarrow} D^b_m(S, \mathbb{Q}_\ell)$$

where $D^b_m(S, \mathbb{Q}_\ell)$ is the thick subcategory of $D^b_c(S, \mathbb{Q}_\ell)$ consisting of those complexes whose cohomology sheaves are mixed in the sense of [34, (1.2.2)].

Recall [39, Thm. 4.7] where the following pairings are constructed

$$(19.1) \quad \otimes : D^-(S, \mathbb{Z}_\ell) \times D(S, \mathbb{Z}_\ell) \to D(S, \mathbb{Z}_\ell)$$

$$(19.2) \quad \otimes : \tilde{D}^-(k, \mathbb{Z}_\ell) \times \tilde{D}(k, \mathbb{Z}_\ell) \to \tilde{D}(k, \mathbb{Z}_\ell)$$

From these we get similar pairings

$$(19.1) \quad \mathrm{RHom} : D(S, \mathbb{Z}_\ell)^{\mathrm{op}} \times D^+(S, \mathbb{Z}_\ell) \to D(S, \mathbb{Z}_\ell)$$

$$(19.2) \quad \mathrm{RHom} : \tilde{D}(k, \mathbb{Z}_\ell)^{\mathrm{op}} \times \tilde{D}^+(k, \mathbb{Z}_\ell) \to \tilde{D}(k, \mathbb{Z}_\ell)$$

19.1.2. **Remark.** By Deligne’s finiteness theorems in étale cohomology [SGA4 1/2, Th. finitude], the categories $D^b_c(S, \mathbb{Z}_\ell)$ and $D^b_m(S, \mathbb{Z}_\ell)$ are equivalent to those considered in [14].

The category $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$ enjoys a $t$-structure which is the 2-colimit of the natural $t$-structures of $D^b_m(S, \mathbb{Q}_\ell)$, with hearts the categories $\text{Mix}(S, \mathbb{Q}_\ell)$ of mixed $\mathbb{Q}_\ell$-sheaves on $S$.

19.1.3. **Definition.** We write $\text{Mix}(k, \mathbb{Q}_\ell)$ for the 2-colimit of the $\text{Mix}(S, \mathbb{Q}_\ell)$: this is the heart of $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$.

19.1.4. **Remarks.** 1) For any mixed sheaf $F$ on $S$, the restriction of $F$ to a suitable open set is lisse, and if $F$ and $G$ are lisse over $S$, the map

$$\text{Hom}_S(F, G) \to \text{Hom}_U(F, G)$$

is bijective for any open subset $U \subseteq S$, as one sees by interpreting $F$ and $G$ as $\ell$-adic representations of $\pi_1(S)$ [SGA5, VI]. Hence the functor

$$2 - \lim \text{Mix}(S, \mathbb{Q}_\ell) \to \text{Mix}(k, \mathbb{Q}_\ell)$$

is fully faithful, and objects of $\text{Mix}(k, \mathbb{Q}_\ell)$ may be identified with “generically unramified” $\ell$-adic representations of $G_k$, the absolute Galois group of $k$.

2) Let $\text{Perv}(S, \mathbb{Q}_\ell)$ be the category of perverse sheaves over $S$, for the middle perversity. By definition of perverse sheaves, we also have an equivalence

$$2 - \lim \text{Perv}(S, \mathbb{Q}_\ell) \sim \text{Mix}(k, \mathbb{Q}_\ell)[\dim S]$$
inside $\tilde{D}_m^b(k, Q_\ell)$.

3) The definition of $D^-(S, \mathbb{Z}_\ell)$ yields canonical $t$-exact functors

$$D^b(\text{Mix}(S, Q_\ell)) \to D^b_m(S, Q_\ell)$$

hence a canonical $t$-exact functor

$$D^b(\text{Mix}(k, Q_\ell)) \to \tilde{D}_m^b(k, Q_\ell)$$

which is the identity on the hearts.

19.2. DM and DA over a base. Let $S$ be Noetherian and separated. For $R$ a commutative ring, let $\text{NST}(S, R)$ (resp. $\text{EST}(S, R)$) be the category of Nisnevich (resp. étale) sheaves of $R$-modules with transfers over $S$ (using the category $\text{Cor}_S$ of [70, App. 1A]). If $R = \mathbb{Z}$ we drop it from the notation. Then $\text{EST}(S, R)$ is a full subcategory of $\text{NST}(S, R)$ which contains the representable sheaves $\mathbb{Z}_\text{tr}(X)$ for $X$ smooth over $S$. A tensor structure on $\text{EST}(S, R)$ and $\text{NST}(S, R)$ is induced by the rule $\mathbb{Z}_\text{tr}(X) \otimes \mathbb{Z}_\text{tr}(Y) = \mathbb{Z}_\text{tr}(X \times_S Y)$.

Recall that over the base $S$ the category $\text{DM}^\text{eff}(S, R)$ has the same descriptions as done in [96] or [70, Lect. 14] over a field: see [98]. Namely, it may be defined as the localisation of the (unbounded) derived category of Nisnevich sheaves with transfers with respect to $\mathbb{A}^1$-equivalences. Moreover, this localisation functor has a right adjoint so that it may be regarded as the full subcategory of $\mathbb{A}^1$-local objects, cf. [7, 2.2.6].

The same picture works for étale sheaves with transfers, at least if $\text{cd}_R(S) < \infty$: let

$$L_{\mathbb{A}^1} : D(\text{EST}(S, R)) \to \text{DM}^\text{eff}_{\text{ét}}(S, R)$$

be the localisation of $D(\text{EST}(S, R))$ with respect to $\mathbb{A}^1$-equivalences. Then $L_{\mathbb{A}^1}$ has a fully faithful right adjoint $i$, identifying $\text{DM}^\text{eff}_{\text{ét}}(S, R)$ with the full subcategory of $\mathbb{A}^1$-local objects in $D(\text{EST}(S, R))$.

Moreover, there are non-effective versions of these categories

$$\text{DM}^\text{eff}(S, R) \to \text{DM}(S, R), \quad \text{DM}^\text{eff}_{\text{ét}}(S, R) \to \text{DM}_{\text{ét}}(S, R)$$

obtained by stabilising with respect to tensor product with $\mathbb{Z}_\text{tr}(\mathbb{G}_m, 1)$, cf. [29, §10].

In the next subsection we shall need a version without transfers. Let $\text{NSh}(S, R)$ and $\text{ESH}(S, R)$ be the categories of Nisnevich (resp. étale) sheaves of $R$-modules over $\text{Sm}(S)$. One constructs triangulated categories $\text{DA}(S, R)$ and $\text{DA}_{\text{ét}}(S, R)$, based on $\text{NSh}(S, R)$ and $\text{ESH}(S, R)$, in the same fashion as above, see [5, §3].

The forgetful functors $\text{NST}(S, R) \to \text{NSh}(S, R)$ and $\text{EST}(S, R) \to \text{ESH}(S, R)$ have left adjoints which respect the tensor structures. This
yields a naturally commutative diagram of triangulated \(\otimes\)-functors:

\[
\begin{array}{ccc}
DA(S, R) & \longrightarrow & DM(S, R) \\
\downarrow & & \downarrow \\
DA_{\text{\acute{e}t}}(S, R) & \longrightarrow & DM_{\text{\acute{e}t}}(S, R).
\end{array}
\]

Ayoub proves in [5, Th. B.1]:

19.2.1. **Theorem.** The bottom horizontal functor in (19.3) is an equivalence of categories if \(S\) is normal and universally Japanese and any prime number is invertible either in \(R\) or in \(O_S\).

19.3. **\(\ell\)-adic realisations for \(DA\) and \(DM\).** Let \(S\) be separated of finite type over \(\text{Spec } \mathbb{Z}\). For \(\ell \neq 2\) invertible on \(S\), Ayoub constructs a triangulated \(\otimes\)-functor

\[
DA_{\text{\acute{e}t}}(S, \mathbb{Z}(\ell)) \longrightarrow D(S, \mathbb{Z}_\ell)
\]

which commutes with the six operations [5, Th. 7.9].

If \(S\) is a smooth \(\mathbb{F}_p\)-scheme, \(p \neq \ell\), we can take \(R = \mathbb{Z}(\ell)\) in Theorem 19.2.1. In this way we get a \(\otimes\)-functor

\[
DM_{\text{\acute{e}t}}(S, \mathbb{Z}(\ell)) \longrightarrow D(S, \mathbb{Z}_\ell)
\]

hence a composite realisation functor

\[
R^\ell : DM(S) \rightarrow DM_{\text{\acute{e}t}}(S) \rightarrow DM_{\text{\acute{e}t}}(S, \mathbb{Z}(\ell)) \rightarrow D(S, \mathbb{Z}_\ell)
\]

The construction of (19.4) relies on a generalisation of the Suslin-Voevodsky rigidity theorem of [93]; using this, one sees that given a smooth \(S\)-scheme \(f : X \rightarrow S\), one has a canonical isomorphism

\[
R^\ell M_S(X) \simeq (Rf_* \mathbb{Z}_\ell)^*
\]

where \(M_S(X)\) is the motive of \(X\), defined as the image in \(DM(S)\) of \(\mathbb{Z}_{\text{tr}}(X)\). Another way to get this is to use [5, Prop. 5.9], which relates \(R^\ell\) with Ivorra’s (contravariant) realisation functor [51].

Recall the category \(\text{DM}_{\text{gm}}^\text{eff}(S)\), constructed over a base exactly as over a field except that the Mayer-Vietoris relations for the Zariski topology are replaced by Nisnevich excision relations [51, Def. 1.14]. In [52], Ivorra also constructs a functor \(\text{DM}_{\text{gm}}^\text{eff}(S) \rightarrow \text{DM}_{\text{Nis}}^\text{eff}(S)\) extending Voevodsky’s functor for base fields. Using it, we can restrict \(R^\ell\) to \(\text{DM}_{\text{gm}}^\text{eff}(S)\).

By construction, \(R^\ell\) commutes with pull-backs for arbitrary morphisms. By [51, Prop. 4.16], if \(S\) runs through the smooth models of \(k\) over \(\mathbb{F}_p\), the natural functor

\[
2 - \lim_{\longleftarrow} \text{DM}_{\text{gm}}^\text{eff}(S) \rightarrow \text{DM}_{\text{gm}}^\text{eff}(k)
\]
is an equivalence of categories; hence the $R_S^\ell$ induce a triangulated functor

$$\tilde{R}^\ell : \text{DM}_{\text{gm}}^\text{eff}(k) \to \tilde{D}(k, \mathbb{Z}_\ell).$$

19.4. **Weights and niveaux.** By definition of a mixed sheaf, we can define a filtration $(\text{Mix}(k, \mathbb{Q}_\ell)_{\leq n})_{n \in \mathbb{Z}}$ on $\text{Mix}(k, \mathbb{Q}_\ell)$ in the sense of Definition E.7.1 as follows: $\mathcal{F} \in \text{Mix}(k, \mathbb{Q}_\ell)$ is in $\text{Mix}(k, \mathbb{Q}_\ell)_{\leq n}$ if and only if its punctual weights (on a suitable model of $k$) are all $\leq n$. This filtration is clearly exhaustive and separated. 14

By Remarks 19.1.2 and 19.1.4 and by [34, (3.4.1)], the category $\text{Mix}(k, \mathbb{Q}_\ell)$ of Definition 19.1.3 then enjoys a good theory of weights. Namely:

19.4.1. **Proposition.** Suppose $\text{char } k > 0$.

a) The filtration $\text{Mix}(k, \mathbb{Q}_\ell)_{\leq n}$ provides $\text{Mix}(k, \mathbb{Q}_\ell)$ with a weight filtration in the sense of Definition E.7.2.

b) The categories $\text{Mix}(k, \mathbb{Q}_\ell)_n$ of objects of pure weight $n$ are semi-simple.

**Proof.** a) Consider the filtration $W_n$ defined on mixed sheaves by [34, (3.4.1) (ii)]. By Remark E.7.8, it suffices to know that the $W_n$ are exact, exhaustive and separated. The last two facts are clear, and the first follows from the strict compatibility with morphisms. b) follows from [34, (3.4.1) (iii)].

The weight filtration we shall need on $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$ is not the one considered in [14] and [48], but rather the one in Definition E.21.1, which coincides with the one introduced by S. Morel in [73, §3.1]:

19.4.2. **Definition.** An object $C \in \tilde{D}^b_m(k, \mathbb{Q}_\ell)$ is of weight $\leq w$ if the weights of $H^i(C)$ are $\leq w$ for all $i \in \mathbb{Z}$ (compare Remark 19.1.4 2)).

We also need a notion of effectivity:

19.4.3. **Definition.** a) An object $\mathcal{F} \in \text{Mix}(k, \mathbb{Q}_\ell)$ is effective if the eigenvalues of arithmetic Frobenius elements acting on the stalk(s) of (a finite level representative of) $\mathcal{F}$ are algebraic integers. We denote by $\text{Mix}(k, \mathbb{Q}_\ell)_{\text{eff}}$ their full subcategory.

b) We denote by $\tilde{D}^b_m(k, \mathbb{Q}_\ell)_{\text{eff}}$ the full subcategory of $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$ consisting of objects with cohomology in $\text{Mix}(k, \mathbb{Q}_\ell)_{\text{eff}}$.

14This is not a weight filtration if $\text{char } k = 0$: this fact was pointed out by J. Wildeshaus. More precisely, the inclusions

$$\iota_n : \text{Mix}(k, \mathbb{Q}_\ell)_{\leq n} \hookrightarrow \text{Mix}(k, \mathbb{Q}_\ell)_{\leq n+1}$$

do not have right adjoints: see [53, p. 90, Remark 6.8.4 i)].
Clearly, the abelian category $\text{Mix}(k, \mathbb{Q}_\ell)^{\text{eff}}$ is thick in $\text{Mix}(k, \mathbb{Q}_\ell)$, hence $\tilde{D}^b_m(k, \mathbb{Q}_\ell)^{\text{eff}}$ is a thick triangulated subcategory of $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$, with heart $\text{Mix}(k, \mathbb{Q}_\ell)^{\text{eff}}$.

19.4.4. Proposition. $\tilde{R}^\ell$ verifies Hypotheses 15.4.1 and 15.5.2.

Proof. We first prove that $\tilde{R}^\ell$ maps $\text{DM}_{\text{gm}}^{\text{eff}}(k) \otimes \mathbb{Q}$ into $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$ (this much does not need characteristic $p$). It suffices to prove that for any smooth model $S$ of $k$, $R^\ell$ maps $\text{DM}_{\text{gm}}^{\text{eff}}(S) \otimes \mathbb{Q}$ into $D^b_m(S, \mathbb{Q}_\ell)$: this follows from (19.5) plus Deligne’s finiteness theorem [SGA4 1/2, Th. finitude].

The fact that $\tilde{R}^\ell(\text{DM}_{\text{gm}}^{\text{eff}}(k) \otimes \mathbb{Q}) \subset \tilde{D}^b_m(k, \mathbb{Q}_\ell)^{\text{eff}}$ now follows from [SGA7, Exp. XXI, (5.2.2)] which says that the eigenvalues of the geometric Frobenius acting on $\ell$-adic cohomology with compact supports are algebraic integers.

The rest of the properties follow from the standard properties of $\ell$-adic cohomology, plus the Riemann hypothesis [33]. □

19.5. Sheaves of level $\leq 1$.

19.5.1. Definition. Let $\mathcal{F} \in \text{Mix}(k, \mathbb{Q}_\ell)$. We say that $\mathcal{F}$ is of level $\leq 1$ if

- $\mathcal{F}$ is effective (Def. 19.4.3) and its weights are in $\{0, -1, -2\}$ (Def. 19.4.2);
- $W_{-2}\mathcal{F}(-1)$ is effective.

We write $\text{Mix}(k, \mathbb{Q}_\ell)(1)$ for the full subcategory of $\text{Mix}(k, \mathbb{Q}_\ell)^{\text{eff}}$ consisting of objects of level $\leq 1$, and $\tilde{D}^b_m(k, \mathbb{Q}_\ell)(1)$ the full subcategory of $\tilde{D}^b_m(k, \mathbb{Q}_\ell)$ consisting of objects with cohomology in $\text{Mix}(k, \mathbb{Q}_\ell)(1)$.

Note that this coincides with the definitions in §15.3, with $\text{Mix}(k, \mathbb{Q}_\ell)_L = \{\mathcal{F}(1) \mid \mathcal{F} \text{ effective of weight } 0\}$. In particular, $\tilde{D}^b_m(k, \mathbb{Q}_\ell)(1)$ is a thick triangulated $t$-subcategory of $\tilde{D}^b_m(k, \mathbb{Q}_\ell)^{\text{eff}}$ with heart $\text{Mix}(k, \mathbb{Q}_\ell)(1)$. Moreover, as a special case of Proposition 15.3.4, we have:

19.5.2. Proposition. The full embeddings $\text{Mix}(k, \mathbb{Q}_\ell)(1) \hookrightarrow \text{Mix}(k, \mathbb{Q}_\ell)^{\text{eff}}$ and $D^b(k, \mathbb{Q}_\ell)(1) \hookrightarrow D^b(k, \mathbb{Q}_\ell)^{\text{eff}}$ have left adjoints $\text{Alb}^\ell$ and $\text{LAlb}^\ell$. □

19.6. Derived realisation for 1-motives. To get the correct derived realisation for 1-motives, we start from Deligne’s $\ell$-adic realisation for smooth 1-motives over a base $S$ [32, (10.1.10)]:

$$T_\ell(S) : \mathcal{M}_1(S) \otimes \mathbb{Q} \to \text{Mix}(S, \mathbb{Q}_\ell).$$
For $S$ running through smooth models of $k$ over $\mathbb{F}_p$, the $T_\ell(S)$ induce an exact functor

$$T_\ell : \mathcal{M}_1(k) \otimes \mathbb{Q} \to \text{Mix}(k, \mathbb{Q}_\ell).$$

Deligne’s description of $T_\ell(S)$ shows that, in fact, $T_\ell$ takes its values in $\text{Mix}(k, \mathbb{Q}_\ell)_{(1)}$. From the definition of $T_\ell$, we get immediately:

19.6.1. **Theorem.** Let $T_\ell$ still denote the trivial extension of $T_\ell$ to a $t$-exact functor $D^b(\mathcal{M}_1(k) \otimes \mathbb{Q}) \to \widetilde{D}_m^b(k, \mathbb{Q}_\ell)$ (via Remark 19.1.4 3)). Then there is a canonical isomorphism $u : T_\ell \xrightarrow{\sim} \tilde{R}_\ell \circ \text{Tot}$. □

19.7. **An $\ell$-adic version of Deligne’s conjecture.** From the above we get, for any $M \in D^\text{eff}_{\text{gm}}(k, \mathbb{Q})$, the base change morphism (15.4):

$$(19.6)\quad \tilde{R}_\ell(M)_{\leq 1} \to T_\ell \text{LAlb}(M).$$

Taking homology of both sides, we get comparison maps

$$(19.7)\quad H_i(\tilde{R}_\ell(M))_{\leq 1} \to T_\ell \text{L}_i \text{Alb}(M)$$

for all $i \in \mathbb{Z}$.

Applying Theorem 15.5.5 and the Tate-Zarhin theorem for endomorphisms of abelian varieties, we get:

19.7.1. **Theorem.**

(i) If $X$ is smooth and projective, then (19.7) is an isomorphism for all $i \neq 2$; for $i = 2$, it is an isomorphism if and only if the Tate conjecture holds in codimension 1 for $X$.

(ii) The map (19.6) is an isomorphism for motives $M$ of abelian type.

(iii) For a general $M$, (19.6) induces an isomorphism after applying the functor $Q \mapsto \text{cone}(W_{-2}Q \to Q)$. □

Using the 4 operations one can define the motive and motive with compact support of schemes of finite type over $k$, cf. [58, §6.7]. Modulo the Tate conjecture in codimension 1, we then get the same corollaries as in Cor. 17.3.2.
Appendices

APPENDIX A. HOMOLOGICAL ALGEBRA

A.1. **Some comparison lemmas.** The following lemma is probably well-known:

**A.1.1. Lemma.** Let $T : \mathcal{T} \to \mathcal{T}'$ be a full triangulated functor between two triangulated categories. Then $T$ is conservative if and only if it is faithful.

*Proof.* “If” is obvious. For “only if”, let $f : X \to X'$ be a morphism of $\mathcal{T}$ such that $T(f) = 0$. Let $g : X' \to X''$ denote a cone of $f$. Then $T(g)$ has a retraction $\rho$. Applying fullness, we get an equality $\rho = T(r)$. Applying conservativity, $u = rg$ is an isomorphism. Then $r' = u^{-1}r$ is a retraction of $g$, which implies that $f = 0$. □

**A.1.2. Proposition.** a) Let $i : E \hookrightarrow A$ be an exact full sub-category of an abelian category $A$, closed under kernels. Assume further that for each $A' \in \mathcal{C}^b(A)$ there exists $E' \in \mathcal{C}^b(E)$ and a quasi-isomorphism $i(E') \to A'$ in $K^b(A)$. Then $i : D^b(E) \to D^b(A)$ is an equivalence of categories.

b) The hypothesis of a) is granted when every object in $A$ has a finite left resolution by objects in $E$.

*Proof.* a) Clearly, the functor $D^b(E) \to D^b(A)$ is conservative. The assumption implies that $i$ is essentially surjective: thanks to Lemma A.1.1, in order to conclude it remains to see that $i$ is full.

Let $f \in D^b(A)(i(D'), i(E'))$. Since $D^b(A)$ has left calculus of fractions there exists a quasi-isomorphism $s$ such that $f = f's^{-1}$ where $f' : A' \to i(E')$ is a map in $K^b(A)$, which then lifts to a map in $C^b(A)$. By hypothesis there exists $F' \in C^b(E)$ and a quasi-isomorphism $s' : i(F') \to A'$. Set $f'' := f's' : i(F') \to i(E')$. Then $f = f''(ss')^{-1}$ where $ss' : i(F') \to i(D')$ is a quasi-isomorphism. By conservativity of $i$, we are reduced to check fullness for effective maps, i.e. arising from true maps in $C^b(A)$: this easily follows from the fullness of the functor $C^b(E) \hookrightarrow C^b(A)$.

b) This follows by adapting the argument in [46, I, Lemma 4.6]. □

**A.1.3. Proposition.** Let $E \hookrightarrow A$ be an exact category. Let $D$ be a triangulated category and let $T : D^b(E) \to D$ be a triangulated functor such that

$$\text{Hom}_{D^b(E)}(E', E[i]) \xrightarrow{\cong} \text{Hom}_{D}(T(E'), T(E[i]))$$
for all $E', E \in E$ and $i \in \mathbb{Z}$. Then $T$ is fully faithful.

**Proof.** Let $C, C' \in C^b(E)$: we want to show that the map

$$\text{Hom}_{D^b(E)}(C, C') \to \text{Hom}_D(T(C), T(C'))$$

is bijective. We argue by induction on the lengths of $C$ and $C'$.

Finally, we have the following very useful criterion for a full embedding of derived categories, that we learned from Pierre Schapira.

**A.1.4. Proposition ([59, p. 329, Th. 13.2.8]).** Let $A \hookrightarrow B$ be an exact full embedding of abelian categories. Assume that, given any monomorphism $X' \hookrightarrow X$ in $B$, with $X' \in A$, there exists a morphism $X \to X''$, with $X'' \in A$, such that the composite morphism $X \to X''$ is a monomorphism. Then the functor

$$D^*(A) \to D^*(B)$$

is fully faithful for $* = +, b$.

**A.2. The Tot construction.**

**A.2.1. Lemma.** Let $A$ be an abelian category and let $A^{[0,1]}$ be the (abelian) category of complexes of length $1$ of objects of $A$. Then the “total complex” functor induces a triangulated functor

$$D^*(A^{[0,1]}) \to D^*(A)$$

for any decoration $*$.

**Proof.** We may consider a complex of objects of $A^{[0,1]}$ as a double complex of objects of $A$ and take the associated total complex. This yields a functor

$$\text{Tot} : C^*(A^{[0,1]}) \to D^*(A).$$

(Note that if we consider a complex of objects of $A^{[0,1]}$

$$M^* = [L^* \xrightarrow{u^*} G^*]$$

as a map $u^* : L^* \to G^*$ of complexes of $A$, then $\text{Tot}(M^*)$ coincides with the cone of $u^*$.)

This functor factors through a triangulated functor from $D^*(A^{[0,1]})$: indeed it is easily checked that a) $\text{Tot}$ preserves homotopies, b) the induced functor on $K^*(A^{[0,1]})$ is triangulated; c) $\text{Tot}$ of an acyclic complex is 0 (which follows from a spectral sequence argument).

**A.2.2. Lemma.** With notation as in Lemma A.2.1, the set of q.i. of $A^{[0,1]}$ enjoys a calculus of left and right fractions within the homotopy category $K(A^{[0,1]})$ (same objects, morphisms modulo the homotopy relation).
Proof. It is enough to show the calculus of right fractions (for left fractions, replace \( A \) by \( A^{op} \)).

a) Let\( \tilde{C} \)
\[
\begin{array}{c}
D \\
\downarrow^u \\
C
\end{array}
\]
be a diagram in \( A^{[0,1]} \), with \( u \) a q.i. Consider the mapping fibre (= shifted mapping cone) \( F \) of the map \( \tilde{C} \oplus D \to C \). The complex \( F \) is in general concentrated in degrees \([0,1,2]\); however, since \( F \to D \) is a q.i., the truncation \( \tau_{<2}F \) is q.i. to \( F \); then \( \tilde{D} = \tau_{<2}F \) fills in the square in \( K(A^{[0,1]}) \).

b) Let \( \begin{bmatrix} C^0 \to C^1 \end{bmatrix} \xrightarrow{f} \begin{bmatrix} D^0 \to D^1 \end{bmatrix} \xrightarrow{u} \begin{bmatrix} \tilde{D}^0 \to \tilde{D}^1 \end{bmatrix} \) be a chain of maps of \( A^{[0,1]} \) such that \( u \) is a q.i. and \( uf \) is homotopic to 0. Let \( s : C^1 \to \tilde{D}^0 \) be a corresponding homotopy. Define \( \tilde{C}^1 \) as the fibre product of \( C^1 \) and \( D^0 \) over \( \tilde{D}^0 \) (via \( s \) and \( u^0 \)), \( \tilde{s} : \tilde{C}^1 \to D^0 \) the corresponding map and \( \tilde{C}^0 \) the fibre product of \( C^0 \) and \( \tilde{C}^1 \) over \( C^1 \). One then checks that \( v : [\tilde{C}^0 \to \tilde{C}^1] \to [C^0 \to C^1] \) is a q.i. and that \( \tilde{s} \) defines a homotopy from \( fv \) to 0. \( \square \)

A.2.3. Remark. One can probably extend these two lemmas to complexes of a fixed length \( n \) by the same arguments: we leave this to the interested reader.

**Appendix B. Torsion objects in additive categories**

B.1. **Additive categories.**

B.1.1. **Definition.** Let \( A \) be an additive category, and let \( A \) be a subring of \( \mathbb{Q} \).

a) We write \( A \otimes A \) for the category with the same objects as \( A \) but morphisms
\[
(A \otimes A)(X,Y) := A(X,Y) \otimes A.
\]

b) We denote by \( A\{A\} \) the full subcategory of \( A \):
\[
\{ X \in A \mid \exists n > 0 \text{ invertible in } A, n1_X = 0 \}.
\]

For \( A = \mathbb{Q} \), we write \( A\{A\} = A_{tors} \). We say that \( X \in A\{A\} \) is an \( A \)-torsion object (a torsion object if \( A = \mathbb{Q} \)).

c) A morphism \( f : X \to Y \) in \( A \) is an \( A \)-isogeny (an isogeny if \( A = \mathbb{Q} \)) if there exists a morphism \( g : Y \to X \) and an integer \( n \) invertible in \( A \) such that \( fg = n1_Y \) and \( gf = n1_X \). We denote by \( \Sigma_A(A) \) the collection
of $A$-isogenies of $A$.

d) We say that two objects $X,Y \in A$ are $A$-isogenous if they can be linked by a chain of $A$-isogenies (not necessarily pointing in the same direction).

B.1.2. Proposition. a) The subcategory $A\{A\}$ is additive and closed under direct summands.
b) The $A$-isogenies $\Sigma_A(A)$ form a multiplicative system of morphisms in $A$, enjoying calculi of left and right fractions. The corresponding localisation of $A$ is isomorphic to $A \otimes A$.

Proof. a) is clear. For b), consider the obvious functor $P : A \rightarrow A \otimes A$. We claim that

$$\Sigma_A(A) = \{ f | P(f) \text{ is invertible} \}$$

One inclusion is clear. Conversely, let $f : X \rightarrow Y$ be such that $P(f)$ is invertible. This means that there exists $\gamma \in (A \otimes A)(Y,X)$ such that $P(f) \gamma = 1_Y$ and $\gamma P(f) = 1_X$. Choose an integer $m \in A - \{0\}$ such that $m \gamma = P(g_1)$ for some $g_1$. Then there is another integer $n \in A - \{0\}$ such that

$$n(fg_1 - m1_Y) = 0 \text{ and } n(g_1f - m1_X) = 0.$$

Taking $g = ng_1$ shows that $f \in \Sigma_A(A)$.

It is also clear that homotheties by nonzero integers of $A$ form a cofinal system in $\Sigma_A(A)$. This shows immediately that we have calculi of left and right fractions.

It remains to show that the induced functor

$$\Sigma_A(A)^{-1}A \rightarrow A \otimes A$$

is an isomorphism of categories; but this is immediate from the well-known formula, in the presence of calculus of fractions:

$$\Sigma_A(A)^{-1}A(X,Y) = \lim_{X \xrightarrow{f} X \in \Sigma} A(X,Y) = \lim_{X \xrightarrow{\gamma} X, n \in A - \{0\}} A(X,Y).$$

\[\square\]

The following lemma is clear.

B.1.3. Lemma. Let $B$ be a full additive subcategory of $A$, and suppose that every object of $B$ is $A$-isogenous to an object of $A$. Then $B \otimes A \xrightarrow{\sim} A \otimes A$.

\[\square\]
B.2. Triangulated categories. (See [83, A.2.1] for a different treatment.)

B.2.1. Proposition. Let $\mathcal{T}$ be a triangulated category. Then
a) The subcategory $\mathcal{T}\{A\}$ is triangulated and thick.

b) Let $X \in \mathcal{T}$ and $n \in A - \{0\}$. Then “the” cone $X/n$ of multiplication by $n$ on $X$ belongs to $\mathcal{T}\{A\}$.

c) The localised category $\mathcal{T}/\mathcal{T}\{A\}$ is canonically isomorphic to $\mathcal{T} \otimes A$. In particular, $\mathcal{T} \otimes A$ is triangulated.

d) A morphism $f$ of $\mathcal{T}$ belongs to $\Sigma_A(\mathcal{T})$ if and only if $cone(f) \in \mathcal{T}\{A\}$.

Proof. a) It is clear that $\mathcal{T}\{A\}$ is stable under direct summands; it remains to see that it is triangulated. Let $X,Y \in \mathcal{T}\{A\}$, $f : X \to Y$ a morphism and $Z$ a cone of $f$. We may assume that $n1_X = n1_Y = 0$. The commutative diagram

\[
\begin{array}{ccc}
Y & \longrightarrow & Z \\
\downarrow \scriptstyle{n=0} & & \downarrow \scriptstyle{n=0} \\
Y & \longrightarrow & Z \\
\end{array}
\]

show that multiplication by $n$ on $Z$ factors through $Y$; this implies that $n^21_Z = 0$.

b) Exactly the same argument as in a) shows that multiplication by $n$ on $X/n$ factors through $X$, hence that $n^21_{X/n} = 0$.

c) Let $f \in \mathcal{T}$ be such that $C := cone(f) \in \mathcal{T}\{A\}$, and let $n > 0$ be such that $n1_C = 0$. The same trick as in a) and b) shows that there exist factorisations $n = ff' = f''f$, hence that $f \in \Sigma_A(\mathcal{T})$. In particular, $f$ becomes invertible under the canonical (additive) functor $\mathcal{T} \to \mathcal{T} \otimes A$. Hence an induced (additive) functor

$\mathcal{T}/\mathcal{T}\{A\} \to \mathcal{T} \otimes A$

which is evidently bijective on objects; b) shows immediately that it is fully faithful.

d) One implication has been seen in the proof of c). For the other, if $f \in \Sigma_A(\mathcal{T})$, then $f$ becomes invertible in $A \otimes A$, hence $cone(f) \in \mathcal{T}\{A\}$ by c).

\[\square\]

B.2.2. Remark. As is well-known, the stable homotopy category gives a counterexample to the expectation that in fact $n1_{X/n} = 0$ in b) ($X = S^0$, $n = 2$).

We now show that $\otimes A$ is a “flat” operation on triangulated categories.
B.2.3. Lemma. Let $0 \to T' \to T \to T'' \to 0$ be a short exact sequence of triangulated categories (by definition, this means that $T'$ is strictly full in $T$, stable under cones and shifts, and that $T''$ is equivalent to $T/T'$). Then the sequence

$$0 \to T' \otimes A \to T \otimes A \to T'' \otimes A \to 0$$

is exact.

Proof. By Proposition B.2.1 b), all categories remain triangulated after $\otimes A$ and the induced functors are clearly triangulated functors. Since $T' \to T$ is strictly full, so is $T' \otimes A \to T \otimes A$. If $f$ is a morphism in $T' \otimes A$, then $f$ is the composition of an isomorphism with a morphism coming from $T'$, whose cone in $T$ lies in $T'$, thus the cone of $f$ in $T \otimes A$ lies in $T' \otimes A$.

We now show that the functor

$$a : \frac{T \otimes A}{T'} \otimes A \to \frac{T'' \otimes A}{T'}$$

is an equivalence of categories. Since the left hand side is $A$-linear, the natural functor

$$\frac{T}{T'} \to \frac{T \otimes A}{T'} \otimes A$$

canonically extends to a functor

$$b : (\frac{T}{T'}) \otimes A \to \frac{T \otimes A}{T'} \otimes A.$$

It is clear that $a$ and $b$ are inverse to each other. \qed

B.2.4. Proposition. a) Let $T : S \to T$ be a triangulated functor between triangulated categories. Then $T$ is fully faithful if and only if the induced functors $T\{A\} : S\{A\} \to T\{A\}$ and $T \otimes A : S \otimes A \to T \otimes A$ are fully faithful.

b) Assuming a) holds, $T$ is an equivalence of categories if and only if $T\{A\}$ and $T \otimes A$ are.

Proof. a) “Only if” is obvious; let us prove “if”. Let $X, Y \in S$: we have to prove that $T : S(X,Y) \to T(T(X),T(Y))$ is bijective. We do it in two steps:

1) $Y$ is torsion, say $n1_Y = 0$. The claim follows from the commutative diagram with exact rows

$$\begin{array}{cccc}
S(X/n[1],Y) & \to & S(X,Y) & \overset{n=0}{\to} & S(X,Y) & \to & S(X/n,Y) \\
T \downarrow & & T \downarrow & & T \downarrow & & T \downarrow \\
T(T(X)/n[1],T(Y)) & \to & T(T(X),T(Y)) & \overset{n=0}{\to} & T(T(X),T(Y)) & \to & T(T(X)/n,Y)
\end{array}$$

and the assumption (see Proposition B.2.1 b)).
2) The general case. Let \( n > 0 \). We have a commutative diagram with exact rows

\[
\begin{array}{cccccc}
0 & \to & S(X,Y) / n & \to & S(X,Y/n) & \to & nS(X,Y[1]) & \to & 0 \\
\downarrow T & & \downarrow T & & \downarrow T & & \downarrow T & & \\
0 & \to & T(T(X), T(Y))/n & \to & T(T(X), T(Y)/n) & \to & nT(T(X), T(Y)[1]) & \to & 0 \\
\end{array}
\]

where the middle isomorphism follows from 1). The snake lemma yields an exact sequence

\[
0 \to S(X,Y) \to T(T(X), T(Y))/n \\
\to nS(T(X), T(Y)[1]) \to nT(T(X), T(Y)[1]) \to 0.
\]

Passing to the limit over \( n \), we get another exact sequence

(B.1) \[
0 \to S(X,Y) \otimes A/Z \to T(T(X), T(Y)) \otimes A/Z \\
\to S(T(X), T(Y)[1]) \{ A \} \to T(T(X), T(Y)[1]) \{ A \} \to 0.
\]

Consider now the commutative diagram with exact rows

\[
\begin{array}{cccccc}
0 & \to & S(X,Y) \{ A \} & \to & S(X,Y) & \to & S(X,Y) \otimes A & \to & S(X,Y) \otimes A/Z & \to & 0 \\
\downarrow T & & \downarrow T & & \downarrow T & & \downarrow T & & \downarrow T & & \\
0 & \to & T(T(X), T(Y)) \{ A \} & \to & T(T(X), T(Y)) & \to & T(T(X), T(Y)) \otimes A & \to & T(T(X), T(Y)) \otimes A/Z & \to & 0 \\
\end{array}
\]

where the isomorphism is by assumption. By this diagram and (B.1), \( \Phi \) is an isomorphism. Using this fact in (B.1) applied with \( Y \{ -1 \} \), we get that \( \Phi \) is an isomorphism; then \( \Psi \) is an isomorphism by the 5 lemma, as desired.

b) If \( T \) is essentially surjective, so is \( T \otimes A \), as well as \( T \{ A \} \) as long as \( T \) is faithful, which is implied by a). Conversely, let \( X \in T \). Using only the essential surjectivity of \( T \otimes A \), we find an \( A \)-isogeny

\[
\varphi : X \to T(Y)
\]

with \( Y \in S \). A cone of \( \varphi \) is a torsion object, hence, if \( T \{ A \} \) is essentially surjective, it is isomorphic to \( T(C) \) for \( C \in S \{ A \} \). Thus \( X \) sits in an exact triangle

\[
X \xrightarrow{\xi} T(Y) \xrightarrow{\psi} T(C) \xrightarrow{\delta}
\]

If \( T \) is full, then \( \psi = T(\psi') \) and \( X \simeq T(X') \), where \( X' \) is a fibre of \( \psi' \). \( \square \)
B.3. Torsion objects in an abelian category. The proof of the following proposition is similar to that of Proposition B.2.1 and is left to the reader.

B.3.1. Proposition. Let $\mathcal{A}$ be an abelian category. Then

a) The full subcategory $\mathcal{A}\{A\}$ is thick (a Serre subcategory, in another terminology).

b) Let $X \in \mathcal{A}$ and $n > 0$ invertible in $A$. Then the kernel and cokernel of multiplication by $n$ on $X$ belong to $\mathcal{A}\{A\}$.

c) The localised category $\mathcal{A}/\mathcal{A}\{A\}$ is canonically isomorphic to $\mathcal{A} \otimes A$. In particular, $\mathcal{A} \otimes A$ is abelian.

d) A morphism $f \in \mathcal{A}$ is in $\Sigma_A(\mathcal{A})$ if and only if $\text{Ker} \ f \in \mathcal{A}\{A\}$ and $\text{Coker} \ f \in \mathcal{A}\{A\}$. □

The following corollary is a direct consequence of Proposition B.3.1 and Lemma B.1.3:

B.3.2. Corollary. Let $\mathcal{A}$ be an abelian category. Let $\mathcal{B}$ be a full additive subcategory of $\mathcal{A}$, and suppose that every object of $\mathcal{B}$ is $A$-isogenous to an object of $\mathcal{A}$ (see Definition B.1.1). Then $\mathcal{B} \otimes A$ is abelian, and in particular idempotent-complete. □

B.4. Abelian and derived categories.

B.4.1. Proposition. Let $\mathcal{A}$ be an abelian category. Then the natural functor $D^b(\mathcal{A}) \to D^b(\mathcal{A} \otimes A)$ induces an equivalence of categories

$$D^b(\mathcal{A}) \otimes A \sim \to D^b(\mathcal{A} \otimes A).$$

In particular, $D^b(\mathcal{A}) \otimes A$ is idempotent-complete.

Proof. In 3 steps:

1) The natural functor $C^b(\mathcal{A}) \otimes A \to C^b(\mathcal{A} \otimes A)$ is an equivalence of categories. Full faithfulness is clear. For essential surjectivity, take a bounded complex $C$ of objects of $\mathcal{A} \otimes A$. Find a common denominator to all differentials involved in $C$. Then the corresponding morphisms of $\mathcal{A}$ have torsion composition; since they are finitely many, we may multiply by a common bigger integer so that they compose to 0. The resulting complex of $C^b(\mathcal{A})$ then becomes isomorphic to $C$ in $C^b(\mathcal{A} \otimes A)$.

2) The functor of 1) induces an equivalence of categories $K^b(\mathcal{A}) \otimes A \sim \to K^b(\mathcal{A} \otimes A)$. Fullness is clear, and faithfulness is obtained by the same technique as in 1).

3) The functor of 2) induces the desired equivalence of categories. First, the functor

$$D^b(\mathcal{A})/D^b_{A\{A\}}(\mathcal{A}) \to D^b(\mathcal{A}/A\{A\})$$
is obviously conservative. But clearly \( D^b_{A(A)}(A) = D^b(A)\{A\} \). Hence, by Propositions B.2.1 and B.3.1, this functor translates as

\[
D^b(A) \otimes A \rightarrow D^b(A \otimes A).
\]

Let \( A^b(A) \) denote the thick subcategory of \( K^b(A) \) consisting of acyclic complexes. By Lemma B.2.3 we have a commutative diagram of exact sequences of triangulated categories

\[
\begin{array}{ccccccccc}
0 & \longrightarrow & A^b(A) \otimes A & \longrightarrow & K^b(A) \otimes A & \longrightarrow & D^b(A) \otimes A & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \\
0 & \longrightarrow & A^b(A \otimes A) & \longrightarrow & K^b(A \otimes A) & \longrightarrow & D^b(A \otimes A) & \longrightarrow & 0.
\end{array}
\]

We have just seen that the right vertical functor is conservative, and by 2), the middle one is an equivalence. Hence the left one is essentially surjective. By the same argument as in the proof of Proposition B.2.4 b), we get that the right functor is full, and the result follows from Lemma A.1.1.

\[\square\]

**APPENDIX C. 1-motives with torsion**

Effective 1-motives which admit torsion are introduced in [10, §1] (in characteristic 0). We investigate some properties (over a perfect field of exponential characteristic \( p \geq 1 \)) which are not included in op. cit. as a supplement to our Sect. 1.

**C.1. Effective 1-motives.** An effective 1-motive with torsion over \( k \) is a complex of group schemes \( M = [L \; \overset{u}{\longrightarrow} \; G] \) where \( L \) is finitely generated locally constant for the étale topology \( i.e. \) a discrete sheaf of Def. 1.1.1, and \( G \) is a semi-abelian \( k \)-scheme. Therefore \( L \) can be represented by an extension

\[
0 \rightarrow L_{\text{tor}} \rightarrow L \rightarrow L_{\text{fr}} \rightarrow 0
\]

where \( L_{\text{tor}} \) is a finite étale \( k \)-group scheme and \( L_{\text{fr}} \) is free, \( i.e. \) a lattice.

Also \( G \) can be represented by an extension of an abelian \( k \)-scheme \( A \) by a \( k \)-torus \( T \).

**C.1.1. Definition.** An effective map from \( M = [L \; \overset{u}{\longrightarrow} \; G] \) to \( M' = [L' \; \overset{u'}{\longrightarrow} \; G'] \) is a commutative square

\[
\begin{array}{ccc}
L & \overset{u}{\longrightarrow} & G \\
\downarrow{f} & & \downarrow{g} \\
L' & \overset{u'}{\longrightarrow} & G'
\end{array}
\]
in the category of group schemes. Denote by \((f, g) : M \to M'\) such a map. The natural composition of squares makes up a category, denoted by \(\mathcal{M}_1^{\text{eff}}\). We will denote by \(\text{Hom}_{\text{eff}}(M, M')\) the abelian group of effective morphisms.

For a given 1-motive \(M = [L \to G]\) we have (in the abelian category of commutative group schemes) a commutative diagram

\[
\begin{array}{cccccc}
0 & 0 & \downarrow & \downarrow & \downarrow & 0 \\
0 & \to & \text{Ker}(u) \cap L_{\text{tor}} & \to & L_{\text{tor}} & \stackrel{u}{\to} u(L_{\text{tor}}) & \to 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow \\
0 & \to & \text{Ker}(u) & \to & L & \stackrel{u}{\to} G \\
\downarrow & & \downarrow & & \downarrow & & \downarrow \\
L_{\text{fr}} & \stackrel{\pi}{\to} & G/u(L_{\text{tor}}) & & & & \\
\downarrow & & \downarrow & & \downarrow & & \downarrow \\
0 & 0 & & & & & 
\end{array}
\]

(C.1)

with exact rows and columns. We set

- \(M_{\text{fr}} := [L_{\text{fr}} \to G/u(L_{\text{tor}})]\)
- \(M_{\text{tor}} := [\text{Ker}(u) \cap L_{\text{tor}} \to 0]\)
- \(M_{\text{tf}} := [L/\text{Ker}(u) \cap L_{\text{tor}} \to G]\)

considered as effective 1-motives. From Diagram (C.1) there are canonical effective maps \(M \to M_{\text{tf}}, M_{\text{tor}} \to M\) and \(M_{\text{tf}} \to M_{\text{fr}}\).

C.1.2. **Definition.** A 1-motive \(M = [L \to G]\) is **free** if \(L\) is free, i.e. if \(M = M_{\text{fr}}\). \(M\) is **torsion** if \(L\) is torsion and \(G = 0\), i.e. if \(M = M_{\text{tor}}\), and **torsion-free** if \(\text{Ker}(u) \cap L_{\text{tor}} = 0\), i.e. if \(M = M_{\text{tf}}\).

Denote by \(\mathcal{M}_1^{\text{eff,fr}}, \mathcal{M}_1^{\text{eff,tor}}\) and \(\mathcal{M}_1^{\text{eff,tf}}\), the full sub-categories of \(\mathcal{M}_1^{\text{eff}}\) given by free, torsion and torsion-free 1-motives respectively.

The category \(\mathcal{M}_1^{\text{eff,fr}}\) is nothing else than the category \(\mathcal{M}_1\) of Deligne 1-motives and we shall henceforth use this notation. It is clear that \(\mathcal{M}_1^{\text{eff,tor}}\) is equivalent to the category of finite étale group schemes. If \(M\) is torsion-free then Diagram (C.1) is a pull-back, i.e. \(L\) is the pull-back of \(L_{\text{fr}}\) along the isogeny \(G \to G/L_{\text{tor}}\).

C.1.3. **Proposition.** The categories \(\mathcal{M}_1^{\text{eff}}\) and \(\mathcal{M}_1\) have all finite limits and colimits.
Proof. Since these are additive categories (with biproducts), it is enough to show that they have kernels, dually cokernels. Now let \( \varphi = (f, g) : M \to M' \) be an effective map. We claim that

\[
\text{Ker} \varphi = [\text{Ker}^0(f) \xrightarrow{u} \text{Ker}^0(g)]
\]

is the pull-back of \( \text{Ker}^0(g) \) along \( u \big|_{\text{Ker} f} \), where \( \text{Ker}^0(g) \) is the (reduced) connected component of the identity of the kernel of \( g : G \to G' \) and \( \text{Ker}^0(f) \subseteq \text{Ker}(f) \). We have to show that the following diagram of effective 1-motives

\[
\begin{array}{ccc}
0 & 0 \\
\downarrow & \downarrow \\
\text{Ker}^0(f) & \xrightarrow{u} & \text{Ker}^0(g) \\
\downarrow & & \downarrow \\
L & \xrightarrow{u} & G \\
\downarrow f & & \downarrow g \\
L' & \xrightarrow{u'} & G'
\end{array}
\]

satisfies the universal property for kernels. Suppose that \( M'' = [L'' \xrightarrow{u''} G''] \) is mapping to \( M \) in such a way that the composition \( M'' \to M \to M' \) is the zero map. Then \( L'' \) maps to \( \text{Ker}(f) \) and \( G'' \) maps to \( \text{Ker}(g) \). Since \( G'' \) is connected, it actually maps to \( \text{Ker}^0(g) \) and, by the universal property of pull-backs in the category of group schemes, \( L'' \) then maps to \( \text{Ker}^0(f) \). Finally note that if \( L \) is free then also \( \text{Ker}^0(f) \) is free.

For cokernels, we see that

\[
[\text{Coker}(f) \xrightarrow{\overline{\varphi}} \text{Coker}(g)]
\]

is an effective 1-motive which is clearly a cokernel of \( \varphi \).

For \( \mathcal{M}_1 \), it is enough to take the free part of the cokernel, i.e. given \( (f, g) : M \to M' \) then \( [\text{Coker}(f) \to \text{Coker}(g)]_{\text{fr}} \) meets the universal property for coker of free 1-motives. \( \square \)

C.2. Quasi-isomorphisms. (cf. [10, §1]).

C.2.1. Definition. An effective morphism of 1-motives \( M \to M' \), here \( M = [L \xrightarrow{u} G] \) and \( M' = [L' \xrightarrow{u'} G'] \), is a quasi-isomorphism (q.i. for
short) of 1-motives if it yields a pull-back diagram

\[
\begin{array}{ccc}
0 & 0 \\
\downarrow & \downarrow \\
F & \cong & F \\
\downarrow & \downarrow \\
L \xrightarrow{u} G \\
\downarrow & \downarrow \\
L' \xrightarrow{u'} G' \\
\downarrow & \downarrow \\
0 & 0
\end{array}
\]

(C.2)

where \( F \) is a finite étale group.

C.2.2. Remarks. 1) Note that kernel and cokernel of a quasi-isomorphism of 1-motives are 0 but, in general, a quasi-isomorphism is not an isomorphism in \( \text{^1M}^{\text{eff}}_1 \). Hence the category \( \text{^1M}^{\text{eff}}_1 \) is not abelian.

2) A q.i. of 1-motives \( M \to M' \) is actually a q.i. of complexes of group schemes. In fact, an effective map of 1-motives \( M \to M' \) is a q.i. of complexes if and only if we have the following diagram

\[
\begin{array}{ccc}
0 & \to & \text{Ker}(u) \\
\| & \downarrow & \| \\
L & \xrightarrow{u} & G \\
\| & \downarrow & \| \\
L' & \xrightarrow{u'} & G' \\
\downarrow & \downarrow \\
0 & \to & \text{Coker}(u)
\end{array}
\]

Therefore \( \text{Ker} \) and \( \text{Coker} \) of \( L \to L' \) and \( G \to G' \) are equal. Then \( \text{Coker}(G \to G') = 0 \), since it is connected and discrete, and \( \text{Ker}(G \to G') \) is a finite group. Conversely, Diagram (C.2) clearly yields a q.i. of complexes. In particular, it easily follows that the class of q.i. of 1-motives is closed under composition of effective morphisms.

C.2.3. Proposition. Quasi-isomorphisms are simplifiable on the left and on the right.

Proof. The assertion “on the right” is obvious since the two components of a q.i. are epimorphisms. For the left, let \( \varphi = (f, g) : M \to M' \) and...
\( \sigma = (s, t) : M' \to \tilde{M} \) a q.i. such that \( \sigma \varphi = 0 \). In the diagram

\[
\begin{array}{c}
L & \xrightarrow{u} & G \\
\downarrow f & & \downarrow g \\
L' & \xrightarrow{u'} & G' \\
\downarrow s & & \downarrow s \\
\tilde{L} & \xrightarrow{\tilde{u}} & \tilde{G}
\end{array}
\]

we have \( \tilde{L} = L'/F, \tilde{G} = G'/F \), for some finite group \( F \), \( \text{Im}(f) \subseteq F \) and \( \text{Im}(g) \subseteq F \). Now \( u' \) restricts to the identity on \( F \) thus \( \text{Im}(f) \subseteq \text{Im}(g) \) and \( \text{Im}(g) = 0 \), since \( \text{Im}(g) \) is connected, hence \( \varphi = 0 \). \( \square \)

C.2.4. **Proposition.** The class of q.i. admits a calculus of right fractions in the sense of (the dual of) [42, Ch. I, §2.3].

*Proof.* By [10, Lemma 1.2], the first condition of calculus of right fractions is verified, and Proposition C.2.3 shows that the second one is verified as well. (Note that we only consider isogenies with étale kernel here.) \( \square \)

C.2.5. **Remark.** The example of the diagram

\[
\begin{array}{c}
[L \to G] & \xrightarrow{\sigma} & [L' \to G'] \\
\downarrow (1,0) & & \\
[L \to 0]
\end{array}
\]

where \( \sigma \) is a nontrivial q.i. shows that calculus of left fractions fails in general.

C.2.6. **Lemma.** Let \( s, t, u \) be three maps in \( t\mathcal{M}_{1}^{\text{eff}} \), with \( su = t \). If \( s \) and \( t \) are q.i., then so is \( u \). \( \square \)

*Proof.* Consider the exact sequence of complexes of sheaves

\[
0 \to \text{Ker} \, u \to \text{Ker} \, t \to \text{Ker} \, s \to \text{Coker} \, u \to \text{Coker} \, t \to \text{Coker} \, s \to 0.
\]

Since \( s \) and \( t \) are q.i., the last two terms are 0. Hence \( \text{Coker}(u) = [L \to G] \) is a quotient of \( \text{Ker}(s) \); since \( G \) is connected, we must have \( G = 0 \). On the other hand, as a cokernel of a map of acyclic complexes of length 1, \( \text{Coker}(u) \) is acyclic, hence \( L = 0 \). Similarly, \( \text{Ker}(u) \) is acyclic. \( \square \)
C.3. 1-motives. We now define the category of 1-motives with torsion from $\mathcal{M}_1^{\text{eff}}$ by formally inverting quasi-isomorphisms.

C.3.1. Definition. The category $\mathcal{M}_1$ of 1-motives with torsion is the localisation of $\mathcal{M}_1^{\text{eff}}$ with respect to the multiplicative class $\{\text{q.i.}\}$ of quasi-isomorphisms.

C.3.2. Remark. Note that there are no nontrivial q.i. between free (or torsion) 1-motives. However, the canonical map $M_\text{tf} \to M_\text{fr}$ is a quasi-isomorphism (it is an effective isomorphism when $u(L_{\text{tor}}) = 0$).

It follows from Proposition C.2.4 and [42, Ch. I, Prop. 2-4] that the Hom sets in $\mathcal{M}_1$ are given by the formula

$$\text{Hom}(M, M') = \lim_{\text{q.i.}} \text{Hom}_{\text{eff}}(\widetilde{M}, M')$$

where the limit is taken over the filtering set of all quasi-isomorphisms $\widetilde{M} \to M$. A morphism of 1-motives $M \to M'$ can be represented as a diagram

$$\begin{array}{ccc}
M & & M' \\
\text{q.i.} & \nearrow & \searrow \text{eff} \\
\widetilde{M} & & \\
\end{array}$$

and the composition is given by the existence of a $\widehat{M}$ making the following diagram commutative. (This $\widehat{M}$ is in fact unique, see [10, Lemma 1.2].)

C.4. Strict morphisms. The notion of strict morphism is essential in order to show that the $\mathbb{Z}[1/p]$-linear category of 1-motives with torsion is abelian (cf. [10, §1]).

C.4.1. Definition. We say that an effective morphism $(f, g) : M \to M'$ is strict if we have

$$\text{Ker}(f, g) = [\text{Ker}(f) \to \text{Ker}(g)]$$

i.e. if $\text{Ker}(g)$ is (connected) semiabelian.

To get a feeling on the notion of strict morphism, note:
C.4.2. **Lemma.** Let \( \varphi = (f, g) : M \to N \) be a strict morphism, with \( g \) onto. Suppose that \( \varphi = \sigma \tilde{\varphi} \), where \( \sigma \) is a q.i. Then \( \sigma \) is an isomorphism.

Conversely, we obtain:

C.4.3. **Proposition** ([10, Prop. 1.3]). Any effective morphism \( \varphi \in \text{Hom}_{\text{eff}}(M, M') \) can be factored as follows

\[
\begin{array}{ccc}
M & \xrightarrow{\varphi} & M' \\
\tilde{\varphi} & \downarrow & \nearrow \\
\tilde{M} & & \\
\end{array}
\]

where \( \tilde{\varphi} \) is a strict morphism and \( \tilde{M} \to M' \) is a q.i. or a \( p \)-power isogeny.

**Proof.** (Sketch) Note that if \( \varphi = (f, g) \) we always have the following natural factorisation of the map \( g \) between semi-abelian schemes

\[
\begin{array}{ccc}
G & \xrightarrow{g} & G' \\
\downarrow & & \uparrow \\
G/\text{Ker}^0(g) & & \\
\end{array}
\]

If \( g \) is a surjection we get the claimed factorisation by taking \( \tilde{M} = [\tilde{L} \to G/\text{Ker}^0(g)] \) where \( \tilde{L} \) is the pull-back of \( L' \), the lifting of \( f \) is granted by the universal property of pull-backs. In general, we can extend the so obtained isogeny on the image of \( g \) to an isogeny of \( G' \) (see the proof of Prop. 1.3 in [10] for details). \( \square \)

C.4.4. **Lemma.** Let

\[
\begin{array}{ccc}
M' & \xrightarrow{f} & M \\
u & & t \\
\uparrow & & \uparrow \\
N' & \xrightarrow{h} & N \\
\end{array}
\]

be a commutative diagram in \( ^t \mathcal{M}_1^{\text{eff}} \), where \( f \) is strict and \( u, t \) are q.i. Then the induced map \( v : \text{Coker}(h) \to \text{Coker}(f) \) is a q.i.

**Proof.** In all this proof, the term “kernel” is taken in the sense of kernel of complexes of sheaves. Let \( K \) and \( K' \) be the kernels of \( f \) and \( h \) respectively:

\[
\begin{array}{ccc}
0 & \xrightarrow{} & K & \xrightarrow{} & M' & \xrightarrow{f} & M & \xrightarrow{} & \text{Coker}(f) \\
u & & w & & u & & t & & v \\
0 & \xrightarrow{} & K' & \xrightarrow{} & N' & \xrightarrow{h} & N & \xrightarrow{} & \text{Coker}(h) \\
\end{array}
\]
By a diagram chase, we see that $v$ and $\text{Ker} \ t \to \text{Ker} \ v$ are onto. To conclude, it will be sufficient to show that the sequence of complexes

\[(C.4) \quad \text{Ker}(u) \to \text{Ker}(t) \to \text{Ker}(v)\]

is exact termwise. For this, note that the second component of $w$ is onto because $f$ is strict and by dimension reasons. This implies by a diagram chase that the second component of $(C.4)$ is exact. But then the first component has to be exact too. \[\square\]

C.5. **Exact sequences of $1$-motives.** We have the following basic properties of $1$-motives.

C.5.1. **Proposition.** The canonical functor

\[\mathcal{M}_{1}^{\text{eff}} \to \mathcal{M}_{1}\]

is left exact and faithful.

*Proof.* Faithfulness immediately follows from Proposition C.2.3, while left exactness follows from Proposition C.2.4 and (the dual of) [42, Ch. I, Prop. 3.1]. \[\square\]

C.5.2. **Lemma.** Let $f : M' \to M$ be an effective map.

1. The canonical projection $\pi : M \to \text{Coker}(f)$ remains an epimorphism in $\mathcal{M}_{1}[1/p]$.
2. If $f$ is strict then $\pi$ remains a cokernel in $\mathcal{M}_{1}[1/p]$.
3. Cokernels exist in $\mathcal{M}_{1}[1/p]$.

*Proof.* To show Part 1 let $\pi : M \to N$ be an effective map. One sees immediately that $\pi$ is epi in $\mathcal{M}_{1}[1/p]$ if and only if for any commutative diagram

\[
\begin{array}{ccc}
M & \xrightarrow{\pi} & N \\
\uparrow{s'} & & \uparrow{s} \\
Q' & \xrightarrow{\pi'} & Q
\end{array}
\]

with $s, s'$ q.i., the map $\pi'$ is an epi in the effective category. Now specialise to the case $N = \text{Coker}(f)$ and remark that (up to modding out by Ker $f$) we may assume $f$ to be a monomorphism as a map of complexes, thus strict. Take $\pi', s, s'$ as above. We have a commutative
diagram of effective maps

\[
\begin{array}{cccccc}
0 & \longrightarrow & M' & \overset{f}{\longrightarrow} & M & \overset{\pi}{\longrightarrow} & \text{Coker}(f) \\
\uparrow{s''} & & \uparrow{s'} & \text{Coker}(f') & \uparrow{s} & \text{Coker}(f) & \uparrow{t} \\
Q'' & \overset{f'}{\longrightarrow} & Q' & \overset{\pi'}{\longrightarrow} & Q.
\end{array}
\]

Here \(s''\) is a q.i. and \(Q'', f', s''\) are obtained by calculus of right fractions (Proposition C.2.4). By Lemma C.4.4, the induced map \(t : \text{Coker}(f') \to \text{Coker}(f)\) is a q.i. By Proposition C.2.3, \(\pi' f' = 0\), hence the existence of \(u\). By Lemma C.2.6, \(u\) is a q.i. Hence \(\pi'\) is a composition of two epimorphisms and Part 1 is proven.

To show Part 2, let \(g t^{-1} : M \to M''\) be such that the composition \(M' \to M''\) is zero. By calculus of right fractions we have a commutative diagram

\[
\begin{array}{cccccc}
M' & \overset{f}{\longrightarrow} & M & \overset{\pi}{\longrightarrow} & \text{Coker}(f) \\
\uparrow{u} & & \uparrow{t} & \text{Coker}(h) & \uparrow{v} \\
N'' & \overset{h}{\longrightarrow} & N'' & \longrightarrow & \text{Coker}(h) & \downarrow{g} \\
& & & & \text{Coker}(f) & \downarrow{M''}
\end{array}
\]

where all maps are effective and \(u\) is a q.i. As above we have \(g h = 0\), hence the factorisation of \(g\) through \(\text{Coker}(h)\). Moreover \(\text{Coker}(h)\) maps canonically to \(\text{Coker}(f)\) via a map \(v\) (say), which is a q.i. by Lemma C.4.4. This shows that \(g t^{-1}\) factors through \(\text{Coker}(f)\) in \(\mathcal{M}_1[1/p]\). Uniqueness of the factorisation is then granted by Part 1.

In a category, the existence of cokernels is invariant by left or right composition by isomorphisms, hence Part 3 is a consequence of Parts 1 and 2 via Proposition C.4.3. \(\square\)

Now we can show the following key result (cf. [10, Prop. 1.3]).

C.5.3. Theorem. The category \(\mathcal{M}_1[1/p]\) is abelian.

Proof. Existence and description of kernels follows from Propositions C.1.3, C.2.4, C.5.1 and (the dual of) [42, Ch. 1, Cor. 3.2], while existence of cokernels has been proven in Lemma C.5.2. We are then left to show that, for any (effective) strict map \(\varphi : M \to M'\), the
canonical effective morphism from the coimage of $\varphi$ to the image of $\varphi$ is a q.i. of 1-motives, i.e. the canonical morphism

\[(C.5) \quad \text{Coker}(\text{Ker} \varphi \to M) \to \text{Ker}(M' \to \text{Coker} \varphi)\]

is a quasi-isomorphism. Since we can split $\varphi$ in two short exact sequences of complexes in which each term is an effective 1-motive we see that (C.5) is even a isomorphism in $^t\mathcal{M}^{\text{eff}}_1[1/p]$.

C.5.4. **Remark.** Note that (even in characteristic zero) for a given non-strict effective map $(f,g) : M \to M'$ the effective morphism (C.5) is not a q.i. of 1-motives. In fact, the following diagram

\[
\begin{array}{cccc}
0 & 0 \\
\downarrow & \downarrow \\
\text{Ker}(f)/\text{Ker}^0(f) & \subseteq & \text{Ker}(g)/\text{Ker}^0(g) \\
\downarrow & \downarrow \\
L/\text{Ker}^0(f) & \longrightarrow & G/\text{Ker}^0(g) \\
\downarrow & \downarrow \\
\text{Im}(f) & \longrightarrow & \text{Im}(g) \\
\downarrow & \downarrow \\
0 & 0 \\
\end{array}
\]

is not a pull-back, in general. For example, let $g : G \to G'$ be with finite kernel and a proper sub-group $F \subseteq \text{Ker}(g)$, and consider

\[(0, g) : [F \to G] \to [0 \to G'] .\]

C.5.5. **Corollary.** A short exact sequence of 1-motives in $^t\mathcal{M}_1[1/p]$

\[(C.6) \quad 0 \to M' \to M \to M'' \to 0\]

can be represented up to isomorphisms by a strict effective epimorphism $(f,g) : M \to M''$ with kernel $M'$, i.e. by an exact sequence of complexes.

C.5.6. **Example.** Let $M$ be a 1-motive with torsion. We then always have a canonical exact sequence in $^t\mathcal{M}_1[1/p]$

\[(C.7) \quad 0 \to M_{\text{tor}} \to M \to M_{\text{fr}} \to 0\]
induced by (C.1), according to Definition C.1.2. Note that in the following canonical factorisation
\[ M \rightarrow M_{fr} \]
\[ M_{tf} \downarrow \uparrow \]
\[ M \]
the effective map \( M \rightarrow M_{tf} \) is a strict epimorphism with kernel \( M_{tor} \) and \( M_{tf} \rightarrow M_{fr} \) is a q.i. (providing an example of Proposition C.4.3).

C.6. \( \ell \)-adic realisation. Let \( n : M \rightarrow M \) be the (effective) multiplication by \( n \) on a 1-motive \( M = [L \rightarrow G] \) over a field \( k \) where \( n \) is prime to the characteristic of \( k \). It is then easy to see, e.g. by the description of kernels in Proposition C.1.3, that
\[ nM := \text{Ker}(M \xrightarrow{n} M) = \{\text{Ker}(u) \cap nL \rightarrow 0\}. \]
Thus \( nM = 0 \) (all \( n \) in characteristic zero) if and only if \( M \) is torsion-free, i.e. \( M_{tor} = 0 \). Moreover, by Proposition C.4.3 and Lemma C.5.2, we can see that \( M/n := \text{Coker}(M \xrightarrow{n} M) \) is always a torsion 1-motive. If \( L = 0 \), let simply \( G \) denote, as usual, the 1-motive \([0 \rightarrow G]\). Then we get an extension in \( \mathcal{M}_1[1/p] \)
\begin{equation}
0 \rightarrow G \xrightarrow{n} G \rightarrow nG[1] \rightarrow 0
\end{equation}
where \( nG[1] \) is the torsion 1-motive \([nG \rightarrow 0]\). If \( L \neq 0 \) then \( M/n \) can be regarded as an extension of \( L/n \) by \( \text{Coker}(nL \rightarrow nG) \), e.g. also by applying the snake lemma to the multiplication by \( n \) on the following canonical short exact sequence (here \( L[1] = [L \rightarrow 0] \) as usual)
\begin{equation}
0 \rightarrow G \rightarrow M \rightarrow L[1] \rightarrow 0
\end{equation}
of effective 1-motives (which is also exact in \( \mathcal{M}_1[1/p] \) by Corollary C.5.5). Summarizing up from (C.8), (C.9) we then get a long exact sequence in \( \mathcal{M}^{tor}_1[1/p] \)
\begin{equation}
0 \rightarrow nM \rightarrow nL[1] \rightarrow nG[1] \rightarrow M/n \rightarrow L/n[1] \rightarrow 0.
\end{equation}

Let now be \( n = \ell^\nu \) where \( \ell \neq \text{char}(k) \). Set:

C.6.1. Definition. The \( \ell \)-adic realisation of a 1-motive \( M \) is
\[ T_\ell(M) := \text{"lim"}_{\nu} L_\nu \]
in the category of \( l \)-adic sheaves, where \( M/\ell^\nu = [L_\nu \rightarrow 0] \).
Since the inverse system “\(\lim_{\leftarrow \nu} L\) is Mittag-Leffler trivial, we obtain a short exact sequence
\[
0 \to T_\ell(G) \to T_\ell(M) \to L \otimes \mathbb{Z}_\ell \to 0
\]
where \(T_\ell(G)\) is the Tate module of the semiabelian variety \(G\). More generally, using Corollary C.5.5, we have:

C.6.2. Lemma. The functor \(T_\ell\) is exact on \(tM_1[1/p]\), and extends canonically to \(tM_1 \otimes \mathbb{Z}_\ell\). \qed

C.7. Deligne 1-motives. Let \(tM^{fr}_1[1/p], tM^{tor}_1[1/p]\) and \(tM^{tf}_1[1/p]\) denote the corresponding full sub-categories of \(tM_1[1/p]\) given by free, torsion and torsion-free effective 1-motives respectively. The following \(M \mapsto M_{fr}\) (resp. \(M \mapsto M_{tor}\)) define functors from \(tM_1[1/p]\) to \(tM^{fr}_1[1/p]\) (resp. from \(tM_1[1/p]\) to \(tM^{tor}_1[1/p]\)). We have (cf. [10, (1.1.3)]):

C.7.1. Proposition. The natural functor \(tM_1[1/p] \to tM_1[1/p]\) from Deligne 1-motives to 1-motives with torsion has a left adjoint/left inverse given by \(M \mapsto M_{fr}\). In particular, it is fully faithful and makes \(tM_1[1/p]\) an exact sub-category of \(tM_1[1/p]\).

Proof. Consider an effective map \((f, g) : \widetilde{M} \to M'\), to a free 1-motive \(M'\), and a q.i. \(\widetilde{M} \to M\), i.e. \(M = [\tilde{L}/F \to \tilde{G}/F]\) for a finite group \(F\). Since \(M'\) is free then \(F\) is contained in the kernel of \(f\) and the same holds for \(g\). Thus \((f, g)\) induces an effective map \(M \to M'\). Let \(M = [L \to G]\). Then \(L_{tor} \subseteq \text{Ker}(f)\) and also \(u(L_{tor}) \subseteq \text{Ker}(g)\) yielding an effective map \((f, g) : M_{fr} \to M'\). This proves the first assertion.

Since \(tM^{eff, fr}_1 \hookrightarrow tM^{eff, tf}_1\), the claimed equivalence is obtained from the canonical q.i. \(M \to M_{fr}\) for \(M \in tM^{eff, tf}_1\), see (C.1). Finally, consider the exact sequence (C.6) of 1-motives with torsion such that \(M'_{tor} = M''_{tor} = 0\). Since \(M_{tor}\) is mapped to zero in \(M''\), it injects in \(M'\). Thus also \(M\) is torsion-free, i.e. \(M = M_{tf}\), and quasi-isomorphic to \(M_{fr}\). \qed

C.7.2. Remark. We also clearly have that the functor \(M \mapsto M_{tor}\) is a right-adjoint to the embedding \(tM^{tor}_1[1/p] \hookrightarrow tM_1[1/p]\), i.e.

\[
\text{Hom}_{eff}(M, M_{tor}') \cong \text{Hom}(M, M')
\]

for \(M \in tM^{tor}_1[1/p]\) and \(M' \in tM_1[1/p]\).
C.7.3. **Corollary.** We have $^t\mathcal{M}_1^{\text{tor}} \otimes \mathbb{Q} = 0$ and the full embedding $\mathcal{M}_1[1/p] \to ^t\mathcal{M}_1[1/p]$ induces an equivalence

$$\mathcal{M}_1 \otimes \mathbb{Q} \sim \to ^t\mathcal{M}_1 \otimes \mathbb{Q}.$$ 

C.8. **Non-connected 1-motives.** We consider a larger category allowing non-connected (reduced) group schemes as a supplement of Proposition 1.1.5.

C.8.1. **Definition.** Let $\mathcal{M}_\text{nc}^{\text{eff}}$ denote the following category. The objects are $N = [L \to G]$ complexes of étale sheaves over the field $k$ where $L$ is discrete and $G$ is a reduced group scheme locally of finite type over $k$ such that

(i) the connected component of the identity $G^0$ is semiabelian, and

(ii) $\pi_0(G)$ is finitely generated.

The morphisms are just maps of complexes. We call $\mathcal{M}_\text{nc}^{\text{eff}}$ the category of effective non-connected 1-motives.

We denote $\mathcal{M}_\text{anc}^{\text{eff}}$ the full subcategory of $\mathcal{M}_\text{nc}^{\text{eff}}$ whose objects are $N = [L \to G]$ as above such that $G$ is of finite type over $k$ (then condition (ii) is automatically granted and $\pi_0(G)$ is a finite group scheme). We call $\mathcal{M}_\text{anc}^{\text{eff}}$ the category of algebraic effective non-connected 1-motives.

Note that a representable presheaf on the category of schemes over $k$ can be characterised by axiomatic methods, including Condition (i) above, *cf.* the Appendix in [11].

Associated to $N = [L \to G]$ we have the following diagram

\[
\begin{array}{ccc}
0 & & 0 \\
\downarrow & & \downarrow \\
L^0 & \longrightarrow & G^0 \\
\downarrow & & \downarrow \\
L & \longrightarrow & G \\
\downarrow & & \downarrow \\
L/L^0 & \longrightarrow & \pi_0(G) \\
\downarrow & & \downarrow \\
0 & & 0
\end{array}
\]

here $L^0$ denote the pull-back of $G^0$ along $L \to G$. Let

$$N^0 := [L^0 \to G^0]$$
denote the effective 1-motive associated to $N$ and denote

$$\pi_0(N) := [L/L^0 \hookrightarrow \pi_0(G)].$$

We say that $D = [L \hookrightarrow L']$ is discrete if $L'$ is a discrete sheaf and $L$ injects into $L'$.

Denote $\mathcal{M}_{\text{nc}}^{\text{dis}}$ the full subcategory of $\mathcal{M}_{\text{nc}}^{\text{eff}}$ given by discrete objects. Note that $N$ is discrete if and only if $\pi_0(N) = N$ (if and only if $N^0 = 0$).

C.8.2. Proposition. The operation $N \mapsto N^0$ defines a functor

$$c^{\text{eff}} : \mathcal{M}_{\text{nc}}^{\text{eff}} \to \mathcal{M}_{1}^{\text{eff}}$$

which is right adjoint to the embedding $i_1 : \mathcal{M}_{1}^{\text{eff}} \hookrightarrow \mathcal{M}_{\text{nc}}^{\text{eff}}$ and $c^{\text{eff}}i_1 = 1$. Moreover, we have a functor

$$\pi_0 : \mathcal{M}_{\text{nc}}^{\text{eff}} \to \mathcal{M}_{\text{nc}}^{\text{dis}}$$

which is left adjoint to $i_{\text{dis}} : \mathcal{M}_{\text{nc}}^{\text{dis}} \hookrightarrow \mathcal{M}_{1}^{\text{eff}}$ and $\pi_0i_{\text{dis}} = 1$.

Proof. Straightforward. □

C.8.3. Remarks. 1) The same results as in Proposition C.8.2 above refine to $\mathcal{M}_{\text{anc}}^{\text{eff}}$ and $\mathcal{M}_{\text{anc}}^{\text{dis}}$.

2) Note that $\mathcal{M}_{\text{nc}}^{\text{eff}}$ has kernels. Let $\varphi = (f, g) : N \to N'$ be a map in $\mathcal{M}_{\text{nc}}^{\text{eff}}$. Let $g^0 : G^0 \to G'^0$ and $\pi_0(g) : \pi_0(G) \to \pi_0(G')$ be the induced maps. Then $\text{Ker}(\varphi) = [\text{Ker}(f) \to \text{Ker}(g)]$ as a complex of sheaves; in fact, $\text{Ker}(g)$ is representable, $\text{Ker}^0(g^0) = (\text{Ker}(g))^0$ and $\pi_0(\text{Ker}(g))$ maps to $\text{Ker}(\pi_0(g))$ with finite kernel. However, it is easy to see that $\mathcal{M}_{\text{nc}}^{\text{eff}}$ is not abelian.

C.8.4. Proposition. The category $\mathcal{M}_{\text{anc}}^{\text{eff}}[1/p]$ is abelian.

Proof. Regard $\mathcal{M}_{\text{anc}}^{\text{eff}}[1/p]$ as a full subcategory of $C(-1,0)(\text{Shv}(k_{\text{et}}))[1/p]$ of the abelian category of complexes of sheaves concentrated in degree $-1$ and $0$. For a map $\varphi = (f, g) : N \to N'$, $\text{Ker}(\varphi) = [\text{Ker}(f) \to \text{Ker}(g)] \in \mathcal{M}_{\text{anc}}^{\text{eff}}$ and $\text{Coker}(\varphi) = [\text{Coker}(f) \to \text{Coker}(g)] \in \mathcal{M}_{\text{anc}}^{\text{eff}}$. For an extension $0 \to N \to N' \to N'' \to 0$ in $C(-1,0)(\text{Shv}(k_{\text{et}}))$ such that $N$ and $N''$ belongs to $\mathcal{M}_{\text{anc}}^{\text{eff}}$ then also $N'' \in \mathcal{M}_{\text{anc}}^{\text{eff}}$. □

C.9. Homs and Extensions. We will provide a characterisation of the Yoneda Ext in the abelian category $\mathcal{M}_{1}[1/p]$.

C.9.1. Proposition. We have

(a) $\text{Hom}_{\mathcal{M}_{1}}(L[1], L'[1]) = \text{Hom}_{k}(L, L')$,

(b) $\text{Hom}_{\mathcal{M}_{1}}(L[1], G') = 0$,

(c) $\text{Hom}_{\mathcal{M}_{1}}(G, G') \subseteq \text{Hom}_{k}(A, A') \times \text{Hom}_{k}(T, T')$ if $G$ (resp. $G'$) is an extension of an abelian variety $A$ by a torus $T$ (resp. of $A'$ by $T'$),
In particular, the group $\text{Hom}_{\mathcal{M}_1}(M, M')$ is finitely generated for all 1-motives $M, M' \in \mathcal{M}_1[1/p]$.

Proof. Since there are no q.i to $L[1]$, we have $\text{Hom}_{\mathcal{M}_1}(L[1], L'[1]) = \text{Hom}_e(L[1], L'[1])$ and the latter is clearly isomorphic to $\text{Hom}_k(L, L')$. By Proposition C.7.1, we have $\text{Hom}_{\mathcal{M}_1}(L, G) = \text{Hom}_e(L, G)$ and $\text{Hom}_{\mathcal{M}_1}(G, G') = \text{Hom}_e(G, G')$. The former is clearly 0 while $\text{Hom}_e(G, G') = \text{Hom}_k(G, G') \subseteq \text{Hom}_k(A, A') \times \text{Hom}_k(T, T')$ since $\text{Hom}_k(T, A') = \text{Hom}_k(A, T') = 0$. For (d), let $[F \to \tilde{G}] \to [0 \to G]$ be a q.i. and $[F \to \tilde{G}] \to [L' \to 0]$ be an effective map providing an element of $\text{Hom}(G, L'[1])$. If $L'$ is free then it yields the zero map, as $F$ is torsion. Thus $\text{Hom}_{\mathcal{M}_1}(G, L'[1]) = \text{Hom}_{\mathcal{M}_1}(G, L'[\text{tor}]_1) = \text{Hom}_k(nG, L'_{\text{tor}})$. For $n \in \mathbb{N}$ consider the short exact sequence (C.8) in $\mathcal{M}_1$. If $n$ is such that $nL'_{\text{tor}} = 0$ taking $\text{Hom}_{\mathcal{M}_1}(-, L'[1])$ we further obtain $\text{Hom}_{\mathcal{M}_1}(G, L'[1]) = \text{Hom}_k(nG, L'_{\text{tor}})$.

The last statement follows from these computations and an easy d\'evissage from (C.9). \qed

C.9.2. Remark. If we want to get rid of the integer $n$ in (d), we may equally write

$$\text{Hom}_{\mathcal{M}_1}(G, L'[1]) = \text{Hom}_\text{cont}(\hat{T}(G), L'_{\text{tor}}) = \text{Hom}_\text{cont}(\hat{T}(G), L')$$

where $\hat{T}(G) = \prod \ell T_\ell(G)$ is the complete Tate module of $G$.

C.9.3. Proposition. We have isomorphisms (for $\text{Ext}$ in $\mathcal{M}_1[1/p]$):

(a) $\text{Ext}^1_k(L, L') \to \text{Ext}^1_{\mathcal{M}_1}(L[1], L'[1])$

(b) $\text{Hom}_k(L, G') \to \text{Ext}^1_{\mathcal{M}_1}(L[1], G')$

(c) $\text{Ext}^1_k(G, G') \to \text{Ext}^1_{\mathcal{M}_1}(G, G')$ and

(d) $\lim_n \text{Ext}^1(nG, L') \to \text{Ext}^1_{\mathcal{M}_1}(G, L'[1])$; these two groups are 0

if $L'$ is torsion and $k$ algebraically closed.

Proof. By Corollary C.5.5, any short exact sequence of 1-motives can be represented up to isomorphism by a short exact sequence of complexes in which each term is an effective 1-motive.

For (a), just observe that there are no nontrivial q.i of 1-motives with zero semiabelian part. For (b), note that an extension of $L[1]$ by $G'$ is given by a diagram

$$0 \longrightarrow F' \longrightarrow L'' \longrightarrow L \longrightarrow 0$$

(C.11)

\[ \begin{array}{ccc}
0 & \to & \tilde{G}'' \\
\downarrow & & \downarrow \\
0 & \to & G''
\end{array} \]

\[ \begin{array}{ccc}
0 & \to & G'' \\
\downarrow & & \downarrow \\
0 & \to & 0
\end{array} \]
where \( \widetilde{M}' = [F' \to \widetilde{G}'] \) is q.i. to \([0 \to G']\). When \( F' = 0 \), this diagram is equivalent to the datum of \( v \): this provides a linear map \( \text{Hom}_k(L, G') \to \text{Ext}^1_{tM_1}(L[1], G') \). This map is surjective since we may always mod out by \( F' \) in (C.11) and get a quasi-isomorphic exact sequence with \( F' = 0 \). It is also injective: if (C.11) (with \( F' = 0 \)) splits in \( tM_1[1/p] \), it already splits in \( tM_{\text{eff}}[1/p] \) and then \( v = 0 \).

For (c) we see that an extension of \( G \) by \( G' \) in \( tM_1[1/p] \) can be represented by a diagram

\[
\begin{array}{ccccccc}
0 & \longrightarrow & F' & \longrightarrow & L'' & \longrightarrow & F & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \\
0 & \longrightarrow & \widetilde{G}' & \longrightarrow & G'' & \longrightarrow & \widetilde{G} & \longrightarrow & 0
\end{array}
\]

with \( \widetilde{M}' \) as in (b) and \( \widetilde{M} = [F \to \widetilde{G}] \) q.i. to \([0 \to G] \). Since the top line is exact, \( L'' \) is finite. For \( F = F' = 0 \) we just get a group scheme extension of \( G \) by \( G' \), hence a homomorphism \( \text{Ext}^1_k(G, G') \to \text{Ext}^1_{tM_1}(G, G') \). This homomorphism is surjective: dividing by \( F' \) we get a quasi-isomorphic exact sequence

\[
\begin{array}{ccccccc}
0 & \longrightarrow & 0 & \longrightarrow & L''/F' & \longrightarrow & \sim F & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \\
0 & \longrightarrow & G' & \longrightarrow & G''/F' & \longrightarrow & \widetilde{G} & \longrightarrow & 0
\end{array}
\]

and further dividing by \( F \) we then obtain

\[
\begin{array}{ccccccc}
0 & \longrightarrow & 0 & \longrightarrow & 0 & \longrightarrow & 0 & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \\
0 & \longrightarrow & G' & \longrightarrow & G''/L'' & \longrightarrow & G & \longrightarrow & 0.
\end{array}
\]

Injectivity is seen as in (b).

For (d) we first construct a map \( \Phi_n : \text{Ext}^1_k(nG, L') \to \text{Ext}^1_{tM_1}(nG, L'[1]) \) for all \( n \). Let \([L''] \in \text{Ext}^1_k(nG, L') \) and consider the following diagram

\[
\begin{array}{ccccccc}
0 & \longrightarrow & L' & \longrightarrow & L'' & \longrightarrow & nG & \longrightarrow & 0 \\
\downarrow & & \downarrow & & \downarrow & & \downarrow & & \\
0 & \longrightarrow & 0 & \longrightarrow & G & \longrightarrow & G & \longrightarrow & 0.
\end{array}
\]

Since \([nG \to G] \) is q.i. to \([0 \to G] \), this provides an extension of \( G \) by \( L'[1] \) in \( tM_1[1/p] \). For \( n \) variable \( \{\text{Ext}^1_k(nG, L')\}_n \) is a direct system and one checks easily that the maps \( \Phi_n \) are compatible (by pull-back), yielding a well-defined linear map

\[
\Phi : \lim \text{Ext}^1_k(nG, L') \to \text{Ext}^1_{tM_1}(G, L'[1]).
\]
This map is surjective since any extension of $G$ by $L'[1]$ can be represented by a diagram (C.12) for some $n$ (as multiplication by $n$ is cofinal in the direct system of isogenies). We now show that $\Phi$ is also injective.

In fact, we have a short exact sequence (C.8) of 1-motives yielding the following short exact sequence

$$0 \to \text{Hom}_{tM_1}(G, L'[1]) \otimes \mathbb{Z}/n \to \text{Ext}^1_{tM_1}(nG[1], L'[1]) \to n \text{Ext}^1_{tM_1}(G, L'[1]) \to 0$$

Passing to the limit we obtain

$$\text{Ker } \Phi \longrightarrow \lim_{\rightarrow} \text{Ext}^1_{tM_1}(nG[1], L'[1]) \longrightarrow \text{Ext}^1_{tM_1}(G, L'[1])$$

In fact, $\lim_{\rightarrow} \text{Hom}_{tM_1}(G, L'[1]) \otimes \mathbb{Z}/n = 0$ because $\text{Hom}_{tM_1}(G, L'[1])$ is a finite group by Proposition C.9.1 (d), $\text{Ext}^1_{tM_1}(G, L'[1])$ is torsion as $\Phi$ is surjective and we then just apply (a).

Finally, let $n \mid m$, e.g. $rn = m$, so that the following sequence is exact

$$0 \to _rG \to _mG \xrightarrow{r} nG \to 0$$

and yields a long exact sequence

$$\text{Hom}_k(nG, L') \to \text{Hom}_k(_rG, L') \to \text{Ext}^1_k(nG, L') \to \text{Ext}^2_k(nG, L')$$

If $L'$ is torsion, we have $rL' = 0$ for some $r$, hence $\lim_{\rightarrow} \text{Ext}^1_k(nG, L') = 0$ if $k$ is algebraically closed. In particular, it shows that $\text{Ext}^1_{tM_1}(G, L'[1]) = 0$ in this case. \[\square\]

C.10. Projective objects in $tM_1[1/p]$. We show that there are not enough projective objects in $tM_1[1/p]$, at least when $k$ is algebraically closed:

C.10.1. Proposition. Suppose that $k = \overline{k}$. Then the only projective object of $tM_1[1/p]$ is 0.

Proof. Suppose that $M = [L \to G] \in tM_1[1/p]$ is such that $\text{Ext}(M, N) = 0$ for any $N \in tM_1[1/p]$. From (C.9) we then get a long exact sequence

$$\text{Hom}(G, \mathbb{G}_m) \to \text{Ext}(L[1], \mathbb{G}_m) \to \text{Ext}(M, \mathbb{G}_m)$$

$$\to \text{Ext}(G, \mathbb{G}_m) \to \text{Ext}^2(L[1], \mathbb{G}_m)$$

where $\text{Ext}(M, \mathbb{G}_m) = 0$, thus i) $\text{Ext}(G, \mathbb{G}_m)$ is finite, and ii) $\text{Hom}(L, \mathbb{G}_m)$ is finitely generated. We also have an exact sequence

$$\text{Hom}(T, \mathbb{G}_m) \to \text{Ext}(A, \mathbb{G}_m) \to \text{Ext}(G, \mathbb{G}_m)$$
where $\text{Hom}(T, \mathbb{G}_m)$ is the character group of the torus $T$ and $\text{Ext}(A, \mathbb{G}_m)$ is the group of $k$-points of the dual abelian variety $A$, the abelian quotient of $G$. From i) we get $A = 0$. Since $\text{Hom}(L, \mathbb{G}_m)$ is an extension of a finite group by a divisible group, from ii) we get that $L$ is a finite group. Now consider the exact sequence, for $l \neq p$

$$0 \to \text{Hom}(L[1], \mathbb{Z}/l[1]) \to \text{Hom}(M, \mathbb{Z}/l[1]) \to \text{Hom}(T, \mathbb{Z}/l[1]) \to \text{Ext}(L[1], \mathbb{Z}/l[1]) \to 0$$

where the right-end vanishing is $\text{Ext}(M, \mathbb{Z}/l[1]) = 0$ by assumption.

Now $\text{Hom}(T, \mathbb{Z}/l[1]) = \text{Ext}(T, \mathbb{Z}/l)$ and any extension of the torus $T$ is lifted to an extension of $M$ by $\mathbb{Z}/l$, therefore to an element of $\text{Hom}(M, \mathbb{Z}/l[1]) = \text{Ext}(M, \mathbb{Z}/l)$. This yields $\text{Ext}(L, \mathbb{Z}/l) = 0$ for any prime $l \neq p$, thus we see that $L = 0$.

Finally, $[0 \to \mathbb{G}_m]$ is not projective since $\text{Ext}^1(\mathbb{G}_m, \mathbb{Z}[1]) \neq 0$ by Proposition C.9.3 (d).

□

C.11. Weights. If $M = [L \overset{u}{\to} G] \in \mathcal{M}_1[1/p]$ is free then Deligne [32] equipped $M = M_{fr}$ with an increasing filtration by sub-1-motives as follows:

$$W_{-2}(M) := [0 \to T] \subseteq W_{-1}(M) := [0 \to G] \subseteq W_0(M) := M$$

If $M$ is torsion-free we then pull-back the weight filtration along the effective map $M \to M_{fr}$ as follows:

$$W_i(M) := \begin{cases} M & i \geq 0 \\ [L_{tor} \to G] & i = -1 \\ [L_{tor} \cap T \to T] & i = -2 \\ 0 & i \leq -3 \end{cases}$$

Note that $W_i(M)$ is q.i. to $W_i(M_{fr})$.

If $M$ has torsion we then further pull-back the weight filtration along the effective map $M \to M_{tf}$.

C.11.1. Definition. Let $M = [L \overset{u}{\to} G]$ be an effective 1-motive. Let $u_A : L \to A$ denote the induced map where $A = G/T$. Define

$$W_i(M) := \begin{cases} M & i \geq 0 \\ [L_{tor} \to G] & i = -1 \\ [L_{tor} \cap \ker(u_A) \to T] & i = -2 \\ M_{tor} = L_{tor} \cap \ker(u)[1] & i = -3 \\ 0 & i \leq -4 \end{cases}$$

C.11.2. Remark. It is easy to see that $M \mapsto W_i(M)$ yields a functor from $\mathcal{M}_1[1/p]$ to $\mathcal{M}_1[1/p]$. However, this does not define a weight filtration on $\mathcal{M}_1[1/p]$ in the sense of Definition E.7.2 or Remark E.7.8.
C.12. 1-motives over a base. Let $S$ be a scheme. According to [32, (10.1.10)], a smooth 1-motive over $S$ is a complex $[L \to G]$ of $S$-group schemes where $L$ is a lattice (corresponding to a locally constant $\mathbb{Z}$-constructible free étale sheaf) and $G$ is an extension of an abelian scheme $A$ by a torus $T$. By [41, Cor. 2.11], it is sufficient to have this condition fibre by fibre as long as the rank of $T_s$ is locally constant.

Smooth 1-motives form an additive category denoted (here) by $\mathcal{M}_1(S)$. A smooth 1-motive is provided with a weight filtration as over a field.

By [41, loc. cit.] and [27], the same arguments as in the proofs of Propositions 1.1.5 and 15.2.1 yield

C.12.1. Proposition. Suppose $S$ regular connected and essentially of finite type over a field $k$. Then the category $\mathcal{M}_1(S)\otimes\mathbb{Q}$ is abelian and is provided with a 3 step weight filtration in the sense of Definition E.7.2, such that the full subcategories of objects of pure weight are semi-simple.

C.12.2. Lemma. In Proposition C.12.1, we have a canonical monomorphism

$$\text{Ext}^2([0 \to \mathbb{G}_m], [\mathbb{Z} \to 0]) \hookrightarrow \text{Ext}^1_S(\mathbb{Z}, \mathbb{G}_m)\otimes\mathbb{Q}.$$ 

Proof. Let

$$
\begin{array}{cccccc}
0 & \longrightarrow & L_1 & \longrightarrow & L_2 & \longrightarrow & \mathbb{Z} \\
\downarrow & & \downarrow & & \downarrow & & \downarrow \\
\mathbb{G}_m & \longrightarrow & G_1 & \longrightarrow & G_2 & \longrightarrow & 0
\end{array}
$$

be a 2-extension $E$ of $[\mathbb{Z} \to 0]$ by $[0 \to \mathbb{G}_m]$. Taking Tot, we get a short exact sequence of sheaves

$$0 \to L_1 \oplus \mathbb{G}_m \to L_2 \oplus G_1 \to \mathbb{Z} \oplus G_2 \to 0.$$

We define the image of $E$ in $\text{Ext}^1_S(\mathbb{Z}, \mathbb{G}_m)$ as the image of this extension $E'$ under the composition

$$\text{Ext}^1_S(\mathbb{Z} \oplus G_2, L_1 \oplus \mathbb{G}_m) \hookrightarrow \text{Ext}^1_S(\mathbb{Z} \oplus G_2, \mathbb{G}_m) \hookrightarrow \text{Ext}^1_S(\mathbb{Z}, \mathbb{G}_m).$$

It remains to see the injectivity. If the image of $E$ is 0, a diagram chase shows that $E'$ is in the image of

$$\text{Ext}^1_S(\mathbb{Z} \oplus G_2, L_1) \oplus \text{Ext}^1_S(G_2, L_1 \oplus \mathbb{G}_m) \to \text{Ext}^1_S(\mathbb{Z} \oplus G_2, L_1 \oplus \mathbb{G}_m).$$

Since $S$ is regular, both groups are 0 rationally: for the vanishing of $\text{Ext}^1_S(G_2, L_1)$, observe that Proposition 3.1.4 works over $S$ with the same proof. Thus $E'$ is rationally split. Since $\text{Hom}(G_2, L_1) = 0$, this amounts to $\mathbb{Q}$-splittings of $G_1 \to G_2$ and $L_2 \to \mathbb{Z}$ plus a $\mathbb{Q}$-morphism.
\[ Z \to G_1 \text{ with a compatibility condition. After trivialising the splittings, we get a diagram } \]

\[
\begin{array}{ccccccccc}
0 & \to & L_1 & \to & L_1 \oplus \mathbb{Z} & \to & \mathbb{Z} \\
\downarrow & & \downarrow f & & \downarrow g & & \downarrow \\
\mathbb{G}_m & \to & \mathbb{G}_m \oplus \mathbb{G}_2 & \to & \mathbb{G}_2 & \to & 0
\end{array}
\]

and the compatibility condition amounts to \( g|_{L_1} = 0 \) rationally. Then \( f \) factors rationally through \( \mathbb{G}_m \). Thus \( E \) is (rationally) the direct sum of a 2-extension of 0 by \([0 \to \mathbb{G}_m]\) and a 2-extension of \([\mathbb{Z} \to 0]\) by 0, hence is 0.

\[ \square \]

C.12.3. **Proposition.** In Proposition C.12.1, assume \( S \) semi-local. Then \( \mathcal{M}_1(S) \otimes \mathbb{Q} \) is of cohomological dimension \( \leq 1 \).

**Proof.** By Proposition C.12.1 and Lemma E.7.5, we are left to show that \( \text{Ext}^2(M, N) = 0 \) for \( M \) pure of weight 0 and \( N \) pure of weight \(-2\). Since we work with rational coefficients, we may by a transfer argument reduce to \( M = [\mathbb{Z} \to 0], N = [0 \to \mathbb{G}_m] \). Then

\[
\text{Ext}^2(M, N) \hookrightarrow \text{Ext}^1_\mathbb{G}(\mathbb{Z}, \mathbb{G}_m) \otimes \mathbb{Q} = H^{1}_\text{ét}(S, \mathbb{G}_m) \otimes \mathbb{Q}
\]

by Lemma C.12.2, and the latter group is 0 because \( S \) is semi-local and regular.

\[ \square \]

**Appendix D. Homotopy invariance for étale sheaves with transfers**

One of the main results of Voevodsky concerning presheaves with transfers is that, over a perfect field \( k \), a Nisnevich sheaf with transfers \( F \) is homotopy invariant (that is, \( F(X) \sim \to F(X \times \mathbb{A}^1) \) for any smooth \( X \)) if and only if it is strongly homotopy invariant, that is, \( H^i_{\text{Nis}}(X, F) \sim \to H^i_{\text{Nis}}(X \times \mathbb{A}^1, F) \) for any smooth \( X \) and any \( i \geq 0 \). This allows him to define the *homotopy t-structure* on \( \text{DM}_{\text{eff}}^\cdot \).

These results remain “as true as can be” in the étale topology, at least if \( k \) has finite étale cohomological dimension. According to an established tradition, this result is probably well-known to experts but we haven’t been able to find it in the literature: it could have been formulated and proven for example in [70]. The aim of this appendix is to provide proofs, for which our main source of results will be [70].

D.1. **Homotopy invariance and strict homotopy invariance.**

D.1.1. **Definition.** We denote as in [70, Def. 2.1] by \( \text{PST}(k) = \text{PST} \) the category of presheaves with transfers on smooth \( k \)-varieties. We
also denote by EST(\(k\)), or simply EST, the category of étale sheaves with transfers over \(k\).

According to [70, Def. 2.15 and 9.22]:

D.1.2. Definition. a) An object \(F\) of PST or EST is homotopy invariant if \(F(X) \sim \to F(X \times \mathbb{A}^1)\) for any smooth \(k\)-variety \(X\).

b) Let \(F \in\) EST. Then \(F\) is strictly homotopy invariant if \(H^i\text{ét}(X,F) \sim \to H^i\text{ét}(X \times \mathbb{A}^1,F)\) for any smooth \(k\)-variety \(X\) and any \(i \geq 0\).

We denote by \(\mathcal{H}^{s}\text{ét}(k) = \mathcal{H}^{s}\text{ét}\) the full subcategory of EST consisting of homotopy invariant sheaves, and by \(\mathcal{H}^{s}\text{ét}(k) = \mathcal{H}^{s}\text{ét}\) the full subcategory of \(\mathcal{H}^{s}\text{ét}\) consisting of strictly homotopy invariant sheaves.

(Strict homotopy invariance for \(F\) simply means that \(F\) is \(\mathbb{A}^1\)-local in \(\mathcal{D}^{-}\text{ET}\), see [70, Lemma 9.24].)

Note that \(\mathcal{H}^{s}\text{ét}\) is a thick abelian subcategory of EST: if \(0 \to F' \to F \to F'' \to 0\) is an exact sequence in EST, then \(F \in \mathcal{H}^{s}\text{ét}\) if and only if \(F', F'' \in \mathcal{H}^{s}\text{ét}\). We shall see below that the same is true for \(\mathcal{H}^{s}\text{ét}\).

The main example of a sheaf \(F\) which is in \(\mathcal{H}^{s}\text{ét}\) but not in \(\mathcal{H}^{s}\text{ét}\) is \(F = \mathbb{Z}/p\) in characteristic \(p\): because of the Artin-Schreier exact sequence we have

\[
\mathbb{k}[t]/\mathcal{P}(k[t]) \sim \to H^1_{\text{ét}}(\mathbb{A}^1_k, \mathbb{Z}/p)
\]

where \(\mathcal{P}(x) = x^p - x\).

We are going to show that this captures entirely the obstruction for a sheaf in \(\mathcal{H}^{s}\text{ét}\) not to be in \(\mathcal{H}^{s}\text{ét}\).

The following is an étale analogue of [70, Th. 13.8]:

D.1.3. Lemma. Let \(F\) be a homotopy invariant presheaf with transfers. Suppose moreover that \(F\) is a presheaf of \(\mathbb{Z}[1/p]\)-modules, where \(p\) is the exponential characteristic of \(k\). Then the associated étale sheaf with transfers [70, Th. 6.17] \(F'_{\text{ét}}\) is strictly homotopy invariant.

Proof. The following method is classical: let \(0 \to F' \to F \to F'' \to 0\) be an exact sequence of homotopy invariant presheaves with transfers, and consider the corresponding exact sequence \(0 \to F'_{\text{ét}} \to F_{\text{ét}} \to F''_{\text{ét}} \to 0\). If, among \(F'_{\text{ét}}, F_{\text{ét}}\) and \(F''_{\text{ét}}\), two are in \(\mathcal{H}^{s}_{\text{ét}}\), then clearly so is the third. Using the exact sequence

\[
0 \to F_{\text{tors}} \to F \to F \otimes \mathbb{Q} \to F \otimes \mathbb{Q}/\mathbb{Z} \to 0
\]

for the sheaf \(F\) of Lemma D.1.3, this reduces us to the following cases:

- \(F\) is a presheaf of \(\mathbb{Q}\)-vector spaces. Then the result is true by [70, Lemma 14.25] (reduction to [70, Th. 13.8] by the comparison theorem [70, Prop. 14.23]).
• $F$ is a presheaf of torsion abelian groups. Since, by assumption, this torsion is prime to $p$, $F_{\text{ét}}$ is locally constant by Suslin-Voevodsky rigidity [70, Th. 7.20]. Then the result follows from [SGA4, XV 2.2] (compare [70, Lemma 9.23]).

D.1.4. Proposition. The inclusion $\text{HI}^s_{\text{ét}} \rightarrow \text{HI}_{\text{ét}}$ has an exact left adjoint given by $F \mapsto F \otimes \mathbb{Z}[1/p]$. In particular, $\text{HI}^s_{\text{ét}} = \text{HI}_{\text{ét}}[1/p]$.

Proof. The fact that $\text{HI}^s_{\text{ét}}$ is $\mathbb{Z}[1/p]$-linear follows from the Artin-Schreier exact sequence plus the contractibility of $\mathbb{G}_a$ (compare [96, Prop. 3.3.3 2]). Conversely, Lemma D.1.3 implies that any $\mathbb{Z}[1/p]$-linear sheaf of $\text{HI}_{\text{ét}}$ belongs to $\text{HI}^s_{\text{ét}}$. The rest of the proposition follows.

As a complement, let us mention the following proposition, which extends Proposition D.1.4:

D.1.5. Proposition. Let $F \in \text{HI}_{\text{ét}}$. Then the complex $C_*(F)$ is canonically isomorphic to $F[1/p]$ in $\text{DM}^{-}_{\text{eff, ét}}$.

Proof. The map $F \rightarrow F[1/p]$ induces a map $C_*(F) \rightarrow C_*(F[1/p])$. The latter complex is tautologically equal to $C_*(F)[1/p]$. Since $\text{DM}^{-}_{\text{eff, ét}}$ is $\mathbb{Z}[1/p]$-linear, the map $C_*(F) \rightarrow C_*(F)[1/p]$ is a quasi-isomorphism. Finally, since $F[1/p] \in \text{HI}^s_{\text{ét}}$ (Prop. D.1.4), the augmentation $F[1/p] \rightarrow C_*(F[1/p])$ is a quasi-isomorphism by [70, Lemma 9.15].

D.1.6. Corollary. Let $F$ be a homotopy invariant Nisnevich sheaf with transfers. Then, the natural functor $\alpha^* : \text{DM}^{-}_{\text{eff}} \rightarrow \text{DM}^{-}_{\text{eff, ét}}$ sends $F$ to $F_{\text{ét}}[1/p]$.

Proof. According to [70, Remark 14.3], $\alpha^*$ may be described as the composition

$$\text{DM}^{-}_{\text{eff}} \hookrightarrow D^- (\text{Shv}_{\text{Nis}}(\text{Sm}(k))) \xrightarrow{\alpha^*} D^- (\text{Shv}_{\text{ét}}(\text{Sm}(k))) \xrightarrow{RC} \text{DM}^{-}_{\text{eff, ét}}$$

where the middle functor is induced by the inverse image functor (change of topology) on sheaves and $RC$ is induced by $K \mapsto C_*(K)$. The result then follows from Proposition D.1.5.

D.2. Friendly complexes.

D.2.1. Definition. A object $C \in D^- (\text{EST})$ is friendly if there exists an integer $N = N(C)$ such that, for any prime number $l \neq p$, $H_q(C/l) = 0$ for $q > N$ (in other terms, $C/l$ is uniformly bounded below). We denote by $D^-_{\text{fr}} (\text{EST})$ the full subcategory of friendly objects and by $\text{DM}^\text{eff}_{\text{fr, ét}}$ the intersection $D^-_{\text{fr}} (\text{EST}) \cap \text{DM}^\text{eff}_{\text{ét}}$. 

D.2.2. Theorem. $\text{DM}_{\text{gm, ét}}^{\text{eff}} \subset \text{DM}_{\text{ét}}^{\text{eff}}$.

Proof. If is clear that $D^{-}_{\text{et}}(\text{EST})$ is a thick triangulated subcategory of $D^{-}(\text{EST})$; hence it suffices to prove that $C_{*}(L(X))$ is friendly for any smooth scheme $X$. By [70, Lemmas 6.23 and 9.15], we have for any smooth $U$, any prime $l \neq p$ and any $q \in \mathbb{Z}$

$$\text{Hom}(C_{*}(L(X \times U)), \mathbb{Z}/l[q]) \simeq H^{q}_{\text{ét}}(X \times U, \mathbb{Z}/l)$$

hence

$$\mathcal{E}xt^{q}(C_{*}(L(X)), \mathbb{Z}/l) \simeq R^{q}_{\pi*}\mathbb{Z}/l$$

where $\pi : X \to \text{Spec} \, k$ is the structural morphism. By the cohomological dimension results of [SGA4, Exp. X] and the finiteness results of [SGA4 1/2, Th. finitude], this shows that $\text{Hom}_{\text{ét}}(C_{*}(L(X)), \mathbb{Z}/l)$ is a bounded complex of constructible $\mathbb{Z}/l$-sheaves. It follows that the biduality morphism

$$C_{*}(L(X))/l \to \text{Hom}_{\text{ét}}(\text{Hom}_{\text{ét}}(C_{*}(L(X)), \mathbb{Z}/l), \mathbb{Z}/l)$$

is an isomorphism of bounded complexes of constructible $\mathbb{Z}/l$-sheaves. Moreover, the lower bound is at most $2 \dim X$, hence is independent of $l$. \qed

D.3. The étale homotopy $t$-structure. The following is an étale analogue of [70, Prop. 14.8]:

D.3.1. Proposition. Let $K \in D^{-}(\text{EST})$ be a bounded above complex of étale sheaves with transfers. Suppose either that the étale cohomological dimension of $k$ is finite, or that $K$ is friendly. Then $K$ is $\mathbb{A}^{1}$-local if and only if all its cohomology sheaves are strictly homotopy invariant.

Proof. In the finite cohomological dimension case, “if” is trivial (cf. [70, Prop. 9.30]). For “only if”, same proof as that of [70, Prop. 14.8], by replacing the reference to [70, Th. 13.8] in loc. cit. by a reference to Lemma D.1.3 (note that if $K$ is $\mathbb{A}^{1}$-local, then it is $\mathbb{Z}[1/p]$-linear by [96, Prop. 3.3.3 2]) and thus so are its cohomology sheaves.

In the friendly case, note that the two conditions

- $\mathbb{A}^{1}$-local
- having strictly homotopy invariant cohomology sheaves

are stable under triangles: for the first it is obvious and for the second it is because $H^{0}_{\text{ét}}$ is thick in EST by Proposition D.1.4. Considering the exact triangle

$$K \to K \otimes \mathbb{Q} \to K \otimes (\mathbb{Q}/\mathbb{Z})' \xrightarrow{+1}$$

we are reduced to show the statement separately for $K \otimes \mathbb{Q}$ and for $K \otimes (\mathbb{Q}/\mathbb{Z})'$. In the first case this works by reduction to Nisnevich
cohomology, while in the second case the spectral sequence of [70, Prop. 9.30] also converges, this time because $K \otimes (\mathbb{Q}/\mathbb{Z})'$ is bounded below.

D.3.2. Remark. The finite cohomological dimension hypothesis appears in the spectral sequence arguments of the proofs of [70, Prop. 9.30 and 14.8]. We don’t know if it is really necessary.\footnote{It is not: see [57, C.5], which was devised after the present approach.} Nevertheless, Joël Riou pointed out that this argument trivially extends to fields of virtually finite cohomological dimension: the only issue is for the “if” part, but if we know that an object $K$ is $\mathbb{A}^1$-local étale-locally, then it is clearly $\mathbb{A}^1$-local. (For example, this covers all fields of arithmetic origin.) Therefore:

D.3.3. Corollary. If the virtual étale cohomological dimension of $k$ is finite, then $\text{DM}^\text{eff}_{\text{ét}}$ has a homotopy $t$-structure, with heart $\text{HI}^g_{\text{ét}}$, and the functor $\alpha^*: \text{DM}^\text{eff}_{\text{tr}} \to \text{DM}^\text{eff}_{\text{ét}}$ is $t$-exact. Without any cohomological dimension assumption, $\text{DM}^\text{tr}_{\text{tr},\text{ét}}$ has a homotopy $t$-structure.

\[\square\]

Appendix E. Weight filtrations

In this appendix, we propose a theory of weight filtrations adapted to our needs. This is closely related to U. Jannsen’s and A. Huber’s setting in [53] and [47, 1.2], and fits perfectly with S. Morel’s viewpoint in [73]. We relate it precisely to Jannsen’s approach in Remark E.7.8. The interested reader is encouraged to check that this theory behaves well with respect to the weight structure on $\text{DM}^\text{eff}_{\text{gm}}$ constructed by Bondarko in [24], via the realisation functors considered in Sect. 15. (See [25] since then.)

I. Filtrations of abelian categories

E.1. A glueing lemma. Let $\mathcal{A}$ be an abelian category. Consider two exact sequences

\[
\begin{align*}
0 \longrightarrow A' & \longrightarrow A & \longrightarrow A'' & \longrightarrow 0 \\
0 \longrightarrow B' & \longrightarrow B & \longrightarrow B'' & \longrightarrow 0
\end{align*}
\]

and two morphisms $f': A' \to B'$, $f'': A'' \to B''$. We say that $f: A \to B$ is a glueing of $f'$ and $f''$ if it yields a commutative diagram of exact sequences.

E.1.1. Lemma. Let $[A] \in \text{Ext}^1_\mathcal{A}(A'', A')$ and $[B] \in \text{Ext}^1_\mathcal{A}(B'', B')$ be the extension classes of $A$ and $B$. 
For a glueing to exist, it is necessary and sufficient that $f'_* [A] = f''^*[B] \in \text{Ext}^1_A (A'', B')$.

(2) For a glueing to be unique, it is necessary and sufficient that $\text{Hom}_A (A'', B') = 0$.

(3) Suppose that $\mathcal{A}$ is the heart of a triangulated category $\mathcal{T}$ provided with a $t$-structure. Then Condition (1) is equivalent to the following: the diagram

$$
\begin{array}{ccc}
A'' & \xrightarrow{[A]} & A'[1] \\
\downarrow f'' & & \downarrow f' \\
B'' & \xrightarrow{[B]} & B'[1]
\end{array}
$$

commutes in $\mathcal{T}$.

Proof. (1). The condition is clearly necessary, and it is sufficient since by definition, two extension classes are equal if there exists an isomorphism between the corresponding extensions.

(2) is obvious since a difference of two glueings is given by a map from $A''$ to $B'$.

(3) is clear by Axiom TR3 of triangulated categories. \qed

E.2. Extensions panachées. Let $\mathcal{A}$ still be an abelian category, and consider now a filtered object

$$0 \subseteq A_{-2} \subseteq A_{\leq -1} \subseteq A.$$

We write $A_{-1} = A_{\leq -1} / A_{-2}$, $A_0 = A / A_{\leq -1}$, $A_{> -2} = A / A_{-2}$, so that we have a commutative diagram of exact sequences

$$
\begin{array}{ccccccc}
0 & \to & A_{-2} & \xrightarrow{j} & A_{\leq -1} & \xrightarrow{\pi} & A_{-1} & \to & 0 \\
& & \downarrow \downarrow i & & \downarrow & & \downarrow \iota \\
0 & \to & A_{-2} & \xrightarrow{\tilde{j}} & A & \xrightarrow{\tilde{\pi}} & A_{> -2} & \to & 0
\end{array}
$$

(E.1)
From the viewpoint of [SGA7, Exp. IX, §9.3], this displays $A$ as an extension panachée\textsuperscript{16} of $A_{>-2}$ by $A_{<-1}$. We shall call the datum of this diagram minus $A$ a panachage datum (donnée de panachage). There is an obvious notion of morphism of panachage data.

The following is a variant of [19, §1].

**E.2.1. Lemma.** Given a panachage datum as above,

1. An extension panachée exists if and only if the Yoneda product of the extensions $A_{<-1}$ and $A_{>-2}$ is 0.
2. An extension panachée of $A_{>-2}$ by $A_{<-1}$ corresponds up to isomorphism to:
   i. an extension class $\alpha \in \text{Ext}^1_A(A_0, A_{<-1})$;
   ii. an extension class $\tilde{\alpha} \in \text{Ext}^1_A(A_{>-2}, A_{>-2})$;
   such that
   iii. $\pi_*\alpha = [A_{>-2}]$, $i^*\tilde{\alpha} = [A_{<-1}]$.
3. Let $A, A'$ be two extensions panachées, with classes $(\alpha, \tilde{\alpha}), (\alpha', \tilde{\alpha}')$ as in (1). Then $\alpha - \alpha'$ and $\tilde{\alpha} - \tilde{\alpha}'$ come from classes $\gamma, \delta \in \text{Ext}^1_A(A_0, A_{-2})$, well-defined modulo the images of $\text{Hom}_A(A_0, A_{-1})$ and $\text{Hom}_A(A_{-1}, A_{-2})$ respectively. Moreover, $\gamma = \delta \in \text{Coker} (\text{Hom}_A(A_0, A_{-1}) \oplus \text{Hom}_A(A_{-1}, A_{-2}) \rightarrow \text{Ext}^1_A(A_0, A_{-2}))$.

*Proof.* (1) is [SGA7, Exp. IX, 9.3.8 c]). (2) is obvious as well as the existence of $\gamma$ and $\delta$ in (3). The equality can be proven as in [19, lemme 2]. Another way to prove it is to consider the diagram

$\begin{align*}
\text{Hom}_A(A_{-1}, A_{-2}) & \\
\downarrow & \\
\text{Hom}_A(A_0, A_{-1}) \longrightarrow \text{Ext}^1_A(A_0, A_{-2}) & \longrightarrow \text{Ext}^1_A(A_0, A_{<-1}) \\
\text{Ext}^1_A(A_{>-2}, A_{-2}) & \longrightarrow \text{Ext}^1_A(A_{>-2}, A_{<-1})
\end{align*}$

and to apply a variant of [20, Lemma 2.8].

**E.3. The case of 3-step filtrations.** Let $\mathcal{A}$ still be an abelian category, and consider now two filtered objects

$0 \subseteq A_{-2} \subseteq A_{<-1} \subseteq A$

$0 \subseteq B_{-2} \subseteq B_{<-1} \subseteq B$.

\textsuperscript{16}L. Breen suggested \textit{blended extension} for an English translation: we learned this from D. Bertrand.
E.3.1. **Definition.** Suppose given morphisms \( f_i : A_i \to B_i \). A **glueing** of the \( f_i \) is a filtered morphism \( f : A \to B \) inducing the \( f_i \) on the associated graded. A **partial glueing** is a morphism of panachage data inducing the \( f_i \).

We want to find a condition for the \( f_i \) to glue. We shall make the following simplifying hypothesis:

E.3.2. **Hypothesis.** \( \text{Hom}_A(A_i, B_j) = 0 \) for \( i > j \).

E.3.3. **Proposition.**

1. If a glueing exists, it is unique.
2. A necessary condition is that Condition (1) or (2) of Lemma E.1.1 is satisfied for the pairs \( (f_{-2}, f_{-1}) \) and \( (f_{-1}, f_0) \), relative to the extensions \( A_{\leq -1}, B_{\leq -1} \) and \( A_{> -2}, B_{> -2} \).
3. Suppose the conditions of (2) are satisfied. Then we get a (unique) partial glueing.
4. Given a morphism of panachage data \( (f_{-2}, f_{-1}, f_0, f_{\leq -1}, f_{> -2}) \), we have two obstructions in \( \text{Ext}^1_A(A_0, B_{-2}) \) to the existence of a glueing, given respectively (with obvious notation) by \( (f_{\leq -1})_*[A] - f'_{0*}[B] \) and \( (f_{-2})_*[A] - f''_{\geq -2}[B] \).
5. The glueing exists if and only if either of the two obstructions of (4) vanishes.
6. If all \( f_n \) are isomorphisms, so is \( f \).

*Proof.* (1) is easy, (2) is clear and (3) follows from Lemma E.1.1.

For (4), we have to check that these extension classes, which are a priori respectively in \( \text{Ext}^1_A(A_0, B_{\leq -1}) \) and in \( \text{Ext}^1_A(A_{> -2}, B_{-2}) \), define unique elements of \( \text{Ext}^1_A(A_0, B_{-2}) \). For the existence, it suffices to see that their images in \( \text{Ext}^1_A(A_{-1}, B_{-2}) \) are 0, which follows from the conditions of (2), while the uniqueness follows from E.3.2.

(5) follows from Lemma E.1.1. (6) is clear. \( \square \)

E.3.4. **Remark.** It is likely that the two obstructions of Proposition E.3.3 (4) are opposite, but we don’t have a good proof.

E.4. **Right adjoints.** We let \( \mathcal{A} \) be an abelian category. Consider the situation

\[
0 \to \mathcal{A}' \xrightarrow{i} \mathcal{A} \xrightarrow{\pi} \mathcal{A}'' \to 0
\]

where \( \mathcal{A}' \subseteq \mathcal{A} \) is a thick subcategory and \( \pi \) is the corresponding localisation functor. Thus \( \mathcal{A}'' \) is the Serre quotient of \( \mathcal{A} \) by \( \mathcal{A}' \). Note that \( i \) and \( \pi \) are exact.
Let $A \in \mathcal{A}$. Recall that, by definition, the right adjoint $p$ of $i$ is defined at $A$ if the functor

$$\mathcal{A}' \ni B \mapsto \text{Hom}_\mathcal{A}(iB, A)$$

is representable. A representative object is then unique up to unique isomorphism: we write it $pA$ and call it the value of $p$ at $A$. We then have a canonical “counit” map

$$ipA \to A$$

given by the universal property of $pA$.

Define the following full subcategories of $\mathcal{A}$:

$$\mathcal{A}_1 = \{ A \in \mathcal{A} \mid p \text{ is defined at } A \}$$

$$\mathcal{B} = \{ B \in \mathcal{A}_1 \mid pB = 0 \}$$

(E.3) $\mathcal{A}_2 = \{ A \in \mathcal{A} \mid \exists \text{ exact sequence } 0 \to iA' \to A \to A'' \to 0$

with $A' \in \mathcal{A}', A'' \in \mathcal{B}$

$$\mathcal{B}' = \{ B \in \mathcal{B} \mid \text{Hom}_\mathcal{A}(B, iA') = 0 \}$$

$$\mathcal{A}_3 = \{ A \in \mathcal{A}_2 \mid A'' \in \mathcal{B}' \}.$$

E.4.1. **Proposition.**

1. For $A \in \mathcal{A}_1$, the counit map $f : ipA \to A$ is a monomorphism.
2. $\text{Hom}_\mathcal{A}(iA', \mathcal{B}) = 0$. In particular, $iA' \cap \mathcal{B} = 0$.
3. $\mathcal{A}_2 \subseteq \mathcal{A}_1$, with $A' = ipA$ for $A \in \mathcal{A}_2$. In particular, $A'$ is unique and functorial.
4. $\mathcal{A}_3$ is closed under subobjects and quotients (with induced filtrations); in particular, it is abelian, the inclusion functor $\mathcal{A}_3 \hookrightarrow \mathcal{A}$ is exact and morphisms in $\mathcal{A}_3$ are strictly compatible with the filtrations in the sense of [31, (1.1.5)].
5. The restriction of $p$ to $\mathcal{A}_3$ is exact.

**Proof.** (1) Since $\mathcal{A}'$ is thick in $\mathcal{A}$, $\text{Ker } f = i(K)$ for some $K \in \mathcal{A}'$. Thus we have an exact sequence

$$0 \to iK \to ipA \to A.$$ 

By adjunction, we get a complex (0-sequence) in $\mathcal{A}'$

$$K \to pA \xrightarrow{=} pA$$

which shows that $K \to pA$ is the 0 map. Hence $iK \to ipA$ is the 0 map, which means that $iK = 0$. Hence $f$ is a monomorphism.

(2) is obvious by adjunction. For “in particular”, if $C \in i\mathcal{A}' \cap \mathcal{B}$, then $1_C \in \text{Hom}_\mathcal{A}(C, C) = 0$. 

(3) Let \( A_1 \in \mathcal{A}' \). Then we have a short exact sequence

\[
0 \to \text{Hom}_A(iA_1', iA') \to \text{Hom}_A(iA_1', A) \to \text{Hom}_A(iA_1', A''')
\]

in which the last term is 0 by (2).

(4) easily follows from the condition \( \text{Hom}_A(B', iA') = 0 \).

(5) follows from (4). \( \square \)

E.4.2. Corollary. In the situation of (E.2), suppose that \( i \) has an everywhere defined right adjoint \( p \). Then the following conditions are equivalent:

(i) \( p \) is exact.

(ii) The full subcategory \( \text{Ker} p = \{ A \mid pA = 0 \} \) is stable under quotients and contains \( A/ipA \) for any \( A \in \mathcal{A} \).

(iii) In (E.3), \( \mathcal{A}_3 = \mathcal{A} \).

Proof. (i) \( \Rightarrow \) (ii): Applying \( p \) to the exact sequence

\[
0 \to ipA \to A \to A/ipA \to 0
\]

we get an exact sequence

\[
0 \to pA \overset{\sim}{\to} pA \to p(A/ipA) \to 0
\]

which shows that \( p(A/ipA) = 0 \). Moreover, \( \text{Ker} p \) is clearly stable under quotients.

(ii) \( \Rightarrow \) (iii): by hypothesis we have \( \mathcal{A}_2 = \mathcal{A} \), so we are left to show that \( \text{Hom}_A(\text{Ker} p, i\mathcal{A}') = 0 \). Let \( B \in \text{Ker} p, A' \in \mathcal{A}', f : B \to A' \) and \( C = \text{Im} f \). By (ii), \( C \in \text{Ker} p \); since \( i \) is thick, we also have \( C \in \mathcal{A}' \); hence \( C = 0 \) thanks to Proposition E.4.1 (2).

(iii) \( \Rightarrow \) (i): this follows from Proposition E.4.1 (5). \( \square \)

E.5. Split exact sequences. We are still in the situation of (E.2).

E.5.1. Proposition.

(1) The following conditions are equivalent:

(i) \( i \) has an exact right adjoint \( p \).

(ii) \( \pi \) has an exact right adjoint \( j \) and \( j(\mathcal{A}'') \) is thick in \( \mathcal{A} \).

(iii) For any \( A \in \mathcal{A} \) there exists \( A' \in \mathcal{A}' \) and a monomorphism \( i(A') \to A \) such that

\[
\text{Hom}_A(i(\mathcal{A}'), A/ip(A')) = \text{Ext}_A^1(i(\mathcal{A}'), A/ip(A')) = 0.
\]

(iv) Same as (iii), replacing the condition \( \text{Ext}_A^1(i(\mathcal{A}'), A/ip(A')) = 0 \) by \( \text{Hom}_A(A/ip(A'), i\mathcal{A}') = 0 \).

(2) If these conditions are verified, then for any \( A \in \mathcal{A} \) there exists a unique exact sequence

\[
0 \to iA' \to A \to jA'' \to 0
\]
such that $A' \in \mathcal{A}$ and $A'' \in \mathcal{A}'$; this sequence is functorial in $A$. Moreover, we have $\text{Hom}_{\mathcal{A}}(jA'', iA') = 0$ and $\text{Ext}^r_{\mathcal{A}}(iA', jA'') = 0$ for all $r \geq 0$.

(3) If $\mathcal{A}$ is semi-simple, the conditions of (1) are verified.

Proof. (1) (i) ⇒ (ii): Let $\mathcal{B} := \text{Ker} p$. By Corollary E.4.2 (ii), we have a functor $q : \mathcal{A} \to \mathcal{B}$ given by $qA = A/ipA$. The exactness of $i$ and $p$ plus the snake lemma show that $q$ is exact, and $q$ is easily seen to be left adjoint to the inclusion $\mathcal{B} \hookrightarrow \mathcal{A}$. Moreover $qA' = 0$, hence $q$ induces a functor $\overline{q} : \mathcal{A}' \to \mathcal{B}$.

On the other hand, we have the obvious functor $r : \mathcal{B} \to A \to A''$.

Let $B \in \mathcal{B}$. By definition, $\overline{q}rB$ is represented by $B/ipB = B$. This provides a natural isomorphism $B \sim \overline{q}rB$.

Let $A \in \mathcal{A}$. The projection $A \to A/ipA$ induces another natural isomorphism $A \sim r\overline{q}A$, where $A$ is now viewed in $\mathcal{A}'$. So $\overline{q}$ and $r$ are quasi-inverse equivalences of categories. Under this equivalence, $q$ becomes $\pi$, and the inclusion $\mathcal{B} \hookrightarrow \mathcal{A}$ defines a functor $j : \mathcal{A}' \to \mathcal{A}$, which is right adjoint to $\pi$. Finally, since $\mathcal{B} = \text{Ker} p$ is thick, $j(\mathcal{A}'')$ is thick.

(ii) ⇒ (iii): let $A \in \mathcal{A}$. The functor $\pi$ kills the kernel and cokernel of the unit map $f : A \to j\pi A$. By the thickness assumption, $\text{Coker} f \in j(\mathcal{A}'')$ which implies that $f$ is epi; on the other hand, we get $\text{Ker} f \in i(\mathcal{A}')$. Thus we have an exact sequence

$$0 \to iK \to A \to j\pi A \to 0.$$ 

If $A' \in \mathcal{A}'$, then

$$\text{Hom}(iA', j\pi A) = \text{Hom}(\pi iA', \pi A) = \text{Hom}(0, \pi A) = 0.$$ 

On the other hand, let $0 \to j\pi A \xrightarrow{\alpha} E \to iA' \to 0$ be an extension. Since $\pi i = 0$ and $\pi$ is exact, $\pi(\alpha)$ is an isomorphism. Its inverse $\pi(\alpha)^{-1} : \pi E \to \pi A$ yields by adjunction a map $\beta : E \to j\pi A$ and one verifies that $\beta$ is a retraction of $\alpha$.

(iii) ⇒ (i): let $A, B \in \mathcal{A}$, with $A', B' \in \mathcal{A}'$ as in (iii), and let $f : A \to B$ be a morphism. By assumption, the composition

$$iA' \to A \xrightarrow{f} B \to B/ipB'$$

is 0, hence $f$ induces a map $A' \to B'$. This shows that $A'$ is unique up to unique isomorphism (take $f = 1_{A'}$) and is functorial in $A$. Thus we have a functor $p : \mathcal{A} \to \mathcal{A}'$ mapping $A$ to $A'$, and exactly the same argument shows that, for $B \in \mathcal{A}'$, a map $iB \to A$ induces a map...
\( iB \to ipA \), hence \( B \to pA \) since \( i \) is fully faithful. This yields the claimed adjunction.

It remains to see that \( p \) is right exact. For this, we may apply the criterion (ii) of Corollary E.4.2. Let \( A \in \mathcal{A} \): then \( ip(A/ipA) \) is a subobject of \( A/ipA \), hence is 0 by the hypothesis \( \text{Hom}(i(A'), A/ipA) = 0 \). Thus \( A/ipA \in \text{Ker} p \). Let now \( B \in \text{Ker} p \) and \( C \) be a quotient of \( B \) so that we have an exact sequence

\[
\text{(E.4)} \quad 0 \to A \to B \to C \to 0.
\]

Note that \( A \in \text{Ker} p \). Pulling back the extension (E.4) via the monomorphism \( ipC \to C \), we get an extension of \( ipC \) by \( A \), which is split by hypothesis. A given splitting yields a monomorphism \( f : ipC \to B \), which is 0 again by hypothesis, and finally \( C \in \text{Ker} p \).

(i) \( \Rightarrow \) (iv): this follows from (i) \( \Rightarrow \) (iii) in Corollary E.4.2 and from Proposition E.4.1 (2).

(iv) \( \Rightarrow \) (i): in (iv), the condition \( \text{Hom}_A(i(A'), A/i(A')) = 0 \) implies a fortiori that \( p \) is defined at \( A \), with value \( A' \). This condition is then equivalent to \( p(A/iA') = 0 \), thus (iv) implies Condition (iii) in Corollary E.4.2.

(2) Everything follows from (1), except the vanishing of the higher Ext’s; the claimed exact sequence is given by

\[
\text{(E.5)} \quad 0 \to ipA \to A \to j\pi A \to 0.
\]

For \( \text{Ext}^r \) with \( r > 0 \), we argue by induction on \( r \). This reduces us to show that, for all \( r > 0 \) and all \( A' \in \mathcal{A}' \), the functor

\[
\mathcal{A}'' \ni A'' \mapsto \text{Ext}_A^r(iA', jA'')
\]

is effaceable.

Let \( \mathcal{E} \in \text{Ext}_A^r(iA', jA'') \), represented by the exact sequence

\[
0 \to jA'' \xrightarrow{f} E_1 \to \cdots \to E_r \to iA' \to 0.
\]

Clearly, \( f_* \mathcal{E} = 0 \in \text{Ext}_A^r(iA', E_1) \) (to see this, let \( F = \text{Coker} f \), and note that \( \mathcal{E} \) is the image of \( [0 \to F \to E_2 \to \cdots \to E_r \to iA' \to 0] \in \text{Ext}_A^{r-1}(iA', F) \) by the boundary map associated to the exact sequence \( 0 \to jA'' \to E_1 \to F \to 0 \)). A fortiori, \( \mathcal{E} \) maps to 0 under the composition

\[
\text{Ext}_A^r(iA', jA'') \xrightarrow{f} \text{Ext}_A^r(iA', E_1) \to \text{Ext}_A^r(iA', j\pi E_1).
\]

It remains to observe that the composition \( jA'' \to E_1 \to j\pi E_1 \) is a monomorphism: indeed, it is the image of the monomorphism \( jA'' \to E_1 \) under the exact functor \( j\pi \).
Let $I$ be the set of isomorphism classes of simple objects of $\mathcal{A}$, and $J$ the subset of $I$ defined by simple objects of $\mathcal{A}$ belonging to $\mathcal{A}'$. For any $A \in \mathcal{A}$, we have a direct sum decomposition

$$A = A_J \oplus A_{I-J}$$

where $A_J$ (resp. $A_{I-J}$) is the sum of simple subobjects of $A$ whose class belongs to $J$ (resp. to $I-J$). Clearly, $A_J \in \mathcal{A}'$, and $\text{Hom}(A_J, A_{I-J}) = 0$. Also, $\text{Ext}^1(A_J, A_{I-J}) = 0$ since $\mathcal{A}$ is semi-simple. Thus Condition (iii) of (1) is satisfied.

**E.5.2. Definition.** In the situation of Proposition E.5.1, we say that the exact sequence (E.2) is split.

We shall need the following lemma:

**E.5.3. Lemma.** In the situation of Proposition E.5.1, let $\mathcal{B}$ be an additive category and let $E : \mathcal{A}'' \to \mathcal{B}$, $F : \mathcal{A}' \to \mathcal{B}$ be two additive functors. Then a natural transformation $E\pi \Rightarrow F\pi$ on $\mathcal{A}$ is equivalent to a bivariant transformation

$$\text{Ext}_A^*(jA'', iA') \to \text{Hom}_\mathcal{B}(E(A''), F(A'))$$

on $\mathcal{A}'' \times \mathcal{A}'$.

*Proof.* Let $u_A : E\pi A \to F\pi A$ be a natural transformation. For $(A', A'') \in \mathcal{A}' \times \mathcal{A}''$ and two extensions $A_1, A_2$ of $jA''$ by $iA'$ in $\mathcal{A}$, the Baer sum $A_1 \oplus A_2$ may be obtained as $\Delta^*\Sigma_*(A_1 \oplus A_2)$, where $\Delta : jA'' \to jA'' \oplus jA''$ is the diagonal map and $\Sigma : iA' \oplus iA' \to iA'$ is the sum map. Since $u_{A_1 \oplus A_2} = u_{A_1} + u_{A_2}$, this implies that $u_{A_1 \oplus A_2} = u_{A_1} + u_{A_2}$ so that $u$ induces a homomorphism as in the lemma. The converse will not be used and is left to the interested reader. \qed

**E.6. More adjoints.** Assume that (E.2) is split. Let us now consider the conditions

(b) $j$ has a right adjoint $\pi'$.

(♯) $i$ has a left adjoint $p'$.

Recall that, under (b), we get a canonical natural transformation $\alpha : \pi' \Rightarrow \pi$ from the composition $j\pi'A \to A \to j\pi A$ for any $A \in \mathcal{A}$, and the full faithfulness of $j$. Similarly, under (♯), we get a canonical natural transformation $\beta : p \Rightarrow p'$.

**E.6.1. Proposition.** We have (b) $\iff$ (♯). If this holds, then $\pi'i = 0$, $p'j = 0$, the natural transformation $\alpha$ is a monomorphism and the natural transformation $\beta$ is an epimorphism.

If $\mathcal{A}''$ is Noetherian (resp. $\mathcal{A}'$ is Artinian), then (b) (resp. (♯)) holds.
Proof. Suppose that $\pi'$ exists. Since $\text{Hom}_A(jA'', iA') = 0$ (Proposition E.5.1 (2)), we have $\text{Hom}_{A'}(\pi''A', \pi'iA') = 0$, i.e., $\pi'i = 0$. Note that $\pi'$ is left exact, as a right adjoint. Let now $A \in A$. Applying $\pi'$ to the exact sequence (E.5), we get an exact sequence

$$0 \to 0 = \pi'iA \to \pi'\cong \piA.$$

This shows that $\alpha_A$ is injective. Dually, if $p'$ exists then $p'j = 0$ and $\beta$ is an epimorphism.

Suppose that $\pi'$ exists. Let $A \in A$, $A' \in A'$: the exact sequence

$$0 \to \text{Hom}_A(A/j\pi'\cong, iA') \to \text{Hom}_A(A, iA') \to \text{Hom}_A(j\pi'\cong, iA') = 0$$

shows that $A \mapsto A/j\pi'\cong$ defines a left adjoint $p'$ to $i$. We get the reverse implication by the dual reasoning.

It remains to prove the last assertions. Let $A \in A$. For a subobject $B$ of $\pi\cong$, consider the pull-back $A' \overset{\varphi}{\to} jB$ of the map $A \to j\pi\cong$. We define $\pi'\cong$ as the largest $B$ such that $\varphi$ is split; clearly, $\pi'\cong$ is functorial in $A$. Moreover, a splitting of $\varphi$ is unique (still by Proposition E.5.1 (2)), hence defines a natural transformation

$$\varepsilon_A : j\pi'\cong \to A' \to A.$$

On the other hand, $\pi'j$ is clearly the identity functor; define then for $A'' \in A''$ a unit map $\eta_{A''} : A'' \to \pi'jA''$ as the identity map. The adjunction identities are readily checked. The case of (1) is dealt with dually. $\square$

E.7. Filtrations.

E.7.1. Definition. Let $A$ be an abelian category.

a) A filtration on $A$ is a sequence of thick subcategories

(E.6) \( \cdots \overset{i_{n+1}}{\to} A_{\leq n+1} \overset{i_n}{\to} A_{\leq n} \overset{i_{n-1}}{\to} \cdots \to A \).

It is separated if $\bigcap A_{\leq n} = \{0\}$ and exhaustive if $A = \bigcup A_{\leq n}$.

b) A filtration on $A$ is split if all $i_n$ have exact right adjoints.

E.7.2. Definition. A filtration on $A$ is a weight filtration if it is separated, exhaustive and split.

Let $A$ be provided with a split filtration (Definition E.7.1). Define

$$A_n = A_{\leq n}/A_{\leq n-1}, \quad A_{n,n+1} = A_{\leq n+1}/A_{\leq n-1}$$

so that we have exact sequences

(E.7) \( 0 \to A_n \overset{i_n}{\to} A_{n,n+1} \overset{\pi_n}{\to} A_{n+1} \to 0 \).
where $i_n$ is induced by $\iota_n$. Let us write $j_n$ for the right adjoint of the localisation functor $\mathcal{A}_{\leq n} \to \mathcal{A}_{\leq n}/\mathcal{A}_{\leq n-1}$ (Proposition E.5.1). By abuse of notation, we shall identify $\mathcal{A}_n$ with its thick image in $\mathcal{A}$ via $j_n$ (ibid.).

E.7.3. Lemma. If $\iota_n$ (E.6) has a right (resp. left) adjoint, so does $i_n$ (E.7). If one is exact, so is the other.

Proof. We have a diagram of exact sequences of abelian categories:

\[
\begin{array}{ccccccc}
\mathcal{A}_{\leq n-1} & \longrightarrow & \mathcal{A}_{\leq n-1} \\
\iota_{n-1} \downarrow & & \iota_n \iota_{n-1} \downarrow \\
0 & \longrightarrow & \mathcal{A}_{\leq n} & \longrightarrow & \mathcal{A}_{\leq n+1} & \longrightarrow & \mathcal{A}_{n+1} & \longrightarrow & 0 \\
\pi_{n-1} \downarrow & & q_{n-1} \downarrow & & \downarrow \\
0 & \longrightarrow & \mathcal{A}_n & \longrightarrow & \mathcal{A}_{n,n+1} & \longrightarrow & \mathcal{A}_{n+1} & \longrightarrow & 0.
\end{array}
\]

Let $\varpi_n$ be a right adjoint to $\iota_n$. Since $\iota_n$ is fully faithful, the unit map $\eta_n : Id_{\mathcal{A}_{\leq n}} \Rightarrow \varpi_n \iota_n$ is an isomorphism. Hence $\varpi_n(\iota_{n-1} \mathcal{A}_{\leq n-1}) \subseteq \iota_{n-1} \mathcal{A}_{\leq n-1}$ and $\varpi_n$ induces a functor $\pi_n : \mathcal{A}_{n,n+1} \to \mathcal{A}_n$. Let $\varepsilon_n : \iota_n \varpi_n \Rightarrow Id_{\mathcal{A}_{n,n+1}}$ be the counit map of the adjunction: then $\eta_n$ and $\varepsilon_n$ induce natural transformations $p_{n-1} \ast \eta_n : Id_{\mathcal{A}_n} \Rightarrow p_n \iota_n$ and $q_{n-1} \ast \varepsilon_n : i_n p_n \Rightarrow Id_{\mathcal{A}_{n,n+1}}$. Since $\eta_n$ and $\varepsilon_n$ verify the identities of [68, p. 82, Th. 1 (8)], these identities are preserved when applying $p_{n-1}$ and $q_{n-1}$, hence $p_{n-1} \ast \eta_n$ and $q_{n-1} \ast \varepsilon_n$ define an adjunction between $i_n$ and $p_n$ by ibid., p. 83, Th. 2 (v). (Alternately, one can check directly that $p_n$ is right adjoint to $i_n$.) The assertion on exactness is true because the functor $q_{n-1}$ is exact. The reasoning is the same for a left adjoint. □

E.7.4. Proposition. Suppose that $\mathcal{A}$ is provided with an exhaustive split filtration as in Definition E.7.1 a), b). Then:

1. Every object $A \in \mathcal{A}$ is provided with a unique filtration

\[
\cdots \subseteq A_{\leq n} \subseteq A_{\leq n+1} \subseteq \cdots \subseteq A
\]

with $A_{\leq n} \in \mathcal{A}_{\leq n}$ and $A_n := A_{\leq n}/A_{\leq n-1} \in \mathcal{A}_n$. One has $A_{\leq n} = A$ for $n$ large enough.

2. The functors $A \mapsto A_{\leq n}$ and $A \mapsto A_n$ are exact, as well as $A \mapsto A_{\geq n} := A/A_{\leq n-1}$.

3. If moreover the filtration is separated, the $A \mapsto A_n$ form a set of conservative functors.

4. We have $\text{Hom}_\mathcal{A}(A_n, A_{\leq n-1}) = 0$ and $\text{Ext}^i_\mathcal{A}(A_{\leq n-1}, A_n) = 0$ for all $i \geq 0$ for all $n \in \mathbb{Z}$ and $i \geq 0$. 
Proof. (1) Since $\mathcal{A} = \bigcup \mathcal{A}_{\leq n}$, there exists $n_0$ such that $A \in \mathcal{A}_{\leq n_0}$. For $n < n_0$, write $I_n$ for the inclusion $\mathcal{A}_{\leq n} \to \mathcal{A}_{\leq n_0}$ and $P_n$ for its right adjoint, which exists and is exact as a composition of the right adjoints of the $\iota_r$ for $n \leq r < n_0$. Define

$$A_{\leq n} = I_n P_n A.$$

Since $A = \iota_{n_0} \varpi_{n_0} A$, $A_{\leq n}$ does not depend on the choice of $n_0$, and we have a filtration of $A$ as in Proposition E.7.4. Clearly, $A_{\leq n} \in \mathcal{A}_{\leq n}$ and $A_{\leq n_0} = A$. The fact that $A_{\leq n} \in \mathcal{A}_{\leq n}$ follows from Proposition E.5.1 (2), which also shows the uniqueness of the filtration.

(2) This still follows from Proposition E.5.1 (2).

(3) Let $f : A \to B$ be such that $f_n : A_n \to B_n$ is an isomorphism for all $n \in \mathbb{Z}$. Let $K = \ker f$ and $C = \text{coker } f$. By exactness, $K_n = C_n = 0$ for all $n$. Thus $K, C \in \bigcap A_{\leq n} = 0$ and $f$ is an isomorphism.

(4) This follows from Proposition E.5.1 (2) again. \hfill $\Box$

E.7.5. Lemma. Assume given a weight filtration $\mathcal{A}_{\leq n}$ on $\mathcal{A}$ and assume that the categories $\mathcal{A}_n$ are semi-simple. Let $A \in \mathcal{A}_m$ and $B \in \mathcal{A}_n$. Then, $\text{Ext}^i_A(A, B) = 0$ if $i > m - n$.

Proof. By induction on $i$. For $i = 0$, it means that $\text{Hom}_A(A, B) = 0$ if $m < n$, which is true by E.7.4 (4). For $i = 1$, it means that $\text{Ext}^1_A(A, B) = 0$ if $m \leq n$: for $m < n$ this is still E.7.4 (4) and for $m = n$ it comes from the semi-simplicity of $\mathcal{A}_n$ and its thickness in $\mathcal{A}$ (E.5.1 (1) (ii)).

Suppose now $i > 1$ and $m - n < i$. Let $\alpha \in \text{Ext}^i_A(A, B)$. We may write $\alpha$ as a Yoneda product

$$\alpha = \gamma \beta$$

with $\beta \in \text{Ext}^1_A(A, C)$ and $\gamma \in \text{Ext}^{i-1}_A(C, B)$ for some $C \in \mathcal{A}$. By induction, the map

$$\text{Ext}^{i-1}_A(C_{\geq n+i-1}, B) \to \text{Ext}^{i-1}_A(C, B)$$

is surjective, hence we may assume $C \in \mathcal{A}_{\geq n+i-1}$. But then $\text{Ext}^i_A(A, C) = 0$ and we are done. \hfill $\Box$

E.7.6. Definition. Let $\mathcal{A}$ be provided with an exhaustive split filtration. Let $A \in \mathcal{A}$. We say that $A$ has finite length if $A_{\leq n} = 0$ for $n$ small enough. The length of $A$ is then the integer

$$\ell(A) = n - m$$

where $n$ is the smallest integer such that $A_{\leq n} = A$ and $m$ is the largest integer such that $A_{\leq m} = 0$. 
E.7.7. Lemma. Let $\mathcal{A}$ be provided with a weight filtration $(\mathcal{A}_{\leq n}, t_n)$. Let $A, B \in \mathcal{A}$, with $B$ of finite length. Let $f : A \to B$ be a morphism such that $f_n : A_n \to B_n$ is 0 for all $n$. Then $f = 0$.

Proof. The assumption implies that $f(A_{\leq n}) \subseteq B_{\leq n-1}$ for all $n \in \mathbb{Z}$. Hence $f$ induces morphisms $f^{(1)}_n : A_n \to B_{n-1}$, which are 0 by Proposition E.7.4 (4). Inductively on $k$, we get $f(A_{\leq n}) \subseteq B_{\leq n-k}$ for all $n \in \mathbb{Z}$ and all $k \geq 0$. For $n$ large enough we have $A_{\leq n} = A$ and for $k$ large enough we have $B_{\leq n-k} = 0$, hence $f = 0$. □

E.7.8. Remark. If $\mathcal{A}$ is provided with a weight filtration such that every object has finite length, then the functors $\mathcal{A} \mapsto \mathcal{A}_{\leq n}$ of Proposition E.7.4 (1) verify Jannsen's conditions in [53, p. 83, Def. 6.3 a)]. Conversely, let as in loc. cit. $(W_n)_{n \in \mathbb{Z}}$ be an increasing sequence of exact subfunctors of $\text{Id}_A$ such that, for all $A \in \mathcal{A}$, one has $W_n A = 0$ for $n \ll 0$ and $W_n A = A$ for $n \gg 0$. Define $\mathcal{A}_{\leq n}$ as the full subcategory of $\mathcal{A}$ consisting of objects $A$ such that $W_n A = A$. This filtration is clearly separated and exhaustive in the sense of Definition E.7.1. Moreover, for all $n \in \mathbb{Z}$, $\iota_n : \mathcal{A}_{\leq n} \hookrightarrow \mathcal{A}_{\leq n+1}$ has the exact right adjoint $W_n$, so our filtration is also split. Summarising, the datum of a weight filtration as in [53, p. 83, Def. 6.3 a)] is equivalent to that of a weight filtration in the sense of Definition E.7.2 for which every object has finite length.

In view of this remark, the following is an abstract version of [53, p. 87, Ex. 6.8]:

E.7.9. Proposition. Let $\mathcal{A}$ be provided with a filtration $(\mathcal{A}_{\leq n})_{n \in \mathbb{Z}}$. For each $n \in \mathbb{Z}$, let $\mathcal{A}'_n$ be a full subcategory of $\mathcal{A}_{\leq n}$ such that

(i) For all $n \in \mathbb{Z}$, $\mathcal{A}'_n$ is abelian.
(ii) For $m \neq n$, $\text{Hom}_A(\mathcal{A}'_m, \mathcal{A}'_n) = 0$.

Let $\mathcal{A}'$ be the full subcategory of $\mathcal{A}$ consisting of objects $A$ admitting a finite increasing filtration $(A_{\leq n})$ with

(i) $A_{\leq n} = 0$ for $n \ll 0$.
(ii) $A_{\leq n} = A$ for $n \gg 0$.
(iii) $A_{\leq n}/A_{\leq n-1} \in \mathcal{A}'_n$ for all $n \in \mathbb{Z}$.

Then $\mathcal{A}'$ is an abelian subcategory of $\mathcal{A}$, closed under subobjects and quotients. The above filtration is unique for any $A \in \mathcal{A}'$, and any morphism is strict. If $\mathcal{A}'_{\leq n} := \mathcal{A}' \cap \mathcal{A}_{\leq n}$, then the filtration $\mathcal{A}'_{\leq n}$ is a weight filtration and any object of $\mathcal{A}'$ has finite length.

Proof. In principle this follows from Proposition E.4.1 by induction, but it would be tedious to write up (the induction would have to bear on the length of the filtration of an object). Instead, we observe that the proof in [53, p. 88, Lemma 6.8.1] shows that $\mathcal{A}'$ is provided with a
weight filtration in the sense of [53, p. 83, Def. 6.3 a)], and we apply Remark E.7.8.

II. Morphisms of filtered categories

E.8. The case of a 2-step filtration.

E.8.1. Proposition. Let $0 \to A' \to A \to A'' \to 0$ and $0 \to B' \to B \to B'' \to 0$ be as in (E.2), and consider a naturally commutative diagram of exact functors

$$
\begin{array}{cccccc}
0 & \to & A' & \xrightarrow{i} & A & \xrightarrow{\pi} & A'' & \to & 0 \\
& & R' & \downarrow R & \downarrow R & & \\
0 & \to & B' & \xrightarrow{j'} & B & \xrightarrow{\pi'} & B'' & \to & 0.
\end{array}
$$

Suppose that the two rows are split in the sense of Definition E.5.2; we use the notation $(p, j)$ (resp. $(p', j')$) for the corresponding adjoints.

Then the following are equivalent:

(i) The natural “base change” transformation $R'p \Rightarrow p'R$ of §15.1 is a natural isomorphism.

(ii) $Rj \Rightarrow j'R''$ is a natural isomorphism.

(iii) $R(jA'') \subseteq j'B''$.

Proof. Let $A \in A$. We have a commutative diagram of exact sequences (using (E.5) and the base change morphisms):

$$
\begin{array}{cccccc}
0 & \to & R(ipA) & \to & R(A) & \to & R(j\pi A) & \to & 0 \\
& & \downarrow & & \| & & \downarrow & & \\
0 & \to & i'p'R(A) & \to & R(A) & \to & j'\pi'R(A) & \to & 0.
\end{array}
$$

Thus the left vertical map is an isomorphism if and only if the right vertical map is one, which shows that (i) $\iff$ (ii). If this is the case, then $R(j\pi A) \subseteq j'(B')$, hence (iii). Conversely, if (iii) holds, then all vertical maps must be isomorphisms by the uniqueness of (E.5). □

E.9. The general case.

E.9.1. Definition. Let $A$ and $B$ two filtered abelian categories $(A_{\leq n}, t_n)$, $(B_{\leq n}, t'_n)$ as in Definition E.7.1. Let $R : A \to B$ be an additive functor.

(1) We say that $R$ respects the filtration if it is exact and $R(A_{\leq n}) \subseteq B_{\leq n}$.

(2) Suppose that the two filtrations are split. We say that $R$ respects the splittings if, moreover, $R(A_n) \subseteq B_n$ for all $n \in \mathbb{Z}$. 
(3) We denote by \( R_{\leq n} : A_{\leq n} \rightarrow B_{\leq n} \) the restriction of \( R \) to \( A_{\leq n} \) and by \( R_n : A_n \rightarrow B_n \) its restriction to \( A_n \), if applicable.

E.9.2. Lemma. Let \( A, B, R \) be as in Definition E.9.1. Suppose that the filtrations of \( A \) and \( B \) are exhaustive and split. Then:

1. If every object of \( A \) has finite length in the sense of Definition E.7.6, then \( R \) respects the splittings provided \( R(A_n) \subseteq B_n \) for all \( n \).
2. If \( R \) respects the splittings, then for all \( n \in \mathbb{Z}, R_{\leq n} \) and \( R_n \) are exact.
3. Let \( A \in A \). Then \( R(A_{\leq n}) = R(A)_{\leq n} \) and \( R(A_n) \overset{\sim}{\rightarrow} R(A) \) for any \( n \in \mathbb{Z} \).

Proof. (1) Let \( A \in A \). We have to show that, if \( A \in A_{\leq n} \), then \( R(A) \in B_{\leq n} \). We argue by induction on the length \( \ell(A) \) of the weight filtration on \( A \). If \( \ell(A) = 0 \), then \( A = 0 \) this is clear. If \( \ell(A) > 0 \), we may assume \( n \) minimal. Then \( \ell(A_{\leq n-1}) = \ell(A) - 1 \), hence \( R(A_{\leq n-1}) \in B_{\leq n-1} \), and the exact sequence

\[
0 \rightarrow R(A_{\leq n-1}) \rightarrow R(A) \rightarrow R(A_n) \rightarrow 0
\]

with \( R(A_n) \in B_n \) shows that \( R(A) \in B_{\leq n} \).

(2) This follows from the exactness of the inclusions \( \iota_n \) and \( j_n \), and from the faithful exactness of the \( \iota'_n \) and \( j'_n \).

(3) Let \( A \in A_{\leq n_0} \); then \( R(A) \in B_{\leq n_0} \). For \( n < n_0 \), let \( I'_n \) be the inclusion \( B_{\leq n} \rightarrow B_{n_0} \) and \( P'_n \) its exact right adjoint. We have

\[
R(A_{\leq n}) = I'_n P'_n R(A_{\leq n}) \subseteq I'_n P'_n R(A) = R(A)_{\leq n}.
\]

For equality, consider the commutative diagram of exact sequences

\[
\begin{array}{cccccc}
0 & \rightarrow & R(A_{\leq n}) & \rightarrow & R(A) & \rightarrow & R(A_{\geq n+1}) & \rightarrow & 0 \\
& & a \downarrow & & || \downarrow & & b \downarrow & & \\
0 & \rightarrow & R(A)_{\leq n} & \rightarrow & R(A) & \rightarrow & R(A)_{\geq n+1} & \rightarrow & 0.
\end{array}
\]

(see Proposition E.7.4 (2) for \( A_{\geq n+1} \)). Let \( A_{[n,n_0]} \) be the image of \( A_{\leq n_0} / A_{\leq n} \) by the exact right adjoint of the localisation functor, and similarly for \( B \) (see Proposition E.5.1 (1)). Note that \( R(A_{[n,n_0]}) \subseteq B_{[n,n_0]} \) because \( R(A_i) \subseteq B_i \) for all \( i > n \). Hence \( R(A_{> n}) \in B_{[n,n_0]} \). The snake lemma shows that \( \text{Ker } b \overset{\sim}{\rightarrow} \text{Coker } a \in B_{[n,n_0]} \cap B_{\leq n} = 0 \).

The last claim follows. \( \square \)

III. Glueing natural transformations
E.10. The case of a 2-step filtration. Let \( 0 \to A' \overset{i}{\to} A \overset{\pi}{\to} A'' \to 0 \) and \( 0 \to B' \overset{i'}{\to} B \overset{\pi'}{\to} B'' \to 0 \) be as in (E.2), and consider two naturally commutative diagrams of exact functors

\[
\begin{array}{ccc}
0 & \longrightarrow & A' \\
R_n' & \downarrow & R_n \\
0 & \longrightarrow & A'' \\
\end{array}
\quad \begin{array}{ccc}
0 & \longrightarrow & B' \\
R_n' & \downarrow & R_n \\
0 & \longrightarrow & B'' \\
\end{array}
\]

for \( n = 1, 2 \). We assume that the conditions of Proposition E.8.1 are satisfied for \( n = 1, 2 \). We also assume given two natural transformations \( u' : R'_1 \Rightarrow R'_2 \) and \( u'' : R''_1 \Rightarrow R''_2 \).

E.10.1. Definition. A glueing of \( u' \) and \( u'' \) is a natural transformation \( u : R_1 \Rightarrow R_2 \) such that, for any \( A \in \mathcal{A} \), the diagram

\[
\begin{array}{ccc}
0 & \longrightarrow & i'R'_1(pA) \\
\downarrow i'(u'_{pA}) & & \downarrow u_{pA} \\
0 & \longrightarrow & i'R'_2(pA) \\
\end{array}
\quad \begin{array}{ccc}
0 & \longrightarrow & j'R'_1(A) \\
\downarrow j'(u'_{pA}) & & \downarrow j'(u''_{pA}) \\
0 & \longrightarrow & j'R'_2(A) \\
\end{array}
\]

commutes.

E.10.2. Theorem.

1. For the existence of \( u \), the following condition is necessary: for any \( (A', A'') \in \mathcal{A}' \times \mathcal{A}'' \), the diagram

\[
\begin{array}{ccc}
\text{Ext}^i_A(jA'', iA') & \overset{\overline{R}_1}{\longrightarrow} & \text{Ext}^i_B(j'R''_1A'', i'R'_1A') \\
\downarrow \overline{R}_2 & & \downarrow i'(u'_{A'})^* \overset{\text{Ext}^i_B(j'R''_2A'', i'R'_2A')}{\longrightarrow} \\
\text{Ext}^i_B(j'R''_1A'', i'R'_1A') & \overset{j'(u''_{A''})^*}{\longrightarrow} & \text{Ext}^i_B(j'R''_2A'', i'R'_2A') \\
\end{array}
\]

commutes for \( i = 0, 1 \), where \( \overline{R}_n \) denotes the composition of \( R_n \) with suitable natural isomorphisms.

We may view this obstruction as a bivariant natural transformation

\[
i'(u'_{A'}) \overline{R}_1 - j'(u''_{A''})^* \overline{R}_2 : \text{Ext}^i_A(jA'', iA') \to \text{Ext}^i_B(j'R''_1A'', i'R'_2A').
\]

2. Suppose that \( B \) is the heart of a \( t \)-structure on a triangulated category \( \mathcal{T} \). Then the condition of (1) for \( i = 1 \) is equivalent to
the following: for any \((A', A'') \in \mathcal{A} \times \mathcal{A}'',\) the diagram
\[
\begin{array}{c}
j'_! R'_1(\pi A) \xrightarrow{[R'_1(A)]} i'_! R'_1(pA)[1] \\
j'(u''_p A) \downarrow \quad \downarrow i'(u'_p A)
\end{array}
\]
\[
\begin{array}{c}
j'_! R'_2(\pi A) \xrightarrow{[R'_2(A)]} i'_! R'_2(pA)[1] \\
j'(u'' A) \downarrow \quad \downarrow i'(u'_ A)
\end{array}
\]
commutes in \(\mathcal{T}.'\)

(3) Suppose that Condition (i) of Proposition E.6.1 holds for \(\mathcal{B}.'\)
Then \(u\) exists and is unique if and only if the Condition in (1)
is satisfied for \(i = 1.'\)

(4) \(u\) is a natural isomorphism if and only if \(u'\) and \(u''\) are.

Proof. (1) This is clear for \(n = 0,'\) and for \(n = 1\) it follows by applying
\(u\) to exact sequences of type (E.5).

(2) and (3) follow from Lemma E.1.1.

(4) “Only if” is obvious since \(u'\) and \(u''\) are restrictions of \(u\) to \(\mathcal{A}'\)
and \(\mathcal{A}''\), and “if” is obvious by the snake lemma. \(\square\)

E.11. The case of filtered categories. We now generalise Theorem
E.10.2 to abelian categories provided with weight filtrations.

Let \(\mathcal{A}, \mathcal{B}\) be two abelian categories, filtered in the sense of Definition
E.7.1. We assume that the filtrations are weight filtrations (Definition
E.7.2).

We slightly change notation and consider two exact functors \(T, T': \mathcal{A} \to \mathcal{B}\)
which respect the splittings in the sense of Definition E.9.1.
By Lemma E.9.2 (2), we then have for every object \(A \in \mathcal{A}:'\)
\[
T(A \leq_n) = T(A)_{\leq n}, \quad T'(A \leq_n) = T'(A)_{\leq n}.
\]

If \(u : T' \Rightarrow T\) is a natural transformation, then \(u_A\) maps \(T'(A_{\leq n})\)
to \(T(A_{\leq n})\), hence \(u\) induces natural transformations \(u_{\leq n} : T'_{\leq n} \Rightarrow T_{\leq n}\)
and \(u_n : T'_n \Rightarrow T_n\).

E.11.1. Definition. For each \(n \in \mathbb{Z},\) let \(u_n : T'_n \Rightarrow T_n\) be a natural
transformation. A glueing of the \(u_n\) is a natural transformation \(u : T' \Rightarrow T\)
which induces the \(u_n\).

E.11.2. Theorem. (1) There exists at most one glueing.

(2) Suppose that the glueing \(u\) exists on \(\mathcal{A}_{\leq n-1}'.\) Then \(u\) extends to
\(\mathcal{A}_{\leq n}\) if and only if, for any \((A, B) \in \mathcal{A}_{\leq n-1} \times \mathcal{A}_n,'\) the diagram
\[
\begin{array}{c}
\text{Ext}^1_{\mathcal{A}}(B, A) \xrightarrow{T'} \text{Ext}^1_{\mathcal{B}}(T'(B), T'(A)) \\
\downarrow \quad \downarrow u(A) \\
\text{Ext}^1_{\mathcal{B}}(T(B), T(A)) \xrightarrow{u_n(B)^*} \text{Ext}^1_{\mathcal{B}}(T'(B), T(A))
\end{array}
\]
commutes.

(3) \( u \) is a natural isomorphism on objects of finite lengths if and only if all the \( u_n \) are.

Proof. (1) follows from Lemma E.7.7, while (2) follows from Theorem E.14.1 (2).

(3) “Only if” is obvious, and “if” follows inductively from Theorem E.14.1 (3). \( \Box \)

E.12. The case of a 3-step filtration. We now restrict to the case where the filtration on \( \mathcal{A} \) has only 3 steps, and will try and get a condition involving only the \( u_n \). For convenience, we assume that \( A_n \neq 0 \Rightarrow n \in \{ -2, -1, 0 \} \).

E.12.1. Theorem.

(1) Suppose that, for \((m, n) \in \{(-2, -1), (-1, 0)\} \) and any \((A_m, A_n) \in A_m \times A_n\), the diagram

\[
\begin{array}{ccc}
\text{Ext}^1_A(A_n, A_m) & \xrightarrow{T'} & \text{Ext}^1_B(T'(A_n), T'(A_m)) \\
\downarrow & & \downarrow u_{(A_m) *} \\
\text{Ext}^1_B(T(A_n), T(A_m)) & \xrightarrow{u_n(A_n)^*} & \text{Ext}^1_B(T'(A_n), T(A_m))
\end{array}
\]

commutes or, equivalently, the obstruction in Theorem E.10.2 (1) vanishes. Let \( u_{\leq -1} \) be the resulting natural transformation on \( A_{\leq -1} \) (Theorem E.10.2 (3)). Then, for any \((A_{\leq -1}, A_0) \in A_{\leq -1} \times A_0\), The glueing obstruction

\[
\text{Ext}^1_A(A_0, A_{\leq -1}) \rightarrow \text{Ext}^1_B(T'A_0, TA_{\leq -1})
\]

does not refine to an obstruction

\[
\text{Ext}^1_A(A_0, A_{\leq -1}) \rightarrow \text{Ext}^1_B(T'A_0, TA_{-2}).
\]

(2) Suppose moreover that the diagram of (1) commutes for \((m, n) = (-2, 0)\) and that the map \( \text{Ext}^1_A(A_0, A_{\leq -1}) \rightarrow \text{Ext}^1_A(A_0, A_{-1}) \) is surjective for any \( A_0 \in \mathcal{A}_0 \) and \( A_{\leq -1} \in \mathcal{A}_{\leq -1} \) (for example, that \( \mathcal{A} \) is of cohomological dimension \( \leq 1 \)). Then the obstruction of (1) refines to a bilinear obstruction

\[
\text{Ext}^1_A(A_0, A_{-1}) \times \text{Ext}^1_A(A_{-1}, A_{-2}) \rightarrow \text{Ext}^1_B(T'A_0, TA_{-2})
\]

which is covariant in \( A_2 \), contravariant in \( A_0 \) and “dinatural” in \( A_{-1} \) in the sense that the corresponding map

\[
\text{Ext}^1_A(A_{-1}, A_{-2}) \rightarrow \text{Hom}([\text{Ext}^1_A(A_0, A_{-1}), \text{Ext}^1_B(T'A_0, TA_{-2})])
\]

is contravariant in \( A_{-1} \).
If \( u_{-2} \) is a natural isomorphism, the obstruction of (2) may be reformulated as an obstruction with values in \( \text{Ext}^1_B(T'A_0, TA_{-2}) \).

The glueing exists if and only if the obstruction of (2) vanishes.

Proof. (1) follows from Proposition E.3.3 (4). For (2), we have a commutative diagram

\[
\begin{array}{ccc}
\text{Ext}^1_A(A_0, A_{-2}) & \longrightarrow & \text{Ext}^1_B(T'A_0, TA_{-2}) \\
\downarrow & & \downarrow \\
\text{Ext}^1_A(A_0, A_{\leq -1}) & \longrightarrow & \text{Ext}^1_B(T'A_0, TA_{-2})
\end{array}
\]

and the top horizontal map is 0 by hypothesis. Hence (by the surjectivity assumption) it induces a map \( \text{Ext}^1_A(A_0, A_{-1}) \rightarrow \text{Ext}^1_B(T'A_0, TA_{-2}) \), which is covariant in the second variable viewed as a functor of \( A_{\leq -1} \).

The result then follows from Lemma E.5.3.

(3) is obvious and (4) follows from Theorem E.11.2.

IV. Glueing equivalences of abelian categories

E.13. The case of a 2-step filtration.

E.13.1. Theorem. Let 0 → \( A' \xrightarrow{i} A \xrightarrow{\pi} A'' \rightarrow 0 \) and 0 → \( B' \xrightarrow{j} B \xrightarrow{\pi'} B'' \rightarrow 0 \) be as in (E.2), and consider a naturally commutative diagram of exact functors

\[
\begin{array}{cccc}
0 & \longrightarrow & A' & \longrightarrow & A & \longrightarrow & A'' & \longrightarrow & 0 \\
R' \downarrow & & R \downarrow & & R \downarrow & & R'' \downarrow & & \\
0 & \longrightarrow & B' & \longrightarrow & B & \longrightarrow & B'' & \longrightarrow & 0.
\end{array}
\]

Then:

1. If \( R' \) and \( R'' \) are faithful, \( R \) is faithful.
2. Assume the conditions of Proposition E.8.1 are satisfied and suppose further that, for any two objects \( A' \in A', A'' \in A'' \), the map

\[
\text{Hom}_A(jA'', iA') \rightarrow \text{Hom}_B(R(jA''), R(iA'))
\]

is surjective and the map

\[
\text{Ext}^1_A(jA'', iA') \rightarrow \text{Ext}^1_B(R(jA''), R(iA'))
\]

is injective. Then, if \( R' \) and \( R'' \) are full, \( R \) is full.
3. Assume the conditions of (2) and suppose further that, for any two objects \( A' \in A', A'' \in A'' \), the map \((E.9)\) is surjective. Then, if \( R' \) and \( R'' \) are essentially surjective, \( R \) is essentially surjective.
Proof. (1) Let \( f : A_1 \to A_2 \) in \( \mathcal{A} \) be such that \( R(f) = 0 \). Since \( R'' \pi \simeq \pi'R, \) \( R''\pi(f) = 0 \), hence \( \pi(f) = 0 \). By calculus of fractions, this implies that one can find \( s : A_2 \to B \) with \( \text{Ker}(s), \text{Coker}(s) \in i(\mathcal{A}') \) such that \( sf = 0 \). This means that \( f \) factors as a composition

\[
A_1 \xrightarrow{g} iK \xrightarrow{h} A_2
\]

with \( iK = \text{Ker}(s) \) and \( h \) is a mono. Then \( R(h)R(g) = 0 \). Since \( R \) is exact, \( R(h) \) is a mono, hence \( R(h) = 0 \) which implies that \( R(iK) = i'R(K) = 0 \), hence \( K = 0 \) since \( R' \) and \( i' \) are faithful.

(2) Let \( A_1, A_2 \in \mathcal{A} \) and let \( g \in B(R(A_1), R(A_2)) \). By the functoriality of (E.5), we get a commutative diagram

\[
\begin{array}{cccccc}
0 & \longrightarrow & i'p'R(A_1) & \longrightarrow & R(A_1) & \longrightarrow & j'\pi'R(A_1) & \longrightarrow & 0 \\
& & \downarrow{i'p'(g)} & & \downarrow{g} & & \downarrow{j'\pi'(g)} & \\
0 & \longrightarrow & i'p'R(A_2) & \longrightarrow & R(A_2) & \longrightarrow & j'\pi'R(A_2) & \longrightarrow & 0.
\end{array}
\]

Using the equivalent conditions of (2), \( i'p'(g) \) and \( j'\pi'(g) \) respectively give maps

\[
g' : i'R'(pA_1) \to i'R'(pA_2), \quad g'' : j'R''(\pi A_1) \to j'R''(\pi A_2).
\]

By fullness, \( g' \) and \( g'' \) are induced by maps

\[
f' : pA_1 \to pA_2, \quad f'' : \pi A_1 \to \pi A_2.
\]

Now consider the diagram

\[
\begin{array}{cccccc}
0 & \longrightarrow & ipA_1 & \longrightarrow & A_1 & \longrightarrow & j\pi A_1 & \longrightarrow & 0 \\
& & \downarrow{i(f')} & & \downarrow{j(f'')} & & \\
0 & \longrightarrow & ipA_2 & \longrightarrow & A_2 & \longrightarrow & j\pi A_2 & \longrightarrow & 0.
\end{array}
\]

Consider the extension classes \( [A_r] \in \text{Ext}^1_{\mathcal{A}}(j\pi A_r, ipA_r) \) \((r = 1, 2)\). Then a map \( f \) filling in this diagram exists if and only if

\[
i(f')_*[A_1] = j(f'')*[A_2] \in \text{Ext}^1_{\mathcal{A}}(j\pi A_1, ipA_2).
\]

Hence, by the existence of \( g \), this equality is true after applying the functor \( R \), and therefore it holds by the injectivity assumption.

Now the map \( R(f) - g \) induces a map \( h : Rj\pi(A_1) \to R\pi p(A_2) \). By the surjectivity assumption, \( h \) is of the form \( R(h') \), and then \( R(f-h') = g \).

(3) Let \( B \in \mathcal{B} \). Then \( p'B \) is in the essential image of \( R'' \) and \( \pi'B \) is in the essential image of \( R' \). Using the exact sequence (E.5), Property (ii) of (2) and the surjectivity assumption, we get \( B \simeq R(A) \) for some \( A \in \mathcal{A} \).

Here is a converse to Theorem E.13.1:
E.13.2. Theorem. Keep the notation of Theorem E.13.1. Then:

1. If \( R \) is faithful (resp. full), so is \( R' \).
2. If \( R \) is faithful (resp. full) and the equivalent conditions of Proposition E.8.1 hold, so is \( R'' \).
3. If \( R \) is essentially surjective, \( R'' \) is essentially surjective, and so is \( R' \) provided \( R'' \) is faithful or conservative.

Proof. (1) and (2) are obvious, considering commutative squares of the type

\[
\begin{array}{ccc}
\mathcal{A}'(A'_1, A'_2) & \xrightarrow{\sim} & \mathcal{A}(iA'_1, iA'_2) \\
R' \downarrow & & R' \downarrow \\
\mathcal{A}'(R'A'_1, R'A'_2) & \xrightarrow{\sim} & \mathcal{A}(RiA'_1, RiA'_2) \\
\end{array}
\]

for \( R' \), and similarly for \( R'' \). The first part of (3) is obvious. For the second one, let \( B' \in B' \). Write \( i'B' \simeq RA \) for some \( A \in \mathcal{A} \). Then \( R''\pi A \simeq \pi' RA = 0 \). The hypothesis implies \( \pi A = 0 \), hence \( A \simeq iA \) for some \( A' \in \mathcal{A} \). Now \( i'B' \simeq RiA' \simeq i'R'A' \), hence \( B' \simeq R'A' \).

\[ \square \]

E.13.3. Corollary. With the notation of Theorem E.13.1, suppose that

1. \( R' \) and \( R'' \) are equivalences of categories;
2. the conditions of Proposition E.8.1 are verified;
3. for any two objects \( A' \in \mathcal{A}' \), \( A'' \in \mathcal{A}'' \), the map

\[
\text{Ext}_A^i(jA'', iA') \to \text{Ext}_B^i(R(jA''), R(iA'))
\]

is an isomorphism for \( i = 0, 1 \).

Then \( R \) is an equivalence of categories.

Conversely, if \( R \) is an equivalence of categories and the conditions of Proposition E.8.1 are verified, \( R' \) and \( R'' \) are equivalences of categories.

\[ \square \]

E.14. The general case. Here is now a version of Theorem E.13.1 for filtered abelian categories.

E.14.1. Theorem. Let \( \mathcal{A} \) and \( \mathcal{B} \) be two abelian categories provided with exhaustive separated split filtrations \( (\mathcal{A}_{\leq n}, \iota_n) \) and \( (\mathcal{B}_{\leq n}, \iota'_n) \). Let \( R : \mathcal{A} \to \mathcal{B} \) be an exact functor and assume that \( R \) respects the splittings in the sense of Definition E.9.1.

1. If \( R_n \) is faithful for every \( n \), then \( R \) is faithful.
2. Assume that for any \( m < n \) and any two objects \( A_m \in \mathcal{A}_m \), \( A_n \in \mathcal{A}_n \), the map

\[
\text{Hom}_A(A_n, A_m) \to \text{Hom}_B(R(A_n), R(A_m))
\]
is surjective and the map

$$\text{Ext}^1_A(A_n, A_m) \to \text{Ext}^1_B(R(A_n), R(A_m))$$

is injective. Assume also that every object of $A$ is of finite length in the sense of Definition E.7.6. Then, if $R_n$ is full for every $n$, $R$ is full.

(3) Assume that, for any $n \in \mathbb{Z}$, the map

$$\text{Ext}^1_A(A, B) \to \text{Ext}^1_B(R(A), R(B))$$

is surjective for $A \in A_n$ and $B \in A_{\leq n-1}$. Assume also that every object of $B$ is of finite length. Then, if $R_n$ are essentially surjective for every $n$, $R$ is essentially surjective.

(4) If $\text{Ext}^2_B(A, B) = 0$ for all $A, B \in B$, we may weaken Condition (3) by requesting surjectivity for all $(A, B) \in A_n \times A_m$, $m < n$.

Proof. (1) Let $f : A \to A'$ be such that $R(f) = 0$. There exists $n_0$ such that $A, A' \in A_{n_0}$. By induction, Theorem E.13.1 implies that $f_{\geq n} = 0$ for all $n$ (see Proposition E.7.4 (2) for $f_{\geq n}$). Thus, $\text{Im} f \in \bigcap A_{\leq n} = 0$.

(2) Since the filtrations are exhaustive, it suffices to prove that $R_{\leq n}$ is full for all $n$. Thus we may assume that $A_{\leq n} = A$ for $n$ large enough. Similarly, since every object of $B$ is of finite length, it suffices to prove that the restriction of $R$ to the thick subcategory consisting of objects of length $\leq \ell$ is full for all $\ell \geq 0$. Thus, we may also assume that $A_{\leq n'} = 0$ for $n'$ small enough. By induction on $n - n'$, this reduces us to showing that the assumption of Theorem E.13.1 (3) are verified for $A' = A_{\leq n-1}$.

Let $A' \in A_{\leq n-1}$ and $A'' \in A_n$. We want to show that the map

$$\text{Hom}_A(A'', A') \to \text{Hom}_B(R(A''), R(A'))$$

is surjective and the map

$$\text{Ext}^1_A(A'', A') \to \text{Ext}^1_B(R(A''), R(A'))$$

is injective. Consider the short exact sequence $0 \to A'_{\leq n-2} \to A' \to A'_{n-1} \to 0$. The statement is true by replacing $A'$ by $A'_{\leq n-2}$ (by induction) or by $A'_{n-1}$ (by hypothesis). Hence it is true for $A'$, by the five lemma.

(3) We argue as in (2): since the filtration of $B$ is exhaustive, it suffices to prove that $R_{\leq n}$ is essentially surjective for all $n$, hence we may assume $B_{\leq n} = B$ for $n$ large enough. Since every object of $B$ has finite length, it suffices to prove that every object of $B$ of length $\leq \ell$ is isomorphic to $R(A)$, where $A \in A$ is of length $\leq \ell$. Thus we may also assume that $A_{\leq n'} = B_{\leq n'} = 0$ for $n'$ small enough. We argue by induction on $n - n'$: by induction, $R_{\leq n-1}$ is essentially surjective,
and so is $R_n$ by hypothesis. On the other hand, the assumptions of Theorem E.13.1 (4) are verified for $A' = A_{\leq n-1}$ and $B' = B_{\leq n-1}$.

(4) By the 5 lemma, we deduce the condition of (3) from this weaker condition. □

V. THE CASE OF TRIANGULATED CATEGORIES

E.15. Split exact sequences. We let $\mathcal{T}$ be a triangulated category. Consider the situation

\[(E.10) \quad 0 \to \mathcal{T}' \xrightarrow{i} \mathcal{T} \xrightarrow{\pi} \mathcal{T}'' \to 0\]

where $\mathcal{T}' \subseteq \mathcal{T}$ is a thick subcategory and $\pi$ is the corresponding localisation functor. Thus, $\mathcal{T}''$ is the Verdier quotient of $\mathcal{T}$ by $\mathcal{T}'$.

E.15.1. Proposition (Verdier). The following conditions are equivalent:

(i) $i$ has a right adjoint $p$.

(ii) $\pi$ has a right adjoint $j$ and $j(\mathcal{T}'')$ is thick in $\mathcal{T}$.

(iii) for any $A \in \mathcal{T}$ there exists $A' \in \mathcal{T}'$ and a map $f : i(A') \to A$ such that $\text{Hom}(i(T'), \text{cone}(f)) = 0$.

If these conditions are verified, then for any $A \in \mathcal{T}$ there exists a unique exact triangle

\[A' \to A \to A'' \xrightarrow{+1}\]

such that $A' \in i(\mathcal{T}')$ and $A'' \in j(\mathcal{T}'')$; this triangle is functorial in $A$. Moreover, we have $\text{Hom}_\mathcal{T}(i(T'), j(T'')) = 0$.

Proof. (i) $\Rightarrow$ (ii): let $A \in \mathcal{T}$, and choose a cone $C_A$ of the counit $\varepsilon_A : ipA \to A$. Applying $p$ to the exact triangle

\[ipA \xrightarrow{\varepsilon_A} A \to C_A \xrightarrow{+1}\]

we get an exact triangle

\[pA \xrightarrow{\varepsilon_A} pA \to pC_A \xrightarrow{+1}\]

which shows that

\[(E.11) \quad pC_A = 0.\]

Let $f : A \to B$ be a morphism, and choose a cone $C_B$ analogously. There exists a morphism $g$ such that the diagram of exact triangles

\[
\begin{array}{ccc}
ip A & \xrightarrow{\varepsilon_A} & A \\
\downarrow ipf & \downarrow f & \downarrow g \\
ip B & \xrightarrow{\varepsilon_B} & B \\
\end{array}
\to
\begin{array}{ccc}
C_A & \xrightarrow{+1} & C_A \\
C_B & \xrightarrow{+1} & C_B \\
\end{array}
\]

commutes.
Applying (E.11) to $C_B$, we get by adjunction $\text{Hom}_T(ipA[1], C_B) = 0$, which shows that $g$ is unique; in particular, taking $f = 1_A$, we get that $C_A$ is defined up to unique isomorphism.

Letting $S := \text{Ker } p$, this thus defines a functor $q : T \to S$ ($qA = C_A$), and $q$ is easily seen to be left adjoint to the inclusion $S \hookrightarrow T$. Moreover $q_{T''} = 0$, hence $q$ induces a functor $\bar{q} : T'' \to S$.

On the other hand, we have the obvious functor $r : S \to T''$.

Let $B \in S$. By definition, $\bar{q}rB$ is represented by $C_B = B$. This provides a natural isomorphism $B \overset{\sim}{\to} \bar{q}rB$.

Let $A \in T$. The map $A \to C_A$ induces another natural isomorphism $A \overset{\sim}{\to} r\bar{q}A$, where $A$ is now viewed in $T''$. So $\bar{q}$ and $r$ are quasi-inverse equivalences of categories. Under this equivalence, $q$ becomes $\pi$, and the inclusion $S \hookrightarrow T$ defines a functor $j : T'' \to T$, which is right adjoint to $\pi$. Finally, since $S = \text{Ker } p$ is thick, $j(T'')$ is thick.

(ii) $\Rightarrow$ (iii): let $A \in T$. The functor $\pi$ kills the cone $D_A$ of the unit map $\eta_A : A \to j\pi A$. Hence $D_A \in i(T')$. If $A' \in T'$, then

\[ \text{Hom}(iA', j\pi A) = \text{Hom}(\pi iA', \pi A) = \text{Hom}(0, \pi A) = 0 \]

hence we may take $A' = D_A[-1]$ in (iii).

(iii) $\Rightarrow$ (i): one checks that $A \mapsto A'$ yields the desired adjoint, by the same kind of arguments as in the proof of (i) $\Rightarrow$ (ii).

Finally, the claimed exact triangle is given by

\[ \text{E.12} \quad ipA \xrightarrow{\varepsilon} A \xrightarrow{\eta_A} j\pi A \xrightarrow{\delta} ipA[1] \]

and its properties follow by construction. The vanishing of $\text{Hom}_T(iT', jT'')$ follows from the adjunction. $\square$

E.15.2. Definition. In the situation of Proposition E.15.1, we say that the exact sequence (E.10) is split.

E.16. More adjoints. Assume that (E.10) is split. Let us now consider the conditions

(\�v) $j$ has a right adjoint $\pi'$.

(\�#) $i$ has a left adjoint $p'$.

Recall that, under (\�v), we get a canonical natural transformation $\alpha : \pi' \Rightarrow \pi$ from the composition $j\pi' A \to A \to j\pi A$ for any $A \in T$, and the full faithfulness of $j$. Similarly, under (\�#), we get a canonical natural transformation $\beta : p \Rightarrow p'$.

E.16.1. Proposition. Consider the following conditions:

(i) $\text{Hom}_T(jT'', iT') = 0$. 

(ii) \( (\flat) \) holds and \( \pi' = \pi \).

(iii) \( (\flat) \) holds and \( \pi'i = 0 \).

(iv) \( (\sharp) \) holds and \( p' = p \).

(v) \( (\sharp) \) holds and \( p'j = 0 \).

Then (i) + (\( \flat \)) \( \iff \) (i) + (\( \sharp \)) \( \iff \) (ii) \( \iff \) (iii) \( \iff \) (iv) \( \iff \) (v).

Proof. Suppose that \( \pi' \) exists. Let \( A \in \mathcal{T} \). Applying \( \pi' \) to the exact triangle (E.12), we get an exact triangle

\[
\pi'ipA \to \pi'A \xrightarrow{\alpha_A} \pi A +1 \to 0
\]

This shows that \( \alpha_A \) is an isomorphism if and only if \( \pi'ipA = 0 \). Thus, \( (\alpha_A \text{ injective for all } A) \iff (\pi'ipA = 0 \text{ for all } A) \iff (\pi'i = 0) \) since \( p \) is essentially surjective. Thus, (ii) \( \iff \) (iii). On the other hand, (i) + (\( \flat \)) \( \iff \) (iii) is obvious by adjunction. The other equivalences are obtained dually. \( \square \)

E.17. Filtered triangulated categories.

E.17.1. Definition. Let \( \mathcal{T} \) be an triangulated category.

a) A filtration on \( \mathcal{T} \) is a sequence of thick subcategories

\[
\ldots \xrightarrow{\iota_{n-1}} \mathcal{T}_{\leq n} \xrightarrow{\iota_n} \mathcal{T}_{\leq n+1} \xrightarrow{\iota_{n+1}} \cdots \to \mathcal{T}.
\]

It is separated if \( \bigcap \mathcal{T}_{\leq n} = \{0\} \) and exhaustive if \( \mathcal{T} = \bigcup \mathcal{T}_{\leq n} \).

b) A filtration on \( \mathcal{T} \) is split if all \( \iota_n \) have exact right adjoints.

c) A filtration is a weight filtration if it is separated, exhaustive and split.

Let \( \mathcal{T} \) be provided with a filtration. Define

\[
\mathcal{T}_n = \mathcal{T}_{\leq n}/\mathcal{T}_{\leq n-1}, \quad \mathcal{T}_{n,n+1} = \mathcal{T}_{\leq n+1}/\mathcal{T}_{\leq n-1}
\]

so that we have exact sequences

\[
0 \to \mathcal{T}_n \xrightarrow{i_n} \mathcal{T}_{n,n+1} \xrightarrow{\pi_n} \mathcal{T}_{n+1} \to 0
\]

where \( i_n \) is induced by \( \iota_n \).

E.17.2. Proposition. Suppose that \( \mathcal{T} \) is provided with an exhaustive split filtration as in Definition E.17.1 a), b). For all \( n \in \mathbb{Z} \), let us write \( j_n \) for the right adjoint of the localisation functor \( \mathcal{T}_{\leq n} \to \mathcal{T}_{\leq n}/\mathcal{T}_{\leq n-1} \) (Proposition E.15.1). By abuse of notation, we shall write \( \mathcal{T}_n \) for the thick subcategory \( j_n(\mathcal{T}_{\leq n}/\mathcal{T}_{\leq n-1}) \subset \mathcal{T} \) (ibid. ). Then:

1. Every object \( A \in \mathcal{T} \) is provided with a unique filtration

\[
\ldots \to A_{\leq n} \to A_{\leq n+1} \to \cdots \to A
\]
with \( A_{\leq n} \in \mathcal{T}_{\leq n} \) and \( A_n := \text{cone}(A_{\leq n-1} \to A_{\leq n}) \in \mathcal{T}_n \). One has
\( A_{\leq n} = A \) for \( n \) large enough.

(2) The functors \( A \mapsto A_{\leq n} \) and \( A \mapsto A_n \) are well-defined, as well as \( A \mapsto A_{\geq n} := A/A_{\leq n-1} \).

(3) If moreover the filtration is separated, the \( A \mapsto A_n \) form a set of conservative functors.

(4) We have \( \text{Hom}_\mathcal{T}(\mathcal{T}_m, \mathcal{T}_n) = 0 \) if \( m < n \).

Proof. (1) Since \( \mathcal{T} = \bigcup \mathcal{T}_{\leq n} \), there exists \( n_0 \) such that \( A \in \mathcal{T}_{\leq n_0} \). For \( n < n_0 \), write \( I_n \) for the inclusion \( \mathcal{T}_{\leq n} \to \mathcal{T}_{\leq n_0} \) and \( P_n \) for its right adjoint, which exists and is exact as a composition of the right adjoints of the \( \iota_r \) for \( n \leq r < n_0 \). Define
\[ A_{\leq n} = I_n P_n A. \]
Since \( A = \iota_{n_0} \varpi_{n_0} A, A_{\leq n} \) does not depend on the choice of \( n_0 \), and we have a filtration of \( A \) as requested. Clearly, \( A_{\leq n} \in \mathcal{T}_{\leq n} \) and \( A_{\leq n_0} = A \).

The fact that \( A_n \in \mathcal{T}_n \) follows from Proposition E.15.1, which also shows the uniqueness of the filtration.

(2) This still follows from Proposition E.15.1.

(3) Let \( f : A \to B \) be such that \( f_n : A_n \to B_n \) is an isomorphism for all \( n \in \mathbb{Z} \). Let \( C = \text{cone}(f) \). Then \( C_n = 0 \) for all \( n \). Thus \( C \in \bigcap \mathcal{T}_{\leq n} = 0 \) and \( f \) is an isomorphism.

(4) It suffices to show that \( \text{Hom}_\mathcal{T}(\mathcal{T}_{\leq n-1}, \mathcal{T}_n) = 0 \), which follows again from Proposition E.15.1.  \( \square \)

E.18. Glueing equivalences of triangulated categories.

E.18.1. Theorem. Let \( 0 \to S' \xrightarrow{i} S \xrightarrow{\pi} S'' \to 0 \) and \( 0 \to T' \xrightarrow{j'} T \xrightarrow{\pi'} T'' \to 0 \) be as in (E.10), and consider a naturally commutative diagram of exact functors
\[
\begin{array}{ccc}
0 & \to & S' \\
R' \downarrow & & \downarrow R \\
0 & \to & T' \\
R'' \downarrow & & \downarrow R'' \\
& & 0.
\end{array}
\]

(1) The following are equivalent:
(i) The natural “base change” transformation \( R'p \Rightarrow p'R \) of Section 15.1 is a natural isomorphism.
(ii) \( Rj \Rightarrow j'R'' \) is a natural isomorphism.
(iii) \( R(jS'') \subseteq j''T'' \).

(2) Suppose that
(i) \( R' \) and \( R'' \) are fully faithful;
(ii) the conditions of (1) are verified;
(iii) For any two objects \( A', A'' \in S' \), \( A'' \in S'' \), the map
\[
\text{Hom}_S(jA'', iA') \to \text{Hom}_T(R(jA''), R(iA'))
\]
is an isomorphism.

Then \( R \) is fully faithful.

(3) Suppose that Condition (iii) of (2) holds and that \( R' \) and \( R'' \) are essentially surjective. Then so is \( R \).

(4) Suppose that \( R' \) and \( R'' \) are equivalences of categories and that the conditions of (1) and Condition (iii) of (2) are satisfied. Then \( R \) is an equivalence of categories.

Proof. (1) Let \( A \in S \). We have a commutative diagram of exact triangles (using (E.12) and the base change morphisms):
\[
\begin{array}{ccc}
R(ipA) & \longrightarrow & R(A) \\
\downarrow & & \downarrow \\
\downarrow & & \downarrow \\
i'p'R(A) & \longrightarrow & j'\pi'R(A) \\
\end{array}
\]

Thus the left vertical map is an isomorphism if and only if the right vertical map is one, which shows that (i) \( \iff \) (ii). If this is the case, then \( R(j\pi A) \in j'(T') \), hence (iii). Conversely, if (iii) holds, then all vertical maps must be isomorphisms by the uniqueness of (E.12).

(2) Let \( A_1, A_2 \in S \) and let \( g \in T(R(A_1), R(A_2)) \). By the functoriality of (E.12), we get a commutative diagram
\[
\begin{array}{ccc}
i'p'R(A_1) & \longrightarrow & R(A_1) \\
\downarrow & & \downarrow & g \\
\downarrow & & \downarrow & j'\pi'(g) \\
i'p'R(A_2) & \longrightarrow & j'\pi'R(A_2) \\
\end{array}
\]

Using the equivalent conditions of (1), \( i'p'(g) \) and \( j'\pi'(g) \) respectively give maps
\[
g': i'R'(pA_1) \to i'R'(pA_2), \quad g'': j'R''(\pi A_1) \to j'R''(\pi A_2).
\]

By the fullness of \( R' \) and \( R'' \), \( g' \) and \( g'' \) are induced by maps
\[
f': pA_1 \to pA_2, \quad f'': \pi A_1 \to \pi A_2.
\]

Now consider the diagram
\[
\begin{array}{ccc}
A_1 & \longrightarrow & j\pi A_1 \\
\downarrow & & \downarrow \\
j(f'') & \longrightarrow & i(f'[1]) \\
A_2 & \longrightarrow & j\pi A_2 \\
\end{array}
\]

\[
\begin{array}{ccc}
iA_1[1] & \longrightarrow & +1 \\
\downarrow & & \downarrow \\
iA_2[1] & \longrightarrow & +1 \\
\end{array}
\]
By the injectivity in Condition (iii), the square commutes, hence there exists a map \( f : A_1 \to A_2 \) filling in this diagram. Now the map \( R(f) - g \) induces a map \( h : Rj\pi(A_1) \to Rip(A_2) \). By the surjectivity in Condition (iii), \( h \) is of the form \( R(h') \), and then \( R(f - h') = g \). Thus \( R \) is full.

B. To see that \( R \) is faithful, it now suffices by A.1.1 to show that it is conservative. Let \( A \in \mathcal{S} \) be such that \( RA = 0 \). Then \( R''\pi A = 0 \), hence \( \pi A = 0 \) since \( R'' \), being fully faithful, is conservative. Hence \( A \simeq iA' \) for some \( A' \in \mathcal{S}' \). Then, \( RiA' \simeq iR'A' = 0 \), hence \( A' = 0 \) by the conservativity of \( i \) and \( R' \) and \( A = 0 \).

(3) Let \( B \in \mathcal{T} \). Then \( p'B \) is in the essential image of \( R'' \) and \( \pi'B \) is in the essential image of \( R' \). Thus \( B \) fits in an exact triangle of the form

\[
B \to R(jA'') \xrightarrow{\delta'} R(iA'[1]) \xrightarrow{+1} .
\]

By the surjectivity in (2) (iii), \( \delta' \) is of the form \( R(\delta) \) for \( \delta : jA'' \to iA'[1] \). Let \( A \) denote a fibre (= shifted cone) of \( \delta \). We can then fill in the diagram

\[
\begin{array}{cccccc}
R(iA') & \longrightarrow & R(A) & \longrightarrow & R(jA'') & \xrightarrow{R(\delta)} \\
\| & & & & & \| \\
R(iA') & \longrightarrow & B & \longrightarrow & R(jA'') & \xrightarrow{R(\delta)} \\
\end{array}
\]

with a map which is automatically an isomorphism.

(4) This is just collecting the previous results. \( \square \)

Here is a converse to Theorem E.18.1:

E.18.2. **Theorem.** Keep the notation of Theorem E.18.1. Then:

1. If \( R \) is faithful (resp. full), so is \( R' \).
2. If \( R \) is faithful (resp. full) and the equivalent conditions of Theorem E.18.1 (1) hold, so is \( R'' \).
3. If \( R \) is essentially surjective, \( R'' \) is essentially surjective, and so is \( R' \) provided \( R'' \) is conservative.

**Proof.** Same as for Theorem E.13.2. \( \square \)

VI. **THE CASE OF t-CATEGORIES**

Let \( \mathcal{T} \) be a triangulated category provided with a t-structure with heart \( \mathcal{A} [14, \S 1] \).
E.19. \textit{t}-exact functors.

E.19.1. \textbf{Lemma.} Let $\mathcal{S}$ be another $t$-category, with heart $\mathcal{B}$, and let $T : \mathcal{S} \to \mathcal{T}$ be a triangulated functor. Assume that $T(\mathcal{B}) \subseteq \mathcal{A}$ and that the $t$-structure on $\mathcal{S}$ is bounded. Then:

\begin{enumerate}
\item $T$ is $t$-exact;
\item the induced functor $T : \mathcal{B} \to \mathcal{A}$ is exact.
\end{enumerate}

\textit{Proof.} (1) Let us show right exactness. Let $X \in \mathcal{S}_{\geq 0}$. We must show that $T(X) \in \mathcal{T}_{\geq 0}$. By assumption, there exists $n \geq 0$ such that $X \in \mathcal{S}_{[0,n]}$. For $n = 0$, we have $T(X) \in \mathcal{A}$ by hypothesis. For $n > 0$, we may argue by induction on $n$, using the exact triangle $H_n(X)[n] \to X \to Y \quad \to$
with $Y \in \mathcal{S}_{[0,n-1]}$. Left exactness is proven similarly.

(2) This follows from [14, Prop. 1.3.17 (i)].

E.20. \textbf{The case of a 2-step filtration.} Here we assume that $\mathcal{A}$ sits in a short exact sequence (E.2).

E.20.1. \textbf{Proposition.} Let $\mathcal{T}'$ be the full subcategory of $\mathcal{T}$ consisting of objects $T$ such that $H^i(T) \in \mathcal{A}'$ for all $i \in \mathbb{Z}$. Then:

\begin{enumerate}
\item $\mathcal{T}'$ is thick in $\mathcal{T}$.
\item The $t$-structure of $\mathcal{T}$ induces a $t$-structure on $\mathcal{T}'$.
\item Suppose that (E.2) is split in the sense of Definition E.5.2, and that the $t$-structure of $\mathcal{T}$ is bounded. Then
\begin{enumerate}
\item The exact sequence $0 \to \mathcal{T}' \to \mathcal{T} \to \mathcal{T}/\mathcal{T}' \to 0$
\end{enumerate}
is split in the sense of Definition E.15.2, and the right adjoint $p$ to $i$ is $t$-exact.
\item Via the right adjoint $j$ to $\pi$ (see Proposition E.15.1), the $t$-structure of $\mathcal{T}$ induces a $t$-structure on $\mathcal{T}/\mathcal{T}'$, for which $\pi$ is $t$-exact. Moreover, $j(\mathcal{T}/\mathcal{T}') = \{C \in \mathcal{T} \mid H^*(C) \in j(\mathcal{A}')\}$.
\end{enumerate}

\textit{Proof.} (1) The thickness of $\mathcal{T}'$ in $\mathcal{T}$ follows from the thickness of $\mathcal{A}'$ in $\mathcal{A}$. (2) is clear.

It remains to prove (3).

(i) To prove that $i$ has a right adjoint $p$, it suffices to prove Condition (iii) of Proposition E.15.1 (compare [73, lemmes 3.2.1 and 3.2.3]).

Let $\mathcal{S}$ be the full subcategory of $\mathcal{T}$ consisting of those objects verifying Condition (iii) of Proposition E.15.1. We have to show that $\mathcal{S} = \mathcal{T}$. Since the $t$-structure is supposed to be bounded, it suffices to check that $\mathcal{S}$ is triangulated and contains $\mathcal{A}$.
It is clear that $\mathcal{S}$ is stable under shifts. Let $A_1, A_2 \in \mathcal{S}$, $f : A_1 \to A_2$ and $A'_1, A'_2 \in \mathcal{T}'$ satisfying Condition (iii) of Proposition E.15.1 respectively for $A_1$ and $A_2$. This condition implies that the composition $A'_1 \to A_1 \to A_2$ factors through a (unique) map $f' : A'_1 \to A'_2$. We also get a map $f'' : \text{cone}(f_1) \to \text{cone}(f_2)$ defining a map of exact triangles. Let $A'_3 = \text{cone}(f')$: we may find a map $f_3 : A'_3 \to A_3$ defining a morphism of exact triangles. Then the cone of $f_3$ is isomorphic to the cone of $f''$, hence has the property of Proposition E.15.1. This shows that $\mathcal{S}$ is triangulated.

Let $A \in \mathcal{A}$. By definition of “split” and Proposition E.5.1 (2), $A$ sits in a short exact sequence $0 \to A' \to A \to A'' \to 0$ with $A' \in \mathcal{A}'$ and $\text{Ext}_{\mathcal{A}}^r(B', A'') = 0$ for all $B' \in \mathcal{A}'$ and all $r \geq 0$. Since the $t$-structure is bounded, this implies that $\text{Hom}_\mathcal{T}(\mathcal{T}', A'') = 0$, and $A \in \mathcal{S}$.

This shows the existence of the right adjoint $p$. Moreover, the proof of Proposition E.15.1 shows that, for $A, A', A''$ as in the last paragraph, $p(A) = A'$. Thus $p$ respects the hearts of the $t$-structures on $\mathcal{T}$ and $\mathcal{T}'$, and since the one on $\mathcal{T}$ is bounded, $p$ is $t$-exact by Lemma E.19.1.

(ii) To show that the $t$-structure of $\mathcal{T}$ induces a $t$-structure on $j(\mathcal{T}/\mathcal{T}')$, we have to show that, for $X \in j(\mathcal{T}/\mathcal{T}')$, $\tau_{\leq 0}X \in j(\mathcal{T}/\mathcal{T}')$, or equivalently that if $p(X) = 0$, then $p(\tau_{\leq 0}X) = 0$: this is clear since $p$ is $t$-exact. The proof that $\pi$ is $t$-exact is then the same as the proof of the $t$-exactness of $p$.

For the last assertion, let $C \in j(\mathcal{T}/\mathcal{T}')$. Then, for any $i \in \mathbb{Z}$, $H^i(j(C)) = j(H^i(C)) \in j(\mathcal{A}'')$. Conversely, if $C \in \mathcal{T}$ is such that $H^i(C) \in j(\mathcal{A}'')$ for all $i \in \mathbb{Z}$, then $pH^i(C) = H^i(pC) = 0$ for all $i \in \mathbb{Z}$, hence $pC = 0$ since the $t$-structure is bounded, and $C \in \text{Im} j$ by Proposition E.15.1.

\section*{E.21. Filtered $t$-categories}

We now assume that $\mathcal{A}$ is filtered in the sense of Definition E.7.1 a).

\subsection*{E.21.1. Definition.}

Let $n \in \mathbb{Z}$. We denote by $\mathcal{T}_{\leq n}$ the full subcategory of $\mathcal{T}$ consisting of objects $T$ such that $H^i(T) \in \mathcal{A}_{\leq n}$ for all $i \in \mathbb{Z}$.

This definition is similar to that of Sophie Morel in [73, Prop. 3.1.1].

\subsection*{E.21.2. Proposition.}

(1) The $\mathcal{T}_{\leq n}$ define a filtration of $\mathcal{T}$ in the sense of Definition E.17.1 a).

(2) For any $n$, the $t$-structure of $\mathcal{T}$ induces a $t$-structure on $\mathcal{T}_{\leq n}$.

(3) It is split if the filtration on $\mathcal{A}$ is and the $t$-structure is bounded.

(4) It is separated if the filtration on $\mathcal{A}$ is, and if the $t$-structure is nondegenerate.
(5) It is exhaustive if the filtration on $A$ is and if the t-structure is bounded.

Proof. (1), (2) and (3) follow respectively from Proposition E.20.1 (1), (2) and (3). (4) and (5) are easy. □

E.21.3. Remark. As in [47, Def. 1.2.1], let $T$ be a t-category with compatible triangulated endofunctors $W_n$ with commute with the t-structure and such that the transformations $W_n \to W_{n+1}$ and $W_n \to Id$ are inclusions on the heart $A$ of $T$. In particular, the $W_n$ induce an increasing sequence of exact subfunctors of the identity of $A$. Thus we are in the situation of Remark E.7.8 if they are separated and exhaustive on all objects of $A$. By this remark, we then have a weight filtration on $A$ in the sense of Definition E.7.2.

Define $T_{\leq n}$ as in Definition E.21.1. By Proposition E.21.2, this is a weight filtration on $T$ in the sense of Definition E.17.1 c). By Proposition E.17.2, we get endofunctors of $T$:

$$W_n' C = C_{\leq n}.$$ 

We claim that $W_n' C = W_n C$. First, $W_n C \in T_{\leq n}$ because $W_n$ commutes with $t$ and this is true on $A$ by definition of $A_{\leq n}$. By the universal property of $W_n' C$, the map $W_n C \to C$ factors uniquely into

$$W_n C \to W_n' C.$$ 

That this is an isomorphism is checked again after truncation, and it is true by Remark E.7.8.

Summarising: given a t-category $(T, t)$, a weight filtration $(W_n)$ in the sense of [47, Def. 1.2.1] is equivalent to a weight filtration on $T$ in the sense of Definition E.17.1 c) which is compatible with the t-structure, provided that the weight filtration is separated and exhaustive on objects of the heart.

E.22. From abelian categories to t-categories.

E.22.1. Lemma. Let $A$, $B$ be two abelian categories, $T, T' : A \to B$ be two exact functors and $u_1 : T' \Rightarrow T'$ be a natural transformation. Then $u$ extends uniquely to a natural transformation $u$ between the trivial derivations of $T'$ and $T$ from $D^b(A)$ to $D^b(B)$. Moreover, $u$ is an isomorphism if and only if $u_1$ is.

Proof. Trivial (define $u$ componentwise on chain complexes). □
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