Dynamics of Cohomological Expanding Mappings II: Third and Fourth Main Results

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ABSTRACT

Let $h : V \rightarrow V$ be a Cohomological Expanding Mapping of a smooth complex compact homogeneous manifold with $\dim_{\mathbb{C}}(V) = k \geq 1$ and Kodaira Dimension $\leq 0$. We study the dynamics of such mapping from a probabilistic point of view, that is, we describe the asymptotic behavior of the orbit $O_h(x) = \{h^n(x), n \in \mathbb{N} \text{ or } \mathbb{Z}\}$ of a generic point. Using pluripotential methods, we have constructed in our previous paper [1] a natural invariant canonical probability measure of maximal Cohomological Entropy $\nu_h$ such that $\chi - m^2 \lambda_m(h) \cdot \Omega \rightarrow \nu_h$ as $m \rightarrow \infty$ for each smooth probability measure $\Omega$ in $V$. We have also studied the main stochastic properties of $\nu_h$ and have shown that $\nu_h$ is a smooth equilibrium measure, ergodic, mixing, K-mixing, exponential-mixing. In this paper we are interested on equidistribution problems and we show in particular that $\nu_h$ reflects a property of equidistribution of periodic points by setting out the Third and Fourth Main Results in our study. Finally we conjecture that

$$\nu_h := T_i^+ \land T_{k-i}^-, \quad \dim_H(\nu_h) = \Psi h_x(h),$$

$$\dim_H(\text{Supp}T_i^+) \geq 2(k - l) + \frac{\log \chi^{2l}}{\psi_l},$$

$$|\langle \nu_m^x - \nu_h, \zeta \rangle| \leq M \left[1 + \log^+ \frac{1}{D(x,T)}\right]^{\beta/2} ||\zeta|| \gamma^{-\beta m/2}$$

and

$$|\nu_m^\pi - \nu_h, \zeta| \leq M \left[1 + \log^+ \frac{1}{D(x,E)}\right]^{\beta/2} ||\zeta|| \gamma^{-\beta m/2}.$$  

Keywords: Complex Dynamics · Cohomological Expanding Mapping · Cohomological Degree · Cohomological Entropy · Cohomological Quotient.

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1 Introduction

Note that in this paper we will generalize some results on Complex Dynamics due to Nessim Sibony, Tien-Cuòng Dinh, Duc-Viet Vu and other authors. For this, we will use a new Method called the Cohomological Method introduced in our preview paper [1]. This new Method is based on the Concepts of Cohomological Degree, Cohomological Entropy and Cohomological Quotient which were introduced in ours preview papers [1], [2]. Let $\nu$ be the equilibrium measure of an endomorphism $h$. If $h$ is an observable, $(\zeta \circ h^n)_{n \geq 0}$ can be seen as a sequence of dependent random variables. As the measure is invariant, these variables are distributed in an identical way, that is, the Borel sets $\{\zeta \circ h^n < b\}$ have the same measure $\nu$ for any fixed constant $b$. We recall some general facts of ergodic theory and probability theory. We refer to [38, 40] for the general theory. Consider a dynamic system of a map $h : \mathcal{V} \to \mathcal{V}$, measurable against a $\sigma$-algebra $\mathcal{F}$ on $\mathcal{V}$. The direct image of a probability measure $\nu$ by $h$ is the measure of probability $h_\ast(\nu)$ defined by

$$h_\ast(\nu)(E) := \nu(h^{-1}(E))$$

for each measurable set $E$. Likewise, for any positive measurable function $\zeta$, we have

$$\langle h_\ast(\nu), \zeta \rangle := \langle \nu, \zeta \circ h \rangle.$$

The measure $\nu$ is invariant if $h_\ast(\nu) = \nu$. When $\mathcal{V}$ is a compact metric space and $h$ is continuous, the set $\mathcal{M}(h)$ of invariant probability measures is convex, compact and not empty: for any sequence of probability measures $\nu_n$, the limit values of

$$\frac{1}{N} \sum_{n=0}^{N-1} (h^n)_\ast(\nu_n)$$

are invariant probability measures. A measurable set $E$ is totally invariant if $\nu(E \setminus h^{-1}(E)) = 0$. An invariant probability measure $\nu$ is ergodic if any totally invariant set is of measure $\nu$ zero or complete. It is easy to show that $\nu$ is ergodic if and only if $\zeta \circ h = \zeta$, for $\zeta \in L^1(\nu)$, then $\zeta$ is constant. Here, we can replace $L^1(\nu)$ by $L^p(\nu)$ with $1 \leq p \leq +\infty$. The ergodicity of $\nu$ is also equivalent to the fact that it is extremal on $\mathcal{M}(h)$. We remember Birkhoff’s ergodic theorem, which is the analogue of the law of large numbers for independent random variables [40].

**Theorem 1.1** (Birkhoff). Let $h : \mathcal{V} \to \mathcal{V}$ be a measurable map as above. Suppose that $\nu$ is an invariant ergodic probability measure. Let $\zeta$ be a function on $L^1(\nu)$. Then

$$\frac{1}{N} \sum_{n=0}^{N-1} \zeta(h^n(x)) \to \langle \nu, \zeta \rangle$$

almost everywhere in relation to $\nu$.

When $\mathcal{V}$ is a compact metric space, we can apply Birkhoff’s theorem to continuous functions $\zeta$ and deduce that for $\nu$ almost all $x$

$$\frac{1}{N} \sum_{n=0}^{N-1} \delta_{h^n(x)} \to \nu,$$

where $\delta_x$ indicates the mass of Dirac at $x$. The sum

$$\text{St}_N(\zeta) := \sum_{n=0}^{N-1} \zeta \circ h^n$$

is called **Birkhoff sum**. Therefore, Birkhoff’s theorem describes the behavior of $\frac{1}{N} \text{St}_N(\zeta)$ for an observable $\zeta$. A stronger notion than ergodicity is the notion of mixing. An invariant probability measure $\nu$ is mixing if for each measurable set $E, F$

$$\lim_{n \to \infty} \nu(h^{-n}(E) \cap F) = \nu(E)\nu(F).$$

Clearly, mixing implies ergodicity. It is not difficult to see that $\nu$ is mixing if, and only if, for any test functions $\zeta, \eta$ on $L^\infty(\nu)$ or on $L^2(\nu)$, we have

$$\lim_{n \to \infty} \langle \nu, (\zeta \circ h^n)\eta \rangle = \langle \nu, \zeta \rangle \langle \nu, \eta \rangle.$$

The Quantity

$$W_n(\zeta, \eta) := |\langle \nu, (\zeta \circ h^n)\eta \rangle - \langle \nu, \zeta \rangle \langle \nu, \eta \rangle|$$
is called the correlation on time \( n \) of \( \zeta \) and \( \eta \). Thus, mixing is equivalent to the convergence of \( W_n(\zeta, \eta) \) to 0. We say that \( \nu \) is K-mixing if for each \( \eta \in L^2(\nu) \)

\[
\sup_{\|l\|_{L^2(\nu)} \leq 1} W_n(\zeta, \eta) \to 0.
\]

Note that K-mixing is equivalent to the fact that the \( \sigma \)-algebra \( \mathcal{F}_\infty := \cap h^{-n}(\mathcal{F}) \) contains only sets zero and complete measures. This is the strongest form of mixing for observables on \( L^2(\nu) \). However, it is of interest to obtain quantitative information about the mixing speed for more regular observables, such as smooth functions or Hölder continuous. Now consider an endomorphism \( h \) of degree \( \tau \geq 2 \) of \( \mathbb{P}^k \) as above and its equilibrium measure \( \nu \). We know that \( \nu \) is totally invariant: \( h^*(\nu) = \tau^k \nu \). If \( \zeta \) is a continuous function, so

\[
\langle \nu, \zeta \circ h \rangle = \langle \tau^{-k}h^*(\nu), \zeta \circ h \rangle = \langle \nu, \tau^{-k}h_*(\zeta \circ h) \rangle = \langle \nu, \zeta \rangle.
\]

We use the obvious fact that \( h_*(\zeta \circ h) = \tau^k \zeta \). Thus, \( \nu \) is invariant. Mixing for measure \( \nu \) was proved in [27].

**Theorem 1.2.** Let \( h \) be an endomorphism of degree \( \tau \geq 2 \) of \( \mathbb{P}^k \). So its measure of Green \( \nu \) is K-mixing.

The equilibrium measure \( \nu \) satisfies remarkable stochastic properties that are quite difficult to obtain in the real dynamic systems scenario. Pluripotential methods replace the delicate estimates used in some real dynamic systems. Consider a dynamic system \( h : (\mathcal{V}, \mathcal{F}, \nu) \to (\mathcal{V}, \mathcal{F}, \nu) \) as above, where \( \nu \) is an invariant probability measure. Therefore, \( h^* \) defines a linear operator of norm 1 on \( L^2(\nu) \). We say that \( h \) has the Jacobian limited if there is a constant \( \kappa > 0 \) such that \( \nu(h(E)) \leq \kappa \nu(E) \) for each \( E \in \mathcal{F} \). When \( \mathcal{V} \) is a complex manifold, it is necessarily orientable. Let \( \mathcal{V} \) be a smooth complex compact homogeneous manifold with \( \dim_{\mathbb{C}}(\mathcal{V}) = k \geq 1 \) and Kodaira dimension \( \leq 0 \) and \( h : \mathcal{V} \to \mathcal{V} \) be a dominant surjective meromorphic endomorphism of weight, that is, whose Jacobian is not identically null in any local chart. Let \( \omega \) be a \( (1,1) \)-strictly positive Hermitian form on \( \mathcal{V} \). Let \( \ell \) be a prime number.

**Definition 1.3.** The \( r \)-th Cohomological Degree \( \chi_r(h) \) of \( h \) is defined as the spectral radius of the pullback action \( h^* \) in the cohomology group \( \ell \)-adic étale \( H^*_\ell(\mathcal{V}, \mathbb{Q}_l) \) independent of \( \ell \) by: (cf [32] [6] [43] [2] [30] for more details)

\[
\chi_r(h) = \rho(h^*|_{H^*_\ell(\mathcal{V}, \mathbb{Q}_l)}).
\]

**Definition 1.4.** We define the \((l, n)\)-th Cohomological Quotient \( \xi^n_l(h) \) of \( h \) as follows:

\[
\xi^n_l(h) = \left[ \frac{\chi_{2l-1}(h)}{\chi_{2l}(h)} \right]^n.
\]

**Definition 1.5.** The Cohomological Entropy of \( h \) is defined by

\[
h_\chi(h) = \max \log \chi_\chi(h).
\]

**Definition 1.6.** We say that \( h \) is a Cohomological Expanding Mapping when \( h \) is dynamically compatible (that is \( (h^*)^n = (h^*)^n \)) and there is \( l \in \{1, \ldots, k\} \) such that:

\[
\xi_l^{-1}(h) > 1.
\]

We will write \( \chi_r(h) \) and \( \xi^n_l(h) \) if there is no confusion.

Let \( (\mathcal{V}, \mathcal{F}, v) \) be a probability space and \( h : \mathcal{V} \to \mathcal{V} \) be a measurable map that preserves \( v \), that is, \( v \) is \( h \)-invariant: \( h_* v = v \). The measure \( v \) is ergodic if for any measurable set \( E \) such that \( h^{-1}(E) = E \), we have \( v(E) = 0 \) or \( v(E) = 1 \). This is equivalent to the property that \( v \) is extremal on the convex set of invariant probability measures (if \( v \) is mixing, so it is ergodic). When \( v \) is ergodic, Birkhoff’s theorem implies that if \( \eta \) is an observable on \( L^1(v) \) then

\[
\lim_{n \to \infty} \frac{1}{n} \left( \eta(x) + \eta(h(x)) + \cdots + \eta(h^{n-1}(x)) \right) = \langle v, \eta \rangle
\]

for \( v \) - almost all \( x \). Suppose now that \( \langle v, \eta \rangle = 0 \). Then, the previous limit is equal to 0. The theorem of limit central (TLC), when it occurs, provides the speed of this convergence. We say that \( \eta \) satisfies the TLC if there is a constant \( \sigma > 0 \) such that

\[
\frac{1}{\sqrt{n}} \left( \eta(x) + \eta(h(x)) + \cdots + \eta(h^{n-1}(x)) \right)
\]
converges in distribution for the Gaussian random variable \( N(0, \sigma) \) of mean 0 and variance \( \sigma \). Remember that \( \eta \) is a coboundary whether there is a function \( \eta' \) on \( L^2(\nu) \) such that \( \eta = \eta' - \eta' \circ h \). In that case, it is easy to see that
\[
\lim_{n \to \infty} \frac{1}{\sqrt{n}} \left[ \eta(x) + \eta(h(x)) + \cdots + \eta(h^{n-1}(x)) \right] = \lim_{n \to \infty} \frac{1}{\sqrt{n}} \left[ \eta'(x) - \eta'(h^n(x)) \right] = 0
\]
in distribution. Therefore, \( \eta \) does not satisfy the TLC (sometimes it is said that \( \eta \) satisfies the TLC by \( \sigma = 0 \)). The TLC can be deduced from strong mixing, see \([11,35,37,39]\). In the following result, \( E_t(\eta|\mathcal{F}_n) \) indicates the expectation of \( \eta \) in relation to \( \mathcal{F}_n \), that is, \( \eta \mapsto E_t(\eta|\mathcal{F}_n) \) is the orthogonal projection of \( L^2(\nu) \) in the subspace generated by the measurable functions \( \mathcal{F}_n \).

**Theorem 1.7** (Gordin). Consider the decreasing sequence \( \mathcal{F}_n := h^{-n}(\mathcal{F}) \), \( n \geq 0 \), of algebras. Let \( \eta \) be a function with real value on \( L^2(\nu) \) such that \( \langle \nu, \eta \rangle = 0 \). Suppose that
\[
\sum_{n \geq 0} \| E_t(\eta|\mathcal{F}_n) \|_{L^2(\nu)} < \infty.
\]
So, the positive number \( \sigma \) defined by
\[
\sigma^2 := \langle \nu, \eta^2 \rangle + 2 \sum_{n \geq 1} \langle \nu, \nu(\eta \circ h^n) \rangle
\]
is finite. It vanishes if and only if \( \eta \) is a coboundary. Furthermore, when \( \sigma \neq 0 \), then \( \eta \) satisfies the TLC with variance \( \sigma \).

Note that \( \sigma \) is equal to the limit of \( n^{-1/2} \| \eta + \cdots + \eta \circ h^{n-1} \|_{L^2(\nu)} \). The last expression is equal to \( \| \eta \|_{L^2(\nu)} \) if the family \( (\eta \circ h^n)_{n \geq 0} \) is orthogonal on \( L^2(\nu) \). We refer to \([38,40]\) for the notion of Lyapunov exponent.

**Definition 1.8.** An invariant positive measure is hyperbolic if its Lyapunov exponents are non-zero.

A function quasi-p.s.h. on \( \mathcal{V} \) is a function of \( \mathcal{V} \) on \([0, \infty)\), which is locally the sum of a plurisubharmonic function and a smooth function. For a given \((1,1)\)-continuous form \( \eta \), denote by \( \text{PSH}^0(\eta) \) the set of quasi-p.s.h. functions \( \zeta \) such that \( dd^c \zeta + \eta \geq 0 \) and \( \sup_\mathcal{V} \zeta = 0 \). Endow \( \text{PSH}^0(\eta) \) with induced distance of \( L^1(\mathcal{V}) \) using natural inclusion \( \text{PSH}^0(\eta) \subset L^1(\mathcal{V}) \). Remember from \([33]\) that a complex measure \( \nu \) on \( \mathcal{V} \) is considered PC if each quasi-p.s.h. function is \( \nu \)-integrable and for each sequence \( (\zeta_n)_{n \in \mathbb{N}} \) of quasi-p.s.h. functions converging to \( \zeta \) on \( L^1 \), so that \( dd^c \zeta_n + \eta \geq 0 \) for some smooth form \( \eta \) independent of \( n \), we have \( \langle \nu, \zeta_n \rangle \to \langle \nu, \zeta \rangle \). A pluripolar set on \( \mathcal{V} \) is a subset of \( \mathcal{V} \) contained on \( \{ \zeta = -\infty \} \) for some quasi-p.s.h. function \( \zeta \). Any locally pluripolar set on \( \mathcal{V} \) is pluripolar, cf \([34]\). In particular, this implies that there are profusely quasi-p.s.h singular functions on \( \mathcal{V} \). Note that every PC measure has no mass on pluripolar sets.

Next, we will consider the dynamics of \( h \) with \( \zeta_{\nu}^{-1}(\mathbf{1}) > 1 \). The Third Main Result is as follows.

**Theorem 1.9.** Let \( h : \mathcal{V} \to \mathcal{V} \) be a Cohomological Expanding Mapping with \( l = k \). Let \( \nu_h \) be the equilibrium measure of \( h \). Let \( E_n \) (resp. \( RE_n \)) be the set of isolated periodic points (resp. periodic repellent) of period \( n \). Let \( \Lambda_n \), be the set \( E_n \), \( RE_n \), or their intersections with the support of \( \nu_h \). Then \( \Lambda_n \) is equidistributed asymptotically with respect to \( \nu_h \): we have
\[
\frac{1}{\chi_{2k}^n} \sum_{x \in \Lambda_n} \Gamma_x \to \nu_h \quad \text{when} \quad n \to \infty,
\]
where \( \Gamma_x \) indicates the mass of Dirac on \( x \). In particular, we have \( \#\Lambda_n = \chi_{2k}^n + o(\chi_{2k}^n) \) when \( n \to \infty \).

In fact, when \( h \) admits positive dimensional analytical sets of periodic points, the classic Lefschetz formula does not allow estimate the number of isolated periodic points. The upper limit \( \#\Lambda_n \leq \chi_{2k}^n + o(\chi_{2k}^n) \) is, in fact, obtained using a recent theory of the density of positive closed currents developed by Sibony-Dinh in \([14]\). See too \([24,26,49,23,17]\). Let \( J^l \) be the second set of indeterminacy of \( h \), that is, the set of points \( z \) such that \( h^{-1}(z) \) have a positive dimension. It is an analytical set of codimension at least equal to 2. The open set of Zariski \( \mathcal{V} \setminus J^l \) is the set of points \( x \) such that the fiber \( h^{-1}(x) \) contains exactly \( \chi_{2k}^n \) contains exactly \( h^{-1} \) on subsets of \( \mathcal{V} \). Define \( J_0 := J^l \), \( J_{n+1} := J_0 \cup h(J_n) \) for \( n \geq 0 \) and \( J_\infty := \cup_{n \geq 0} J_n \). Note that the set \( J_\infty \) is characterized by the following property: the sequence of probability measures
\[
\nu_0 := \Gamma_x, \quad \nu_n := \chi_{2k}^{-1} h^n(\nu_0) \quad \text{for} \quad n \geq 0
\]
is well defined if and only if \( x \notin J_\infty \). We have \( \nu_0 = \chi_{2k}^{-1} h^*(\Gamma_x) \). Thus \( \nu_0 \) is the probability measure equidistributed on the fiber \( h^{-n}(x) \) where the points on that fiber are counted with multiplicity. It is necessary to distinguish \( J'_\infty \) with the set \( \cup_{n \geq 0} h^n(J') \), which is a priori minor. Let \( J \) be the (first) set of indeterminacy of \( h \). Also define \( J_0 := J \), \( J_{n+1} := J_0 \cup h(J_n) \) for \( n \geq 0 \) and \( J_\infty := \cup_{n \geq 0} J_n \). The set \( J_\infty \setminus J'_\infty \) consists of points \( x \notin J'_\infty \), so that the support of \( \nu_0 \) intersects \( J \) for some \( n \geq 0 \). Let’s consider \( x \notin J_\infty \cup J'_\infty \). The Fourth Main Result is as follows.
Theorem 1.10. Let \( h : \mathcal{V} \to \mathcal{V} \) and \( \nu_h \) be as in Theorem 1.9. So there is a proper analytic set (possibly empty) \( T \) of \( \mathcal{V} \), so that for \( x \notin J_{\infty} \cup J_{\infty}^{\pm} \) we have
\[
\frac{1}{\chi_{2k}^{m}}(h_m)^*\Gamma_x \to \nu_h \hspace{1em} \text{when} \hspace{1em} m \to \infty
\]
if and only if \( x \notin T \).

Many meromorphic maps with \( J' = \emptyset \) are not holomorphic. For example, if \( f : \mathbb{P}^k \to \mathbb{P}^k \) is an explosion of \( \mathbb{P}^k \) and \( \pi : \mathbb{P}^k \to \mathbb{P}^k \) is a finite holomorphic map, so \( \pi \circ f^{-1} \) is not holomorphic, but its second set of indeterminacy is empty. For holomorphic maps on \( \mathbb{P}^k \), we have \( J = J' = \emptyset \).

2 Third and Fourth Main Results

Recall that in this paper we generalize some results on Complex Dynamics due to Nessim Sibony, Tien-Cuong Dinh, Duc-Viet Vu and other authors. For this, we use a new Method called the Cohomological Method introduced in our previous paper [1]. This new Method is based on the Concepts of Cohomological Degree, Cohomological Entropy and Cohomological Quotient which were introduced in our previous papers [5], [1], [42]. Let \( \mathcal{V} \) be a compact Kähler manifold with dimension \( k \) and \( \omega \) be a Kähler form on \( \mathcal{V} \) normalized such that \( \omega^k \) define a probability measure on \( \mathcal{V} \). Let \( h : \mathcal{V} \to \mathcal{V} \) be a Cohomological Expanding Mapping. The iterated of order \( n \) of \( h \) is defined by \( h^n := h \circ \cdots \circ h \), \( n \) times, on a dense open set of Zariski and extends to a dominant meromorphic map on \( \mathcal{V} \). We refer the reader to [12, 13, 24] for details. The first main result of this paper is as follows.

Theorem 2.1 (Theorem 1.9 "Third Main Result"). Let \( h : \mathcal{V} \to \mathcal{V} \) be a Cohomological Expanding Mapping with \( l = k \). Let \( \nu_x \) be the equilibrium measure of \( h \). Let \( E_n \) (resp. \( RE_n \)) be the set of isolated periodic points (resp. repelling points) of period \( n \). Let \( \Lambda_n \) be any of the sets \( E_n \), \( RE_n \) or their intersections with the support of \( \mu_n \). Then \( \Lambda_n \) is equidistributed asymptotically with respect to \( \nu_x \); we have
\[
\frac{1}{\chi_{2k}^n} \sum_{x \in \Lambda_n} \Gamma_x \to \nu_x \hspace{1em} \text{when} \hspace{1em} n \to \infty,
\]
where \( \Gamma_x \) denotes the mass of Dirac on \( x \). In particular, we have \( \# \Lambda_n = \chi_{2k}^n + o(\chi_{2k}^n) \) when \( n \to \infty \).

In Theorem 2.1, the last statement is an important point in its proof. Therefore the classical Lebesgue formula does not allow to estimate the number of isolated periodic points when \( h \) admits positive dimensional analytic sets of periodic points. So the upper limit \( \# \Lambda_n \leq \chi_{2k}^n + o(\chi_{2k}^n) \) is obtained using the theory of the density of positive closed currents developed by Sibony and Dinh in [14]. One may need to construct enough periodic repellent points on the support of \( \nu_x \). To this end, we will construct on Section 3 a good enough inverse branches of balls for \( h^n \) with controlled size, cf Proposition 3.1 below. This construction will be a generalization of the construction in [30]. The construction of inverse branches for holomorphic discs on projective varieties can be achieved using a method developed by Briend-Duval in [41]. Here we follow the approach developed by Dinh-Sibony in [46] which also allows the construction of discs and spheres on varieties of Kähler. An idea from Buff allows to get periodic repellent points [44]. The presence of indeterminacy sets for Cohomological Expanding Mappings is the source of several delicate technical points. For example, the obstruction to the existence of inverse branches for balls, at least in this approach, may be greater than the orbits of critical values and locus of indeterminacy. One may construct and use a \((1, 1)\)-current \( U \) closed and positive that allows to control this obstruction. Note that when \( \mathcal{V} \) is a projective variety, a weaker version of Theorem 2.1 was stated in [24]. When \( h \) is a holomorphic endomorphism of \( \mathbb{P}^k \), a similar version of the above theorem was obtained by Briend-Duval in [41]. His proof heavily uses the continuity of Hölder of the dynamical function of Green. For Cohomological Expanding Mappings, Green’s dynamical function, even when it exists, is generally not continuous. A similar result for polynomial maps of dominant topological degree, in particular for a large family of rational maps on \( \mathbb{P}^k \), was obtained by Sibony and Dinh [46]. For the case of dimension 1, see Brolin [23], Freire-Lopes-Mañé [47], Lyubich [47] and Tortrat [50]. This construction of inverse branches of balls also allows to study the equidistribution of pre-images of points by \( h^n \). Let \( J' \) be the second set of indeterminacy of \( h \), that is, the set of points \( z \) such that \( h^{-1}(z) \) has a positive dimension. It is an analytical set of codimension at least equal to 2. The open set of Zariski \( \mathcal{V} \setminus J' \) is the set of points \( x \) such that the fiber \( h^{-1}(x) \) contain exactly \( \chi_{2k} \) points counted with multiplicity, see Section 3 for the definition of the action of \( h \) and \( h^{-1} \) on subsets of \( \mathcal{V} \). Define \( J_0' := J' \), \( J_{n+1} := J_n' \cup h(J_n') \) for \( n \geq 0 \) and \( J_{\infty} := \bigcup_{n \geq 0} J_n' \). Note that the set \( J_{\infty} \) is characterized by the following property: the sequence of probability measures
\[
\nu_0 \Gamma_x, \hspace{1em} \nu_n := \chi_{2k}^{-1} h_n^* \nu_n \hspace{1em} \text{for} \hspace{1em} n \geq 0
\]

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is well defined if and only if \( x \notin J'_{\infty} \). We have \( \nu_n^x = \chi_{2k}^n (h^n)^* (\Gamma_x) \). Then \( \nu_n^x \) is the measure of probability equidistributed on fiber \( h^{-n}(x) \) where the points on this fiber are counted with multiplicity. It is necessary to distinguish \( J'_{\infty} \) with the set \( \cup_{n \geq 0} h^n(J') \) which is a priori minor. Let \( J \) be the (first) set of indeterminacy of \( h \). Also define \( J_0 := J, J_{n+1} := J_n \cap h(J_n) \) for \( n \geq 0 \) and \( J_{\infty} := \cup_{n \geq 0} J_n \). The set \( J_{\infty} \setminus J'_{\infty} \) consists of points \( x \notin J'_{\infty} \) such that \( \nu_n^x \) intercepts \( J \) for some \( n \geq 0 \). Let’s consider \( x \notin J_{\infty} \setminus J'_{\infty} \).

**Theorem 2.2 (Theorem 1.10 "Fourth Main Result").** Let \( h : \mathcal{V} \to \mathcal{V} \) and \( \nu_h \) be as in Theorem 1.9. So there is a proper analytic set (possibly empty) \( J \) of \( \mathcal{V} \) such that for \( x \notin J_{\infty} \setminus J'_{\infty} \) we have

\[
\frac{1}{\chi_{2k}^n} (h^n)^* \Gamma_x \to \nu_h \quad \text{when} \quad m \to \infty
\]

if and only if \( x \notin J \).

When \( \mathcal{V} \) is projective, was shown by Guedj in [24] that \( J \) is a finite or enumerable union of analytical sets, see also [13] in the case of compact varieties of Kähler. A similar result to the theorem above was obtained for holomorphic endomorphisms of \( \mathbb{P}^k \) in [29][41][46]. It also applies to maps of the polynomial type with topological dominant degree. For the case of dimension 1, see [17][23][47][50].

## 3 Current density

Suppose \( l \leq k \). In this section, we define several operations for **Cohomological Expanding Mappings** and positive closed currents on compact varieties of Kähler. We also recall some elements of the theory of closed positive current density and establish a preparatory result. We refer the reader to Armand [3], [30], [8] and also to Demailly [11], Dinh-Sibony [15][20] and Voisin [49] for basics of positive closed currents and quasi-plurisubharmonic functions (quasi-p.s.h.) and basic facts about the geometry of Kähler manifold. Let \( \mathcal{V} \) be a compact Kähler manifold with dimension \( k \) and \( \omega \) be a Kähler form on \( \mathcal{V} \) as above. If \( Q \) is a current on \( \mathcal{V} \) and \( \zeta \) is a test form of the right degree, the pairing \( \langle Q, \zeta \rangle \) denotes the value of \( Q \) on \( \zeta \). If \( Q \) is a \((p, p)\)-positive current on \( \mathcal{V} \), its mass is given by the formula

\[
\|Q\| := \langle Q, \omega^{k-p} \rangle.
\]

Note that when \( Q \) is, moreover, closed, its mass depends only on its class of cohomology \( \{Q\} \) on \( H^{p,p}(\mathcal{V}, \mathbb{R}) \). Here \( H^{p,q}(\mathcal{V}, \mathbb{C}) \) denotes the Hodge cohomology group of bidegree \((p, q)\) of \( \mathcal{V} \) and \( H^{p,p}(\mathcal{V}, \mathbb{R}) := H^{p,p}(\mathcal{V}, \mathbb{C}) \cap H^{2p}(\mathcal{V}, \mathbb{R}) \). Let’s write \( Q \leq Q' \) if \( Q' \geq Q \) for two \((p, p)\)-real currents \( Q, Q' \). If \( Q' - Q \) is a positive current. We also write \( c \leq c' \) if \( c' \geq c \) for \( c, c' \in H^{p,p}(\mathcal{V}, \mathbb{R}) \) when \( c' - c \) is the class of a \((p, p)\)-closed positive current. If \( \mathcal{V} \) is an analytic subset of pure dimension \( k-p \) on \( \mathcal{V} \), denote by \([\mathcal{V}]\) the positive closed current of integration on \( \mathcal{V} \) and \([\{V\}]\) its cohomology class on \( H^{p,p}(\mathcal{V}, \mathbb{R}) \). The cup product on \( H^*(\mathcal{V}, \mathbb{C}) \) is denoted by \( \cup \). Now consider a **Cohomological Expanding Mapping**

\( h : \mathcal{V} \to \mathcal{V} \). Remember that \( h \) is holomorphic on an open Zariski set and the closing \( \Gamma \) of its graph on \( \mathcal{V} \times \mathcal{V} \) is an irreducible analytical subset of dimension \( k \). Let \( \pi_1 \) and \( \pi_2 \) be the canonical projections of \( \mathcal{V} \times \mathcal{V} \) on its factors. If \( Z \) is a subset of \( \mathcal{V} \), define \( h(Z) := \pi_2(\pi_1^{-1}(Z) \cap \Gamma) \) and \( h^{-1}(Z) := \pi_1(\pi_2^{-1}(Z) \cap \Gamma) \). The (first) set of indeterminacy \( J \) of \( h \) is the complement of the set of all points \( z \in \mathcal{V} \) such that \( h(z) \) is of dimension 0, or equivalently, that \( h(z) \) contains only one point. The second set of indeterminacy \( J' \) of \( h \) is the complement of the set of all points \( z \in \mathcal{V} \) such that \( h^{-1}(z) \) is of dimension 0, or equivalently, that \( h^{-1}(z) \) contains exactly \( \chi_{2k} \) points counted with multiplicity. Both \( J \) and \( J' \) are analytical subsets of \( \mathcal{V} \) of codimension at least equal to 2. The **Cohomological Expanding Mapping** \( h \) induces linear operators on forms and currents. The presence of locus of indeterminacy makes these operators more delicate to handle. If \( \zeta \) is a \((p, q)\)-smooth form on \( \mathcal{V} \), then \( h^*(\zeta) \) is the \((p, q)\)-current defined by

\[
h^*(\zeta) := (\pi_1)_*(\pi_2^*(\zeta) \cup \Gamma).
\]

One can see that \( h^*(\zeta) \) is a \( L^1 \)-smooth form out of \( J \). Its singularities throughout of \( J \) do not allow iterate the operation in the same way. However, the operation commutes with \( \partial \) and \( \overline{\partial} \). In particular, when \( \zeta \) is closed or exact, so is \( h^*(\zeta) \). Therefore, \( h^* \) induces a linear operator on \( H^{p,q}(\mathcal{V}, \mathbb{C}) \). One can iterate the previous operator and since \( h \) is a **Cohomological Expanding Mapping**, we have \( (h^n)^* = (h^*)^n \). Similarly, the \((p, q)\)-current \( h_*(\zeta) \) is defined by

\[
h_*(\zeta) := (\pi_2)_*(\pi_1^*(\zeta) \cup \Gamma).
\]

This is a \( L^1 \)-smooth form out of the critical values of \( \pi_2|_\Gamma \). The operator \( h_* \) also commutes with \( \partial, \overline{\partial} \) and induces a linear operator \( h_* \) on \( H^{p,q}(\mathcal{V}, \mathbb{C}) \). Let us now consider two particular cases of the pull-back operator \( h^* \) on currents that will be used later. If \( \zeta \) is a continuous function on \( \mathcal{V} \) then \( h_*(\zeta) \) is a limited function on \( \mathcal{V} \), that is continuous outside \( J' \). So if \( \nu \) is a positive measure without mass on \( J' \) we can define

\[
\langle h^*(\nu), \zeta \rangle := \langle \nu, h_*(\zeta) \rangle.
\]
One can see that $h^*(\nu)$ is a positive measure whose mass is equal to $\chi_{2k}$ times the mass of $\nu$ since $\pi_2$ restricted to $\Gamma$ defines a branched covering of degree $\chi_{2k}$ on $V \setminus J'$. If $\nu$ is the mass of Dirac at one point $x \not\in J'$, then $h^*(\nu)$ is the sum of the Dirac masses on the fiber $h^{-1}(x)$ counted with multiplicity. If $\nu$ has no mass on $J$, the positive measure $h_*(\nu)$ given by

$$\langle h_*(\nu), \zeta \rangle := \langle \nu, h^*(\zeta) \rangle$$

for each continuous function $\zeta$ on $V$, is well defined and has the same mass as $\nu$. If $\nu$ is the mass of Dirac on $x \not\in J$, then $h_*(\nu)$ is the mass of Dirac on $h(x)$. The second situation concerns the $(1,1)$-closed positive currents. If $Q$ is a current on $V$, we can write $Q = \alpha + dd^c u$ where $\alpha$ is a $(1,1)$-closed smooth form on class $\{Q\}$ and $u$ is a function quasi-p.s.h. Then $\nu \circ \pi_2$ is a function quasi-p.s.h. on $\Gamma$ and we define

$$h^*(Q) := h^*(\alpha) + (\pi_1)_*(dd^c (u \circ \pi_2|_\Gamma)).$$

Using local regularization of $Q$, one can see that $h^*(Q)$ is a $(1,1)$-closed positive current. The operator is linear and continuous on $Q$. So, using Demailly's regularization of $(1,1)$-currents on $V$ [10], we can verify that the operator is compatible with the cohomology, that is, we have $\{h^*(Q)\} = h^*(Q)$. The operator $h_*$ is defined in the same way on currents $(1,1)$ closed positive and is also compatible with the cohomology. We will recall basic facts about positive closed currents density theory and provide an abstract result that will allow us to ignore Lefschetz's fixed point formula to limit the number of periodic points. We will restrict ourselves to the simplest situation necessary for the present paper. The reader is invited to consult [13] for more details. Let $V$ be an irreducible subvariety of $V$ of dimension $l$. Let $\pi: X \to V$ be the normal vector bundle of $V$ on $V$. For a point $x \in V$, if $\text{Tang}_x V$ and $\text{Tang}_x V'$ denote, respectively, the tangent spaces of $V$ and of $V$ at $x$, the fiber $X_x := \pi^{-1}(x)$ of $X$ over $x$ is canonically identified with the quotient space $\text{Tang}_x V/\text{Tang}_x V$. The zero section of $X$ is naturally identified with $V$. Denote by $\overline{X}$ the natural compactification of $X$, that is, the projectivization $\mathbb{P}(X \otimes \mathcal{C})$ of the vector bundle $X \otimes \mathcal{C}$, where $\mathcal{C}$ is the trivial line bundle over $V$. We still denote by $\pi$ the natural projection of $\overline{X}$ to $V$. Denote by $\lambda$ the multiplication by $\lambda$ on the fibers of $X$ where $\lambda \in \mathcal{C}^\ast$, i.e. $\lambda(u) := \lambda u, u \in X_x, x \in V$. This map extends to a holomorphic automorphism of $\overline{X}$. Let $V_0$ an open subset of $V$ which is naturally identified with an open subset of section 0 on $X$. A diffeomorphism $\tau$ of a neighborhood of $V_0$ on $V$ to a neighborhood of $V_0$ on $X$ is called allowable if it satisfies the following essential three conditions: the restriction of $\tau$ to $V_0$ is the identity, the differential of $\tau$ at each point $x \in V_0$ is $C$-linear and the composition of

$$X_x \hookrightarrow \text{Tang}_x(X) \to \text{Tang}_x(V) \to X_x$$

is the identity, where the morphism $\text{Tang}_x(X) \to \text{Tang}_x(V)$ is given by the differential of $\tau^{-1}$ on $x$ and the other maps are canonical, see [13] for details. Note that an allowable map is not necessarily holomorphic. When $V_0$ is small enough, there are local holomorphic coordinates in a small neighborhood $U$ of $V_0$ on $V$ so that over $V_0$ we naturally identify $X$ with $V_0 \times \mathcal{C}^{k-l}$ and $U$ with an open neighborhood of $V_0 \times \{0\}$ on $V_0 \times \mathcal{C}^{k-l}$ (we reduce $U$, if necessary). In this image, identity is an allowable holomorphic map. There are always allowable maps for $V_0 := V$. However, such an allowable global map is rarely holomorphic. Consider an allowable map $\tau$ as above. Let $Q$ be a $(p,p)$-positive current closed on $V$ without mass on $V$ for simplicity. Define $Q_\lambda := (Z_\lambda)_{\ast}(\tau^\ast(Q))$. The family $(Q_\lambda)$ is relatively compact on $\pi^{-1}(V_0)$ when $\lambda \to \infty$: we can extract convergent subsequences $\lambda \to \infty$. The limit currents $U$ are $(p,p)$-closed positive currents without mass on $V$ that are $V$-conical, that is, $(Z_\lambda)_\ast(U) = U$ for any $\lambda \in \mathcal{C}^\ast$. In other words, $U$ is invariant by $Z_\lambda$. Such a current $U$ depends on the choice of $\lambda \to \infty$ but it is independent of the choice of $\tau$. This property gives us great flexibility to work with allowable maps. In particular, using allowable global maps, we obtain $(p,p)$-closed positive currents $U$ on $\overline{X}$. It is also known that the class of cohomology of $U$ depends on $Q$, but it does not depend on the choice of $\tau$. This class is denoted by $\kappa^V(Q)$ and is called the total tangent class of $Q$ in relation to $V$. The currents $U$ are called tangent currents of $Q$ along $V$. The mass of $U$ and the norm of $\kappa^V(Q)$ are limited by a constant times the mass of $Q$. Let $-h$ be the $(1,1)$-tautological class on $\overline{X}$. Remember that $H^*(\overline{X}, \mathcal{C})$ is a free $H^*(V, \mathcal{C})$-module generated by 1, $h, \ldots, h^{k-l}$ (the fibers of $\overline{X}$ are of dimension $k-l$). So, we can write

$$\kappa^V(Q) = \sum_{j = \max(0,l-p)}^{\min(l,k-p)} \pi^\ast(\kappa_j^V(Q)) \smile h_{j-l+p}$$

where $\kappa_j^V(Q)$ is a class on $H^{l-j, l-j}(V, \mathcal{C})$ with the convention that $\kappa_j^V(Q) = 0$ out of range $\max(0,l-p) \leq j \leq \min(l,k-p)$. Let $s$ be the maximum integer such that $\kappa_s^V(Q) \neq 0$. We call it tangential h dimension of $Q$ along $V$. The class $\kappa_s^V(Q)$ is pseudo-effective, that is, it contains a positive closed current on $V$. The tangential h dimension of $Q$ is also equal to the maximum integer $s \geq 0$ such that $U \cap \pi^\ast(\omega_V(\cdot)) \neq 0$, where $\omega_V$ is any form of Kähler on $V$. In addition, if $Q_n$ and $Q$ are $(p,p)$-positive currents closed on $V$ such that
\( Q_n \to Q \), then \( \kappa^V_n(Q_n) \to 0 \) for \( j > s \) and any limit class of \( \kappa^V_n(Q_n) \) is pseudo-effective and is less than or equal to \( \kappa^V_0(Q) \). The following result will allow us to limit the number of periodic points isolated from a meromorphic map. We identified here the cohomology group \( H^{2k}(\mathcal{V}, \mathbb{C}) \) with \( \mathbb{C} \) using the integrals differential forms of high degree on \( \mathcal{V} \).

**Proposition 3.1.** Let \( \Gamma_\lambda \) be complex submanifolds of pure dimension \( k-l \) on \( \mathcal{V} \). Suppose there is a sequence of positive numbers \( K_\lambda \) such that \( K_\lambda \to \infty \) and \( K^{-1}_\lambda(\Gamma_\lambda) \) converges to a \((l, l)\)-current \( Q \) closed positive on \( \mathcal{V} \). Suppose also that the \( h \)-tangent dimension of \( Q \) in relation to \( \mathcal{V} \) is 0 and that \( \{Q\} \cap \{V\} = \emptyset \). So the number \( \delta_n \) of isolated points at the intersection \( \Gamma_n \cap V \), counted with multiplicity, satisfies \( \delta_n \leq K_n + o(K_n) \) when \( n \to \infty \).

**Proof.** We use the Lemma 3.2 in this proof. Define \( Q_n := K^{-1}_n(\Gamma_n) \). Extracting a subsequence allows us to assume that \( \kappa^V(Q_n) \) converges to a class \( \kappa \). As the \( h \)-tangent dimension of \( Q \) is zero, the above discussion implies that \( \kappa = \lambda L \), where \( L \) is a fiber class of \( E \) and \( \lambda \) is a positive number. We also have \( \kappa^V(Q) = \pi^*(\kappa^V_n(Q_n)) \). In the above construction of \( \kappa^V(Q) \) with an allowable global map, we see that Rham's class of cohomology of \( Q_\lambda \) on a neighborhood of \( V_0 \times \{0\} \) does not depend on \( \lambda \) when \( \lambda \to \infty \). It follows that \( \{Q\} \cap \{V\} = \kappa^V(Q) \cap \{V\} \). This together with the hypothesis \( \{Q\} \cap \{V\} = 1 \) implies that \( \kappa^V(Q) = L \). The above discussion about the superior semi-continuity of \( \kappa^V(Q_n) \) implies that \( \lambda \leq 1 \). By Lemma 3.2, we can write \( \kappa^V(Q_n) = \delta_n K^{-1}_n L + L_n \), where \( L_n \) is a pseudo-effective class. As \( \kappa^V(Q_n) \) converges to \( \kappa = \lambda L \), we deduce that the limit values of \( L_n \) are also equal to positive constants times \( L \) and then \( \limsup \delta_n K^{-1}_n \leq \lambda \). The proposition follows.

We have used the following lemma.

**Lemma 3.2 (30).** Let \( \Gamma \) be a submanifold of pure dimension \( k-l \) on \( \mathcal{V} \). Let \( x_1, \ldots, x_N \) be the isolated points on \( \Gamma \cap V \) and \( m_i \) be the multiplicity of the intersection of \( \Gamma \cap V \) on \( x_i \). So, any tangent current of \( [\Gamma] \) along \( V \) is greater than or equal to \( \sum m_i \pi_{n=1}(x_i) \).

**Proof.** Consider a small open set \( Z_0 \) on \( V \) that contains only one point \( x_i \). As above, we identified \( E \) (resp. \( E \) on \( Z_0 \) with \( Z_0 \times C^{2k-l} \) (resp. \( Z_0 \times C^{2k-l} \)), and a small neighborhood of \( Z_0 \) with \( V \) on an open neighborhood of \( Z_0 \times \{0\} \) on \( Z_0 \times C^{2k-l} \), and \( \pi \) with the canonical projection of \( Z_0 \times C^{2k-l} \) on its first factor. Identity is then an allowable map. It is clear in this context that any tangent current of \( [\Gamma] \) along \( V \) constructed as above is greater than or equal to \( m_i \pi_{n=1}(x_i) \). The lemma follows.

### 4 Branches Constructing

Note that this section is a generalization of the construction in [2], [30]. Let \( h : \mathcal{V} \to \mathcal{V} \) and \( \nu_\lambda \) be as in Theorem 1.9. The purpose of this section is to construct for generic small balls an almost maximum number of inverse branches in relation to \( h^n \) and that we control the size. Remember that \( J, J', d_p, \chi_{2k} \), \( \Gamma \) denote the sets of indeterminacy, the dynamic degree of order \( p \), \( h^n \) the cohomological degree and the closing of the graph of \( h \) on \( \mathcal{V} \times \mathcal{V} \). By definition, the dynamic degree of order \( p \) and \( h \) the cohomological degree of \( h^p \) are equal to \( \lambda_p, \chi_{2k} \) respectively. Denote by \( J(h^n), \mathcal{J}(h^n), \Gamma \), \( \pi \) the indeterminacy sets and the closing of the graph of \( h^n \). Natural projections of \( \mathcal{V} \times \mathcal{V} \) in their factors are denoted by \( \pi_1 \) and \( \pi_2 \). Also remember that \( \mathcal{J}_n := J', J_{n+1} := J_0 \cup h(J'_n) \) for \( n \geq 0 \) and \( J_\infty := \cup_{n \geq 0} J_n \). One must distinguish \( J_\infty ' \) with the set \( \cup_{n \geq 0} \mathcal{J}(h^n) \) and the union of \( \mathcal{J}(h^n) \) which are a priori minor. Choose an analytical subset \( \Sigma_0 \) of \( \mathcal{V} \) containing \( J, \mathcal{J}, h(J), h^{-1}(J) \) such that \( \pi_2 \) restricted to \( \Gamma \setminus \pi_2^{-1}(\Sigma_0) \) defines an unrestricted covering over \( \mathcal{V} \setminus \Sigma_0 \). Let \( Z \) be a connected subset of \( \mathcal{V} \), for example, a holomorphic ball, a holomorphic disc or a family of discs through a point on \( \mathcal{V} \). We call an inverse branch of order \( n \) of \( Z \) any continuous bijective map \( f : Z \to Z_{-n} \) with \( Z_{-n} \subset \mathcal{V} \) such that if we define \( Z_{-1} := h(Z_{-1}) \) with \( 0 \leq i \leq n - 1 \), then \( Z_{-i} \cap \Sigma_0 = \emptyset \) for \( 0 \leq i \leq n \). Let \( h : Z_{-i} \to Z_{-i+1} \) be a bijective map for \( 1 \leq i \leq n \). Let \( Z_0 = Z \) and \( h^0 = f = \text{id} \) on \( Z \). Note that \( h^{n+1} \circ g : Z \to Z_{-n} \) is an inverse branch of order \( i \) of \( Z \) and \( Z \) admits a \( \chi_{2k}^{-1} \) inverse branches of order \( n \). The condition \( B_{-i} \cap \Sigma_0 = \emptyset \) implies that the inverse branch can be extended to any open set small enough containing \( Z \) using local inverses of the map \( h^n \).

We say that the inverse branch above is of size smaller than \( \lambda \) if the diameter of \( Z_{-n} \) is smaller than \( \lambda \). We also call \( Z_{-n} \) the image of the inverse branch \( f : Z \to Z_{-n} \).

**Proposition 4.1 (2), [30].** There is a \((1, 1)\)-closed positive current \( \nu_\lambda \) on \( \mathcal{V} \) satisfying the following property. Let \( \nu, \nu \) be strictly positive numbers with \( \nu \leq 1 \) and let \( x \) be a point on \( \mathcal{V} \) such that Lelong's number \( \nu(U, x) \) of \( U \) on \( x \) is smaller than \( \nu \). So there is a constant \( \tau > 0 \) such that the ball \( B(x, r) \) with center \( x \) and radius \( r \) admits at least \((1 - \nu)\chi_{2k}^{-1} \) inverse branches of order \( n \) and smaller in size than \((\chi_{2k-1}/\chi_{2k} + \epsilon)^n/2 \) for each \( n \geq 0 \).
Proof. A Siu theorem says that \( \{ \nu(U, x) \geq c \} \) is a proper analytical subset of \( V \) for each \( c > 0 \) [45]. Thus, the above proposition applies to generic points \( x \) on \( V \). In the construction of \( U \), we will see that the set \( \{ \nu(U, x) > 0 \} \) contains the orbits of critical values and points of indeterminacy that are obviously an obstruction to obtain inverse branches of balls. However, \( \{ \nu(U, x) > 0 \} \) contains a priori other analytic sets which are a less obvious obstruction to the existence of inverse branches. It can be seen as a local of accumulation of the orbits of the points of indeterminacy. We now give the proof of the above proposition.

The first step is to define the current \( U \). Remember that operators \( (h^n) \), act continuously on currents \((1, 1)\) positive closed and these actions are compatible with the actions of \((h^n)\), on \( H^{1,1}(V, \mathbb{R}) \). If \( Q \) is a \((1, 1)\)-positive current closed on \( V \), its mass depends only on the class of cohomology \( \{Q\} \). Therefore, for a fixed norm in cohomology, the mass of \( Q \) is comparable to the class of \( \{Q\} \). We then deduce the existence of a constant \( L_0 > 0 \) independent of \( Q \), \( h \) and \( n \) so that

\[
\|(h^n)_*(Q)\| \leq L_0 \|(h^n)_*\|_{H^{1,1}(V, \mathbb{R})}\|Q\|.
\]

By definition of \( \chi_{2k-1} \), one can fix an integer \( N \geq 1 \) large enough such that

\[
L_0 \|(h^n)_*\|_{H^{1,1}(V, \mathbb{R})} < \left( \mathcal{Y}(\chi_{2k}) \right)^N,
\]

where \( \chi_{2k-1}/\chi_{2k} < \mathcal{Y} < \chi_{2k-1}/\chi_{2k} + \varepsilon \) is any fixed constant strictly less than \( 1 \). Define \( \Sigma_{i+1} := \{ h(\Sigma_i) \} \) for \( 0 \leq i \leq N - 1 \) and \( \Sigma := \cup_{0 \leq i \leq N} \Sigma_i \). Therefore, any connected and simply connected set outside \( \Sigma \) admits the maximum number \( \chi_{2k} \) of inverse branches of order \( N \) with images outside \( \Sigma \). Choose a desingularization \( \pi : \tilde{\Gamma} \to \Gamma \) which is a composition of explosions of \( \Gamma \) along smooth centers on or over \( \pi^{-1}_1(\Sigma) \cap \Gamma \) and \( \pi^{-1}_2(\Sigma) \cap \Gamma \). Define \( \tau_i := \pi_i \circ \pi \). One can choose \( \pi \) so that \( \pi^{-1}_1(\Sigma) \) and \( \pi^{-1}_2(\Sigma) \) are pure codimension 1 on \( \tilde{\Gamma} \). By Blanchard’s theorem [9], \( \tilde{\Gamma} \) is a compact variety of Kähler. Fix a form of Kähler \( \omega \) on \( \tilde{\Gamma} \) that is bigger than \( \pi_1^* (\omega) \). We also assume that \( \omega \) is large enough that each ball of radius \( 1 \) on \( \tilde{\Gamma} \) in relation to the metric \( \omega \) biholomorph to \( \mathbb{C}^k \). Denote by \( \Sigma' \) and \( \Sigma'' \) respectively, the union of codimension components 1 and the union of the components of codimension \( \geq 2 \) of \( \Sigma \). Define

\[
P_0 := L_1 \mathcal{T}^{-N} \chi_{2k}^{N} \left( \left[ \Sigma' \right] + \left( \tau_2 \right)_* (\omega) \right), \quad P := \sum_{n=0}^{N} (h_n)(P_0),
\]

and

\[
U := 8 \sum_{m \geq 0} \left( \mathcal{Y} \chi_{2k} \right)^{-mN} (h^N)_*(P).
\]

Here \( L_1 \geq \delta_1^{-1} \) is a constant satisfying Lemma 4.2 below and \( \delta_1 \) is a constant whose exact value will be determined after the Lemma 4.4 below. By definition of \( \mathcal{T} \), the last current is well defined. Note that one must distinguish operators \( (h^n)^{m} \) and \( (h^N)^m \). The orbit of \( \Sigma \) is the obstruction to build inverse branches of balls. Now we apply Lemma 4.6 and the Proposition 4.3 for \( d_0 = \nu/4 \). Let \( x^{(i)}_{-n}, \ldots, x^{(i)}_{n} \) with \( 0 \leq s \leq \chi_{2k} \) be the distinct points on \( h^{-n}(x) \) such that \( h^{i}(x^{(i)}_{-n}) \not\in \Sigma \) for all \( 0 \leq i \leq n \) and \( 1 \leq j \leq s \).

If \( f : \Delta_{00} \to \Delta_{00} \) is an inverse branch as in the Lemma 4.6, then \( \Delta_{00} \) contains exactly one of the points \( x^{(i)}_{-n} \). We say that \( x^{(i)}_{-n} \) is the center of \( \Delta_{00} \). Denote by \( \mathcal{F}(j) \) the set of \( \Delta \in \mathcal{F} \) such that \( \Delta_{00} \) admits an inverse branch of order \( n \) as in the Lemma 4.6 with center \( x^{(i)}_{-n} \). Let \( P_n \) be the set of all such \( j \) such that \( \mathcal{L}(\mathcal{F}(j)) \geq \nu/4 \). Let \( j \) be an element of \( P_n \). We show that \( B(x, r) \) admits an inverse branch of order \( n \) of size \( \leq \mathcal{T}^{n/2} \) with center \( x_{j}^{(i)}_{-n} \) for a suitable constant \( r > 0 \) independent of \( n \). Let \( T^{(i)} \) be the intersection of \( \mathcal{F}(j) \) with \( B(x, r_0) \). The inverse branches of \( \Delta_{00} \) with \( \Delta \in \mathcal{F}(j) \) in images centered on \( x_{j}^{(i)}_{-n} \) agree at the common intersection point \( x \) and form a map \( f : T^{(i)} \to T^{(i)}_{j} \) where \( T^{(i)}_{j} \) is the union of the \( \Delta_{00} \) centered on \( x^{(i)}_{-n} \) with \( \Delta \in \mathcal{F}(j) \). Define as above \( x^{(i)}_{-n} := h^{-i}(x_{j}^{(i)}_{-n}) \), \( T^{(i)}_{j} := h^{-i}(T^{(i)}) \) for \( 0 \leq i \leq n \) and \( \tilde{x}^{(i)}_{-n} := \tau_1^{-1}(x^{(i)}_{-n}) \). Let \( \tilde{T}^{(i)} := \tau_1^{-1}(T^{(i)}) \) for \( 0 \leq i \leq n - 1 \). By Lemma 4.6, we have \( \tilde{T}^{(i)} \cap \Sigma = \emptyset \) for \( 0 \leq i < n \). So the map \( \tau_1^{-1} \circ h^{-i} \circ g \) extends holomorphically to a neighborhood of \( T^{(i)} \). In addition, the image of \( T^{(i)} \) is equal to \( \tilde{T}^{(i)} \) which is contained in the ball of radius \( \frac{1}{2} \mathcal{T}^{i/2} \) centered in \( \tilde{x}^{(i)}_{-n} \) and does not intersect the hypersurface \( \tau_1^{-1}(\Sigma) \cup \tau_2^{-1}(\Sigma) \). Remember that the metric \( \omega \) on \( \tilde{T}^{(i)} \) is chosen so that any ball of radius \( 1 \) is contained on an open set biholomorphic to a ball on \( \mathbb{C}^k \). So Proposition 4.3 can be applied to this map. According to this proposition, for \( r \) small enough (equal to \( r_0 \) times a constant independent of \( n, i, j \), all maps \( h^{-i} \circ f \) and \( \tau_1^{-1} \circ h^{-i} \circ f \) extend holomorphically to \( B(x, r) \). Furthermore, his images, denoted by \( B(x, r)^{(i)}_{j} \) and \( B(x, r)^{(i)}_{j} \) respectively, have diameters less than or equal to \( \mathcal{T}^{i/2} \). We also have \( B(x, r)^{(i)}_{j} \cap \Sigma = \emptyset \) and \( B(x, r)^{(i)}_{j} \cap \Sigma = \emptyset \) for \( 0 \leq i \leq n - 1 \). It follows that \( B(x, r)^{(i)}_{j} \cap \Sigma = \emptyset \) for \( 0 \leq i \leq n \). Then the extension of \( g \) defines an inverse branch of order \( n \) and size \( \leq \mathcal{T}^{n/2} \) on \( B(x, r) \). It now remains to show that \( P_n \) contains at least \( (1 - \nu)\chi_{2k}^{N} \) elements. By Lemma

10
we have \( \sum_j \mathcal{L}(\mathcal{F}^{(j)}) \geq \chi_{2k}(1 - \nu/2)^2 \). Since \( \mathcal{L}(\mathcal{F}^{(j)}) \leq \mathcal{L}(\mathcal{F}) = 1 \), we deduce that the last sum is limited by \( \#P_n + (\chi_{2k} - \#P_n)\nu/4 \). It follows that \( \#P_n + (\chi_{2k} - \#P_n)\nu/4 \geq \chi_{2k}(1 - \nu/2)^2 \). Thus, \( \#P_n \geq (1 - \nu)\chi_{2k}^2 \). This completes the proof of the proposition. \( \blacksquare \)

The following Lemma shows that it is visible using the current \( U \).

**Lemma 4.2.** If \( L_1 \) is big enough, so for each \( x \in \Sigma \) Lelong’s number \( \nu(P_0, x) \) of \( P_0 \) on \( x \) is bigger than 1.

**Proof.** The Lemma is clear for \( x \in \Sigma' \). Now consider a point \( x \in \Sigma' \setminus \Sigma' \). As the function \( \nu(P_0, x) \) is semi-continuous superior on \( x \) regarding Zariski’s topology, just check that \( \nu(P_0, x) \) is positive on generic points \( x \in \Sigma' \setminus \Sigma' \). We then choose \( L_1 \) large enough to obtain Lelong numbers greater than 1. Therefore, we can assume that \( x \) is a regular point of \( \Sigma'' \setminus \Sigma' \) and there is a point \( \tilde{x} \in \tau^{−1}_2(\Sigma'' \setminus \Sigma') \) is a smooth hypersurface on \( \tilde{x} \). Choose local coordinates \( \tilde{z} = (\tilde{z}_1, \ldots, \tilde{z}_k) \) on a neighborhood of \( \tilde{x} \) such that \( \tilde{z} = 0 \) on \( \tilde{x} \) and \( \tau^{−1}_2(\Sigma'') \) is given by \( \tilde{z}_1 = 0 \). As \( \Sigma'' \) has codimension \( \geq 2 \), we can choose \( \tilde{z} \) so that the hyperplanes \( \tilde{H}_\xi := \{ \tilde{z}_k = \xi \} \) parallel to \( \{ \tilde{z}_k = 0 \} \) are sent to hypersurfaces, denoted by \( H_\xi \), that contain \( \Sigma'' \) on a neighborhood of \( x \). The average of \( [\tilde{H}_\xi] \) with respect to the Lebesgue measure on \( \xi \) is a smooth form \( \Theta \). So it is limited by a constant times \( \hat{\omega} \). On the other hand, as \( [\tilde{H}_\xi] \) has a positive Lelong number on \( x \), \( (\tau_2)_*(\hat{\omega}) \) has a positive Lelong number on \( x \). We concluded that \( (\tau_2)_*(\hat{\omega}) \) has a positive Lelong number on \( x \). This completes the proof of the lemma. \( \blacksquare \)

We show that \( U \) satisfies the Proposition 4.1. Fix a point \( x \) on \( V \) such that \( \nu(U, x) \leq \nu \). Also fix local holomorphic coordinates close to \( x \). First, construct inverse branches for flat holomorphic disks through \( x \) and then we will extend these inverse branches to a small ball centered on \( x \). We will identify a neighborhood of \( x \) for the unit ball on \( \mathbb{C}^k \) for simplicity. The following version of the Sibony-Wong theorem is the tool for this extension. Let \( B_r \) be the ball of center 0 and radius \( r \) on \( \mathbb{C}^k \). The family \( \mathcal{F} \) of complex lines through 0 is parameterized by the projective space \( \mathbb{P}^{k−1} \), which is endowed with the natural Fubini-Study metric. This metric induces a natural probability measure on \( \mathcal{F} \) that we denote by \( \mathcal{L} \). If \( \Delta \) is an element of \( \mathcal{F} \), denote by \( \Delta_a \) its intersection with \( B_r \).

**Proposition 4.3 (\cite{1}, \cite{30}).** Let \( 0 < \delta_0 \leq 1 \) be a constant. Let \( \mathcal{F}' \subset \mathcal{F} \) be such that \( \mathcal{L}(\mathcal{F}') \geq \delta_0 \), and \( A \) the intersection of \( \mathcal{F}' \) with \( B_r \). Let \( h : A \rightarrow \mathcal{F}' \) be a map that is holomorphic on each \( \Delta_a \) for \( \Delta \in \mathcal{F}' \) and that can be extended holomorphically to a neighborhood of 0. Then \( h \) can be extended to a holomorphic map of \( B_{2r} \) for \( \mathcal{F}' \), where \( 0 < \lambda \leq 1 \) is a constant that depends on \( \delta_0 \) but independent of \( l \), \( \mathcal{F}' \circ r \). Furthermore, if the extension is still denoted by \( h \) then

\[
\sup_{B_{3r}} \| h - h(0) \| \leq \sup_{A} \| h - h(0) \|.
\]

In particular, if \( \| h - h(0) \| \leq \rho \) and if \( h(A) \) does not intersect a complex hypersurface \( Z \) the ball of center \( h(0) \) and radius \( \rho \), then \( h(B_{3r}) \) satisfies the same property.

**Proof.** For \( l = 1 \) a similar result is due to Sibony-Wong \( \cite{48} \). One can deduce from their result the holomorphic extension of \( h \) for any dimension \( l \). To obtain inequality in the proposition, assume \( h(0) = 0 \) for simplicity. Let \( z \) be a point on \( B(0, \lambda r) \) we have to show that \( \| h(z) \| \leq \sup_A \| h \| \). Composing \( h \) with a rotation on \( \mathcal{F}' \) lets assume that \( h(z) = (\| h(z) \|, 0, \ldots, 0) \). One obtains the desired inequality using the Sibony-Wong theorem for the first function of coordinates of \( h \). For the last statement, one can write \( Z = \{ f = 0 \} \) where \( f \) is a holomorphic function of the center \( h(0) \) and radius \( \rho \). The Sibony-Wong theorem applied to \( 1/f \circ h \) implies that \( 1/f \circ h \) is holomorphic on \( B_{3r} \). Thus \( h(B_{3r}) \) does not intersect \( Z \). The proposition follows. \( \blacksquare \)

To control the size of holomorphic discs, one needs the following lemma, see \( \cite{15} \) for the case of any compact complex manifold \( C \).

**Lemma 4.4.** Let \( C \) be a compact complex manifold with a fixed Hermitian metric. Let \( \delta_1 > 0 \) be a small enough constant, depending on \( C \). Let \( f : \Delta_r \rightarrow C \) be a holomorphic map of the center disc 0 and radius \( r \) on \( C \) for \( C \). Suppose the area of \( f(\Delta_r) \), counted with multiplicity, is less than \( \delta_1 \). So, for any \( \varepsilon > 0 \), there is a constant \( 0 < \lambda < 1 \) independent of \( f \) and \( r \) such that the diameter of \( f(\Delta_{\lambda r}) \) is at most equal to \( \varepsilon \sqrt{\text{area}(f(\Delta_r))} \).

We will apply it to \( C = \hat{\Gamma} \). So from now on, we fix a constant \( \delta_1 \) satisfying the last lemma for \( \hat{\Gamma} \). Note that the current \( U \) constructed above can be seen as obstructing the existence of good inverse branches for balls
in the spirit of the Proposition 4.1. To measure the obstruction of the inverse branches of the disks through a point \( x \), we must divide this current using complex lines through \( x \). We will need the following known technical result, cf [15].

**Lemma 4.5.** Let \( Q \) be a \((1,1)\)-positive current closed on \( \mathcal{V} \). So, for any constant \( 0 < \delta_2 < 1 \) there is a constant \( r > 0 \) and a family \( \mathcal{F} \subset \mathcal{F} \) such that \( \mathcal{L}(\mathcal{F}) \geq 1 - \delta_2 \), and for each \( \Delta \in \mathcal{F} \) the measure \( Q \wedge [\Delta_r] \) is well defined and with a mass less than or equal to \( \nu(Q,x) + \delta_2 \). Here, \( \nu(Q,x) \) indicates the Lelong number of \( Q \) on \( x \).

Remember that we can write locally \( Q = dd^c q \) with \( q \) a p.s.h. function. The measure \( Q \wedge [\Delta_r] \) is well defined if \( q \) is not identically \(-\infty \) on \( \Delta_r \). This property is valid for \( \mathcal{L} \)-almost every \( \Delta \) and we have \( Q \wedge [\Delta_r] := dd^c(q|\Delta_r]) \). Now we are ready to construct inverse branches for disks through the point \( x \). We construct inverse branches of order \( \Delta \) from \( x \), a point in the spirit of the Proposition 4.1. To measure the obstruction of the inverse branches of the disks through \( x \), we must divide this current using complex lines through \( x \). We will need the following known technical result, cf [15].

**Lemma 4.6 (2, 30).** There are a number \( r_0 > 0 \) and a family \( \mathcal{F}_0 \subset \mathcal{F} \) with \( \mathcal{L}(\mathcal{F}_0) \geq 1 - \nu/2 \) satisfying the following property. For each complex line \( \Lambda \in \mathcal{F}_0 \) and for each \( n \geq 0 \), the disk \( \Delta_{m,n} \) admits at least \((1 - \nu/2)\chi_{2k}^{N} \) inverse branches \( f: \Delta_{m,n} \to \Delta_{\omega} \) of order \( n \) so that if we define \( \Delta_{\omega} := h^{\nu}1(\Delta_{m,n}) \) for \( 0 \leq i \leq n \) and \( \Delta_{\omega} := \tau^i(\Delta_{m,n}) \) for \( 0 \leq i \leq n - 1 \), then \( \Delta_{\omega} \cap \Omega = \emptyset \) for \( 0 \leq i \leq n \). We have the following lemma.

**Lemma 4.6.** We have the following lemma.

**Proof.** Note that if \( f \) is an inverse branch of order \( n \) that satisfies the properties of the lemma, so \( h \circ f \) is an inverse branch of order \( n - 1 \) that satisfies the same properties. So, we just have to prove the lemma to \( n = mN \) where \( m \) is an integer. By Lemma 4.4, we just need to limit the area \( \Delta_{\omega} \cap \Omega \) by \( \mathcal{L}^1/\epsilon_1 \leq \delta_1 \) and then reduce the radius \( r_0 \) to get the control of the diameter. The rest of the lemma is obtained by induction on \( m \). We will only consider disks \( \Delta \) through \( x \) that are not contained in the orbit of \( \Sigma \). This property applies to almost all discs. By Lemma 4.5 applied to \( U \) and for \( \delta_2 := \nu/2 \), we can choose a number \( r \) and a family \( \mathcal{F}_0 \subset \mathcal{F} \) with \( \mathcal{L}(\mathcal{F}_0) \geq 1 - \nu/2 \) such that for \( \Delta \in \mathcal{F}_0 \) the measure \( U \wedge [\Delta_r] \) is well defined and less than \( 2\nu \). Let \( \nu_m \) be the mass of \( \chi_{2k}^{N}(h^{N})_m(P) \wedge [\Delta_r] \). By definition of \( U \), we have \( \sum_{m\geq 0} U_{\Delta_{\omega}} \nu_m \leq \nu/4 \). By definition of \( m \), for each \( \Delta \in \mathcal{F}_0 \) the disk \( \Delta \) admits at least \( \gamma_m := (1 - 2\sum_{i=0}^{\nu_m} U_{\Delta_{\omega}} \nu_m) \chi_{2k}^{N} \) inverse branches \( f^{(s)}: \Delta \to \Delta^{(s)} \) of order \( Nm \) so that the area of \( \Delta^{(s)} \) is smaller than \( \mathcal{L}^1/\epsilon_1 \) and \( \Delta^{(s)} \cap \Omega = \emptyset \) for \( 0 \leq i \leq n \). Here we use notation similar to that introduced in the lemma of the statement. The index \( s \) satisfies \( 1 \leq s \leq s_m \) and \( \chi_{2k}^{N} \). So the above discussion implies the result. Assume this property for \( m \). The case \( m = 0 \) is clear since the choice of \( \mathcal{F}_0 \) implies that \( \Delta \) is out of \( \Sigma \). We construct inverse branches of order \( N(m + 1) \). The property \( \Delta^{(s)} \cap \Omega = \emptyset \) and the definition of \( \Sigma \) allow us to define the maximal number \( \chi_{2k}^{N} \) inverse branches of order \( N \) for each \( \Delta^{(s)} \). Composing them with \( \chi_{2k}^{N} \) inverse branches of order \( Nm \) of \( \Delta \) gives \( \gamma_m \chi_{2k}^{N} \) inverse branches of order \( (m + 1) \) for \( \Delta \). We will count and remove those which do not satisfy the area control. We call them large size inverse branches. We also have to remove posterior inverse branches whose images intersect \( \Sigma \). First, we count the number of large size inverse branches of order \( N \) of \( \Delta \). For each \( s \) of the matter of simplicity, we drop the letter \( s \) at the moment. Consider all inverse branches \( g: \Delta \to \Delta^{(s)} \) of order \( 1 \leq n \leq N \) of \( \Delta \). The area of \( \Delta^{(s)} \) is limited by \( \mathcal{L}_{\Delta_r} \) for \( \Delta \) for \( 0 \leq i \leq n \) but not for \( i = n \). They are completely disjoint in the sense that these two different branches are not extensions of the same lower-order branch of \( \Delta \). The extensions of order \( N(m + 1) \) of these branches are exactly those of large size. Therefore, the number of large branches of order \( N(m + 1) \) extending \( g \) is \( \chi_{2k}^{N} \). Note that the area \( \Delta^{(s)} \) is the mass of \( [\Delta^{(s)}] \wedge (\tau_2)_s \). This mass is less than or equal to the mass of \( \mathcal{L}(\mathcal{F}_0) \geq 1 - \nu/2 \), and \( \Delta^{(s)} \) admits at least \( \gamma_m \chi_{2k}^{N} \) inverse branches of order \( \Delta^{(s)} \). Therefore, the sum of these areas in all these branches \( f \) (exist at most \( \chi_{2k}^{N} \) of such maps) is limited by \( \epsilon_1^{-1} \mathcal{L}^N \) times the mass of \( P \wedge [\Delta_r] \). As the area of \( \Delta^{(s)} \) is bigger than \( \mathcal{L}^{N+1}/\epsilon_1 \), the number of maps considered \( f \) is at most equal to \( \mathcal{L}^{N+1} \) times the mass of
Proof. Let \( x \) be a point out of \( J\sp{'}_\infty \cup J\sp{'}_{\infty} \). If \( x \) is on \( \mathcal{T} \), it is clear that \( \nu\sp{x}_n \) does not converge to \( \nu \). So assume that \( x \notin \mathcal{T} \). We have to show that \( \zeta_x = 0 \). Fix a constant \( \nu > 0 \). Just prove that \( \zeta_x \leq 4\nu \). Define \( F := \{ \nu(U, \cdot) \geq \nu \} \). By Siu’s theorem, this is a proper analytical subset of \( \mathcal{V} \). By Lemma 5.4 the case where \( x \notin F \) is clear. From now on, assume that \( x \in F \). By Lemma 5.4 applied to \( F \), we have \( \lambda_m(x) \leq \nu \chi\sp{m}_{2k} \) for some integer \( m \) big enough. Consider all the backward orbits of \( x \) of order \( l \leq m \) of form

\[
\emptyset := \{ x_0, x_{-1}, \ldots, x_{-l} \} \quad \text{with} \quad x_0 = x, h(x_{-i-1}) = x_{-i} \quad \text{for} \quad 0 \leq i \leq l - 1
\]

such that \( x_{-i} \in F \) for \( i \leq l - 1 \) and \( x_{-i} \notin F \) unless \( i = m \). These orbits are counted with multiplicity. Using that \( \nu\sp{\times}_n \) is the measure of probability equidistributed on \( h^{-n}(x) \), one can see that

\[
\nu\sp{n} = \sum_{\emptyset} \chi\sp{-l}_{2k} \cdot \nu\sp{x}_{n-l}
\]

for each \( n \geq m \). When considering the masses of measures in the above identity, we have

\[
\sum_{\emptyset} \chi\sp{-l}_{2k} = 1.
\]

We deduce from the same identity that

\[
\zeta_x \leq \sum_{\emptyset} \chi\sp{-l}_{2k} \zeta_{x_{-l}}.
\]

Let \( \Sigma, \Sigma' \) be the sets of \( \emptyset \) with \( x_{-l} \in F \) (consequently \( l = m \)) and with \( x_{-l} \notin F \) respectively. By definition of \( \lambda_n \), we have

\[
\sum_{\emptyset \in \Sigma} \chi\sp{l}_{2k} = \chi\sp{m}_{2k} \lambda_m(x) \leq \nu.
\]

On the other hand, we have \( \zeta_{x_{-l}} \leq 2 \) for each \( \emptyset \) and by Lemma 5.2 \( \zeta_{x_{-l}} \leq 2\nu \) for \( \emptyset \in \Sigma' \). It follows that

\[
\zeta_x \leq \sum_{\emptyset \in \Sigma} \chi\sp{l}_{2k} \zeta_{x_{-l}} + \sum_{\emptyset \in \Sigma'} \chi\sp{-l}_{2k} \zeta_{x_{-l}} \leq 2 \sum_{\emptyset \in \Sigma} \chi\sp{l}_{2k} + 2\nu \sum_{\emptyset \in \Sigma'} \chi\sp{-l}_{2k} \leq 2\nu + 2\nu = 4\nu.
\]

This completes the proof of the theorem. 

We need the following result obtained in [13] in a more general scenario.

**Lemma 5.1.** There is a pluripolar subset \( E \) of \( \mathcal{V} \) containing \( J\sp{'}_\infty \) so that if \( x \) is out of \( E \), then \( \nu\sp{x}_n \) converges to \( \nu \) when \( n \) goes to infinity.

For each \( x \notin J\sp{'}_\infty \), define \( \zeta_x := \sup \| \nu\sp{x}_n - \nu \|_1 \), where the supreme is assumed over all cluster values \( \nu\sp{x}_n \) of the sequence \( \nu\sp{x}_n \). So we have \( \nu\sp{x}_n \to \nu \) if and only if \( \zeta_x = 0 \). We deduce from the above lemma and proposition 4.1, the following property.
Lemma 5.2. Let \( x \) be a point out of \( J_{∞}' \). So we have \( \varsigma_ε < 2ν(U,x) \). In particular, \( ν_{m}' \to ν \) if \( ν(U,x) = 0 \).

Proof. We saw that the condition \( x \notin J_{∞}' \) is needed to define \( ν_{m}' \). As always we will have \( \varsigma_ε < 2 \), we just need to consider the case where \( ν(Q,x) < 1 \). Fix a constant \( ν(U,x) < ν \leq 1 \). Let \( B(x,r) \) be a ball as in the conclusion of the Proposition 4.1. Also choose a point \( y \) on \( B(x,r) \setminus J \). This choice is always possible, since \( E \) is pluripolar. Write

\[
h^{-m}(x) = x_{(1)}^{m}, \ldots, x_{(m)}^{m}
\]

and

\[
h^{-m}(y) = y_{(1)}^{m}, \ldots, y_{(m)}^{m}
\]

where each point is repeated according to its multiplicity. The Proposition 4.1 implies that we can organize these points so that the distance between \( x_{(j)}^{m} \) and \( y_{(j)}^{m} \) be less than \((\chi_{2k-1}/\chi_{2k} + ε)^{m/2} / 2\) for at least \( (1 - ν)\chi_{2k} \) indexes \( j \). Here \( ε > 0 \) is a fixed constant small enough. Since \((\chi_{2k-1}/\chi_{2k} + ε)^{m/2} \) tends to 0, we deduce that any cluster value in the sequence \( ν_{m}' - ν_{m}\) is a measure of mass at most equal to \( 2ν \). The property is valid for all \( ν > ν(U,x) \). Therefore, the result follows from Lemma 5.1 which implies that \( ν_{m}' \to ν \). ■

The set \( T \) in Theorem 2.2 is given in the following proposition.

Proposition 5.3. There is a proper analytic subset \( T \) of \( V \), possibly empty, satisfying the following three conditions:

1. no component of \( T \) is contained on \( J_{∞} \cup J_{∞}' \);
2. \( h^{-1}(T \setminus J) \subset T \);
3. any proper analytic subset of \( V \) satisfying (1) e (2) is contained on \( T \). In addition, we have

\[
T = h^{-1}(T \setminus J) = h(T \setminus J).
\]

Proof. Consider the set \( F_0 := \{ ν(U,x) ≥ 1 \} \). By Siu’s theorem, \( F_0 \) is a proper analytic subset of \( V \). Denote by \( n ≥ 1 \) the analytical set \( F_n \) which is the closing of the set

\[
\{ z \notin J_{∞} \cup J_{∞}', h^{-i}(z) \in F \text{ for } 0 ≤ i ≤ n \}.
\]

Since the sequence \( F_n \) is decreasing, is stationary: we have \( F_n = F_{n+1} \) for \( n \) big enough. Denote by \( T := F_n \) for \( n \) big enough. Is clear that \( T \) satisfies the property (1). We have by definition

\[
h^{-1}(T \setminus (J_{∞} \cup J_{∞}')) \subset T.
\]

As \( h^{-1}(T \setminus (J_{∞} \cup J_{∞}')) \) is dense on \( h^{-1}(T \setminus J) \), the set \( T \) satisfies (2). Denote by \( T_n \) the closing of \( h^{-1}(T \setminus (J_{∞} \cup J_{∞}')) \). This is a decreasing sequence of analytical sets that satisfy the property (1). So it’s stationary: we have \( T_n = T_{n+1} \) for \( m \) big enough. As \( h(T_{n+1} \setminus J) \) is dense on \( T_n \), we deduce from the last identity that \( T_{n-1} = T_n \) and therefore, by induction, \( T_n = T \). It follows that \( T = h^{-1}(T \setminus J) \) which also implies that \( T = h(T \setminus J) \). Let \( T \) be a proper analytic subset of \( V \) satisfying (1) and (2). We have to show that \( T \subset T \). Property (2) implies that if \( x \) is a point on \( T \setminus J_{∞}' \), then any cluster value of \( ν_{m}' \) is supported by \( T \). As \( ν \) has no mass on \( T \), we deduce that \( ν_ε = 2 \). Lemma 5.2 implies that \( x \) is on \( F_0 \). So we have \( T \subset F_0 \). Property (2) also, together with the definition of \( T \), implies that \( T \subset T \). This completes the proof of the proposition. ■

We need the following characterization of the set \( T \).

Lemma 5.4. Let \( F \) be a proper analytic subset of \( V \). Let \( x \) be a point on \( F \) that doesn’t belong to \( J_{∞} \cup J_{∞}' \). Let \( \lambda_n(x) \) be the number of orbits backwards \( x_0, x_{-1}, \ldots, x_{-n} \) counted with multiplicity with \( x_{-n} = x \), \( x_{-i−1} \in h^{-1}(x_{-i}) \) for \( 0 ≤ i ≤ n-1 \) and \( x_{-n} \in F \) for \( 0 ≤ i ≤ n \). If \( x \) is not on \( T \) then \( \chi_{2k} λ_n(x) \to 0 \) when \( n \to ∞ \).

Proof. Note that, as \( x \) is out of \( J_{∞} \cup J_{∞}' \) the same property applies to \( x_{-i} \). By definition, the sequence \( \chi_{2k} λ_n(x) \) is decreasing because each orbit backwards of order \( n+1 \) is one of \( \chi_{2k} \) orbit extensions backwards of order \( n \). As the functions \( λ_n \) are semi-continuous superior in relation to the Zariski topology induced on \( F \setminus (J_{∞} \cup J_{∞}') \), the function \( λ := \lim \chi_{2k} λ_n \) is also semi-continuous superior in relation to this topology. Let \( m \) be the maximum value of \( λ \) on \( F \setminus (J_{∞} \cup J_{∞}') \). Just show that \( m = 0 \). Suppose that \( m > 0 \). Denote by \( Z^* \) the set of points \( x \in F \setminus (J_{∞} \cup J_{∞} \cup T) \) such that \( λ(x) ≥ m \). The closing \( Z \) of \( Z^* \) is an analytical subset of \( F \). No irreducible component of \( Z \) is contained on \( T \). Consider a point
satisfies then for each Hermitian metric \( \eta \).

Let \( \Psi = \sum_i \frac{1}{\psi_i} \) its inverse sum. So the Hausdorff dimension of \( \nu_h \) satisfies

\[
\dim_{\mathcal{H}}(\nu_h) = \Psi \cdot h(\lambda).
\]

Here is the First Conjecture.

**Conjecture 6.1.** Let \( \mathcal{V}, h, \nu_h \) as in Theorem 5.5. Let \( \psi_1, \ldots, \psi_k \) be the Lyapunov exponents of \( \nu_h \) and \( \Psi = \sum_i 1/\psi_i \) its inverse sum. So the Hausdorff dimension of \( \nu_h \) satisfies

\[
\dim_{\mathcal{H}}(\nu_h) = \Psi \cdot h(\chi).
\]

Here is the Second Conjecture.

**Conjecture 6.2.** Let \( \mathcal{V}, h, \nu_h \) as in Theorem 5.5. So there are \( T_i^+ \) and \( T_k^- \) such that \( \nu_h \) is defined by

\[
\nu_h := T_i^+ \land T_k^- ,
\]

where \( T_i^+ \) is a positive invariant closed current of bidegree \((l, l)\), i.e.

\[
\frac{1}{\chi_{2l}^m}(h^m)^* \omega^l \to T_i^+
\]

and \( T_k^- \) designates a positive invariant closed current of \((k - l, k - l)\), i.e.

\[
\frac{1}{\chi_{2(k-l)}^m}(h^m)^* \omega^{k-l} \to T_{k-l}^-.
\]

Here is the Third Conjecture.

**Conjecture 6.3.** Let \( \mathcal{V}, h, \nu_h \) as in Theorem 5.5 and \( T_i^+ \) as in Conjecture 6.2. Let \( \psi_1, \ldots, \psi_k \) be the Lyapunov exponents of \( \nu_h \) with \( \psi_l = \max_{1 \leq i \leq k} \psi_i \). So the Hausdorff dimension of the **Support** of \( T_i^+ \) satisfies

\[
\dim_{\mathcal{H}}(\text{Supp} T_i^+) \geq 2(k - l) + \frac{\log \chi_{2l}}{\psi_l}.
\]

Here is the Fourth Conjecture.

**Conjecture 6.4.** Let \( \mathcal{V}, h, \nu_h \) be as in Theorem 1.9 and \( \mathbb{T} \) a maximal proper algebraic subset possibly empty and totally invariant, and \( \nu_h := \chi_{2m}^{-m}(h^m)^* \Gamma_x \). There is a constant \( \gamma > 1 \) such that if \( x \) is a point out of \( \mathbb{T} \), so \( \nu_h \) converges exponentially to \( \nu_h \), this is, if \( \zeta \) is a function \( C^0 \) on \( \mathcal{V} \) with \( 0 < \beta \leq 2 \), so

\[
|\nu_h - \nu_h, \zeta| \leq M \left[ 1 + \log^+ \frac{1}{D(x, T)} \right]^{\beta/2} \|\zeta\|_e^e \cdot e^{-\gamma \beta^m/2},
\]

where \( M > 0 \) is a constant independent of \( m, x, \zeta, \log^+(\cdot) := \max(0, \log(\cdot)) \) and \( D(x, T) := \text{dist}(x, T) \).
An algebraic set is the set of zeros of a family of polynomials.

Here is the Fifth Conjecture.

**Conjecture 6.5.** Let $\mathcal{V}, h, \nu_h$ be as in Theorem 1.9 and $\nu_m := \chi_{2k}^{-m}(h^m)^* (\Gamma_x)$. Let $1 < \gamma < (\chi_{2k})^{1/k}$ be a fixed constant. There is a proper algebraic subset $E_\gamma$, possibly empty, on $\mathcal{V}$ such that if $x$ is a point out of $E_\gamma$ and if $\zeta$ is a function $C^\beta$ on $\mathcal{V}$ with $0 < \beta \leq 2$, so

$$|\langle \nu_m - \nu_h, \zeta \rangle| \leq M \left[ 1 + \log^+ \frac{1}{D(x, E_\gamma)} \right]^{\beta/2} \|\zeta\|_{C^\beta} \gamma^{-\beta m/2},$$

where $M > 0$ is a constant independent of $m, x, \zeta, \log^+ (\cdot) := \max(0, \log(\cdot))$ and $D(x, E_\gamma) := \text{dist}(x, E_\gamma)$

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