Abstract

A mapping class group of an oriented manifold is a quotient of its diffeomorphism group by the isotopies. In the published version of “Mapping class group and a global Torelli theorem for hyperkähler manifolds” I made an error based on a wrong quotation of Dennis Sullivan’s famous paper “Infinitesimal computations in topology”. I claimed that the natural homomorphism from the mapping class group to the group of automorphisms of cohomology of a simply connected Kähler manifold has finite kernel. In a recent preprint [KS], Matthias Kreck and Yang Su produced counterexamples to this statement. Here I correct this error and other related errors, observing that the results of “Mapping class group and a global Torelli theorem” remain true after an appropriate change of terminology.

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Throughout this paper, “hyperkähler manifold” means compact hyperkähler manifold of maximal holonomy, also known as IHS (irreducible holomorphically symplectic) manifold.

1 Mapping class group

Let $M$ be a manifold, $\text{Diff}(M)$ its diffeomorphism group (sometimes - its oriented diffeomorphism group), and $\text{Diff}_0(M)$ the connected component of unity in $\text{Diff}(M)$. The quotient group $\Gamma = \frac{\text{Diff}(M)}{\text{Diff}_0(M)}$ is called the mapping class
In [Su], Dennis Sullivan compared the mapping class group to the algebraic group $\mathcal{A}$ of automorphisms of the minimal model of the de Rham differential graded algebra preserving the integer structure and Pontryagin classes, and found that $\Gamma$ is mapped to a lattice of integer points of $\mathcal{A}$ with finite kernel and cokernel whenever $M$ has nilpotent fundamental group and $\dim M \geq 5$.

As shown in [DGMS], the de Rham algebra of a Kähler manifold $M$ is formal, that is, quasi-isomorphic to its cohomology. I claimed that this implies that the group $\mathcal{A}$ is isomorphic to the automorphisms of the cohomology preserving the Pontryagin classes.

This is wrong, because in the typical situation the minimal model is still much bigger than the cohomology algebra, and its automorphism group is also bigger. Indeed, as shown by Kreck and Su ([KS]), the natural map from the mapping class group to $\text{Aut}(H^*(M))$ can have infinitely-dimensional kernel.

Therefore, Theorem 3.5 from [V1] is false as stated. The correct version is the following.

**Theorem 1.1:** Let $M$ be a compact hyperkähler manifold of maximal holonomy, and $\Gamma = \text{Diff}/\text{Diff}_0$ its mapping class group. Then $\Gamma$ acts on $H^2(M, \mathbb{R})$ preserving the Bogomolov-Beauville-Fujiki form. Moreover, the corresponding homomorphism $\varphi : \Gamma \to O(H^2(M, \mathbb{Z}), q)$ has finite index in $O(H^2(M, \mathbb{Z}), q)$.

**Proof:** The image of $\varphi$ is described in [V1, Theorem 3.5], using the results of hyperkähler geometry (the local Torelli theorem, Riemann-Hodge relations and the computation of cohomology algebra obtained in [V2]). The kernel (claimed to be finite in [V1, Theorem 3.5]) is not finite. □

The correct quotation from Sullivan’s paper [Su, Theorem 13.3] follows.

**Definition 1.2:** Let $M$ be the minimal model of de Rham algebra of a manifold $M$, $\sigma$ its automorphism, and $\xi \in M$ a class which satisfies $d\xi = \sigma(p) - p$, where $p = (p_1, p_2, ..., p_n)$ is the total Pontryagin class. The pair $(\sigma, \xi)$ is called an **algebraic diffeomorphism** of $M$. An algebraic diffeomorphism $(\sigma, \xi)$ is called an **algebraic isotopy** if there exists a derivation $\delta : M \to M$ of degree -1 such that $\sigma = e^{d\delta + \delta d}$ and

$$\xi = \delta \left( \sum_{i=1}^{\infty} \frac{(d\delta)^i}{(i+1)!} (p) \right)$$

is an explicit homotopy between $p$ and $\sigma(p)$ induced by the expression $\sigma = e^{d\delta + \delta d}$. There is a natural group structure on the set of algebraic diffeomorphisms $\mathcal{D}$ and algebraic isotopies $\mathcal{I}$; moreover, $\mathcal{I}$ is a normal subgroup of $\mathcal{D}$. **An algebraic mapping class group** is the quotient $\mathcal{D}/\mathcal{I}$. It is (generally speaking) a pro-algebraic group, with the natural integer structure induced from the integer structure on the cohomology of the de Rham algebra.

**Theorem 1.3:** ([Su, Theorem 13.3]) Let $M$ be a compact, simply-connected
manifold of dimension \( \geq 5 \). Then its mapping class group is commensurable with the group of integer points in its algebraic mapping class group \( \mathcal{D}_I \).

**Remark 1.4:** If the manifold \( M \) is, in addition, Kähler, its de Rham algebra is formal. Then the Sullivan’s minimal model \( \mathcal{M} \) can be constructed from its cohomology algebra \( H^*(M) \). Any automorphism of \( H^*(M) \) gives an automorphism of \( \mathcal{M} \), but \( \mathcal{M} \) can \textit{a priori} have more automorphisms than \( H^*(M) \). This explains the error in [V1, Theorem 3.5].

**Remark 1.5:** Define the \textbf{Torelli group} \( \mathcal{T} \) of \( M \) as the subgroup of all elements of the mapping class group of \( M \) acting trivially on \( H^2(M) \). Kreck and Su ([KS]) have computed the Torelli group for two 8-dimensional examples of hyperkähler manifolds: the generalized Kummer variety and the second Hilbert scheme of K3 surface. The Torelli group is infinite for the first one, and finite for the second.

**Remark 1.6:** Sometimes one defines the Torelli group as a subgroup \( \widetilde{\mathcal{T}} \) of the mapping class group which acts trivially on the cohomology. In [V1, Theorem 3.5 (ii)], it was shown that the homomorphism \( \text{Aut}(H^*(M, \mathbb{Z}), O(H^2(M, \mathbb{Z}))) \) has finite kernel, hence \( \widetilde{\mathcal{T}} \) has finite index in \( \mathcal{T} \).

## 2 The monodromy group and the marked moduli space

Let \( M \) be a manifold and \( \text{Comp} \) the set of all complex structures on \( M \). Interpreting a complex structure as an endomorphism of the tangent space, we imbue \( \text{Comp} \) with \( C^\infty \)-topology. Let \( \text{Diff}_0 \) be the isotopy group (that is, connected component of the unity in the diffeomorphism group), and \( \Gamma := \frac{\text{Diff}}{\text{Diff}_0} \) its mapping class group. The \textbf{Teichmüller space of complex structures on} \( M \) is the quotient \( \text{Teich} := \frac{\text{Comp}}{\text{Diff}_0} \) equipped with the quotient topology. In many cases (for compact Riemann surfaces, Calabi-Yau manifolds, compact tori and hyperkähler manifolds) the Teichmüller space is smooth. Its quotient \( \text{Teich}/\Gamma \) parametrizes the complex structures on \( M \), and (in many situations) can be understood as the moduli space of deformations.

For convenience, we redefine the notation for hyperkähler manifolds. In this case, \( \text{Teich} \) denotes the Teichmüller space of all complex structures of hyperkähler type (that is, complex structures which are holomorphically symplectic and Kähler). From the local Torelli theorem it follows that this space is open in the more general Teichmüller space of all complex structures.

\textbf{Claim 2.1:} Let \( K \subset \Gamma \) be the Torelli group of \( M \), that is, the group of all elements trivially acting on \( H^2(M) \). Consider an element \( \gamma \in K \) which fixes a point \( I \in \text{Teich} \). Then \( \gamma \) acts trivially on the corresponding connected component of...
Moreover, the group $\mathcal{G}_I$ of such $\gamma$ is finite.

**Proof:** Let $I \in \text{Teich}$ be a fixed point of an element $\gamma \in \Gamma$, and $l \in \text{Gr}_{+,+}(H^2(M, \mathbb{R}))$ be the 2-plane in the Grassmann space of positive 2-planes in $H^2(M, \mathbb{R})$ corresponding to $I$, with $l = (\text{Re} \Omega, \text{Im} \Omega)$, where $\Omega \in H^2(M, \mathbb{C})$ is the cohomology class of the holomorphic symplectic form. Each connected component of the Hausdorff reduction of $\text{Teich}$ is naturally identified with the space $\text{Gr}_{+,+}(H^2(M, \mathbb{R}))$ by the global Torelli theorem.

Let $\gamma$ be an element of the Torelli group of $M$ which fixes $I \in \text{Teich}$. Since $\gamma$ commutes with the period map $\text{Per} : \text{Teich} \rightarrow \text{Gr}_{+,+}(H^2(M, \mathbb{R}))$ and acts trivially on $\text{Gr}_{+,+}(H^2(M, \mathbb{R}))$, it maps the set $\text{Per}^{-1}(l) \subset \text{Teich}$ to itself, for each $l \in \text{Per}$. However, $\text{Per}^{-1}(l)$ is identified with the set of all Kähler chambers in $H^{1,1}(M, I)$ for a complex structure $I \in \text{Per}^{-1}(l)$ ([Ma1, Theorem 5.16]). Since $\gamma$ acts trivially on $H^2(M)$, it acts trivially on the set of Kähler chambers. Then it acts trivially on the whole $\text{Teich}$.

It remains to show only that $\mathcal{G}_I$ is finite. Let $\text{Diff} \cdot I$ be the orbit of $I$, and $G$ the stabiliser of $I$, that is, the group of complex automorphisms of $(M, I)$. Then $\text{Diff} \cdot I = \text{Diff} / G$. Therefore, the set of connected components of the orbit $\text{Diff} \cdot I$ is parametrized by $\Gamma / G$. We obtain that $\gamma \in \Gamma$ fixes a point $J$ in $\text{Teich}$ if and only if it acts on $(M, J)$ by complex automorphisms.

Using Calabi-Yau theorem, it is easy to prove that the group of complex automorphisms acting trivially on $H^2(M)$ is finite ([V1, Theorem 4.26]). Indeed, any such automorphism preserves the Calabi-Yau metric, which is uniquely determined by its Kähler class, and the group of isometries of a compact metric space is compact. ■

**Definition 2.2:** Let $M$ be a hyperkähler manifold. The **marked moduli space** of $M$ is the quotient $\text{Teich} / K$. From Claim 2.1 it follows that each connected component of $\text{Teich} / K$ is diffeomorphic to the corresponding connected component of $\text{Teich}$, because $K$ acts by permuting isomorphic connected components of $\text{Teich}$.

**Definition 2.3:** Let $\text{Teich}^I$ denote the connected component of $\text{Teich}$ containing a point $I \in \text{Teich}$. **Monodromy group** $\text{Mon}_I$ of a hyperkähler manifold $(M, I)$ is the group of all mapping class elements preserving the component $\text{Teich}^I$.

**Remark 2.4:** The monodromy group $\text{Mon}_I$ is the group generated by the monodromy maps associated with the Gauss-Manin connections for all families of deformations of $(M, I)$.

**Remark 2.5:** The intersection of the monodromy group and the Torelli group is finite ([V1, Corollary 7.3]).

Using the erroneous quotation from [Hu1], I claimed that the Teichmüller space has finitely many connected components ([V1, Corollary 1.12]. Generally
speaking, this is false. Indeed, as follows from Theorem 3.1 below, the Torelli group acts on the connected components of the Teichmüller space with finite stabilizers and finitely many orbits. Therefore, the Teichmüller space has infinitely many connected components if and only if the Torelli group is infinite.

[1] Corollary 1.12 was used to prove the following theorem.

Theorem 2.6: Let \( \text{Mon}_I \) be the monodromy group of a hyperkähler manifold \( M \), and \( \Phi : \Gamma \to O(H^2(M, \mathbb{Z})) \) the natural homomorphism. Then

(i) The group \( \Phi(\text{Mon}_I) \) has finite index in \( O(H^2(M, \mathbb{Z})) \), for all \( I \).

(ii) The number of connected components of the marked moduli space of \( M \) is finite.

Proof: The proof is similar to the one given by Bakker and Lehn ([BL, Theorem 8.2]), where they prove this result for projective deformations of singular hyperkähler manifolds. For non-algebraic deformations, their proof needs some adjustments.

First, notice that (i) is equivalent to (ii). Indeed, consider the action of the group \( \Gamma/K \) on \( M = \text{Teich}/K \). The space \( M \) has finitely many components if and only if the stabilizer \( \text{Mon}_I \) of each connected component of \( M \) in \( \Gamma \) has finite index in \( \Gamma/K \). However, the group \( \text{Mon}_I \) is generated by \( K \) and \( \text{Mon}_I \), while \( \Phi(K) = 1 \) by definition of \( K \). Therefore \( \Phi(\text{Mon}_I) = \Phi(\text{Mon}_I) \subset \Phi(\Gamma) \). The group \( \Phi(\Gamma) \) has finite index in \( O(H^2(M, \mathbb{Z})) \) by Theorem 1.1.

Now we prove Theorem 2.6 (i). Fix a very ample line bundle \( L \) on \((M, I)\), and let \( Z \subset M \) be the set of all complex structures \( J \) on \( M \) such that \( c_1(L) \) is very ample on \((M, J)\). All such manifolds \((M, J)\) can be embedded into \( \mathbb{P}^N \) with a fixed \( N \) which is determined from the Riemann-Roch formula. Since the Hilbert scheme with prescribed Poincaré polynomial is bounded, \( Z \) is a union of finitely many deformation families ([Mats]).

Consider the Teichmüller space \( \text{Teich}_L \) of all \( J \in \text{Teich} \) such that \( \eta = c_1(L) \in H^2(M, \mathbb{Z}) \) is the first Chern class of a very ample line bundle on \((M, J)\). Then \( \eta \in H^{1,1}(M) \), and \( H^{1,1}(M) \) can be obtained as the orthogonal complement of the 2-plane \( u_j := \langle \text{Re } \Omega_j, \text{Im } \Omega_j \rangle \), where \( \Omega_j \) is cohomology class of a holomorphically symplectic form on \((M, J)\). The corresponding period space \( \text{Per}_\eta \) is the Grassmannian \( \text{Gr}_{+,+}(\eta^+) \). Since \( \eta^+ \) has signature \((2, b_2 - 3)\), the space

\[ \text{Per}_\eta = \text{Gr}_{+,+}(\eta^+) = \frac{SO^+(2, b_2 - 3)}{SO(2) \times SO(b_2 - 3)} \]

is a symmetric space, with the arithmetic group \( SO(\eta^+ \cap H^2(M, \mathbb{Z})) \) acting properly by isometries. Let \( \Gamma_\eta \) be a subgroup of all elements of \( \Gamma \) fixing \( \eta \). Since \( \Phi(\Gamma) \) is a finite index subgroup in \( O(H^2(M, \mathbb{Z})) \), \( \Phi(\Gamma_\eta) \) is a finite index subgroup in \( O(\eta^+ \cap H^2(M, \mathbb{Z})) \). Therefore, the quotient space \( \text{Per}_\eta / \Gamma_\eta \) is quasiprojective by the Baily-Borel theorem ([BB]).

Let \( \text{Teich}_\eta \) be the Teichmüller space of all \( J \) such that \( \eta \) is of type \((1,1)\) on \((M, J)\). For any point \( J \in \text{Teich}_\eta \) with the Picard group of \((M, J)\) has rank
1, the bundle $L$ is ample ([H2]). Replacing $L$ by $L^N$ if necessary, where $N$ is the appropriate Fujita constant, we may assume that $L$ is very ample. This implies that $\text{Teich}_L$ is dense in $\text{Teich}_\eta$ and has the same number of connected components.

Consider the Hilbert scheme $Z$ defined above. Its universal cover is mapped to $\text{Per}_\eta$, because $\text{Per}_\eta$ is the classifying space of the Hodge structures on $H^2(M)$. This gives a complex analytic map $Z \to \text{Per}_\eta / \Phi(\Gamma_\eta)$, which is algebraic by Borel’s extension theorem ([B, Theorem 3.10]). Therefore, a general point in $\text{Per}_\eta / \Phi(\Gamma_\eta)$ has finite preimage in $Z = \text{Teich}_L / \Gamma_\eta$. On the other hand, each connected component of $Z$ can be identified with a connected component of $\text{Teich}_L / \text{Mon}_\eta^I$, where $\text{Mon}_\eta^I$ is the corresponding subgroup of the monodromy group. We obtain that each component of $\text{Teich}_L / \text{Mon}_\eta^I$ maps to $\text{Per}_\eta / \Phi(\Gamma_\eta)$ with finite fibers, and $\Phi(\text{Mon}_\eta^I)$ has finite index in $\Phi(\Gamma_\eta)$.

The union $\bigcup_{\eta} \Phi(\text{Mon}_\eta^I)$ generates a finite index subgroup in $O(H^2(M, \mathbb{Z}))$, as follows from Lemma 2.7 below. Therefore, $\Phi(\text{Mon}_I)$ also has finite index in $O(H^2(M, \mathbb{Z}))$.  

**Lemma 2.7:** Let $(\Lambda, q)$ be a non-degenerate quadratic lattice of signature $(p, q)$, $p > 2$ and $q > 1$, $O(\Lambda)$ its isometry group, and $O_\eta(\Lambda)$ its subgroup fixing $\eta \in \Lambda$ which satisfies $c := (\eta, \eta) > 0$. For each $\eta \in \Lambda$ with positive square, fix a subgroup $\Gamma_\eta \subset O_\eta(\Lambda)$ of finite index. Let $S := \bigcup_{\eta} \Gamma_\eta \subset O(\Lambda)$ be the union of all $\Gamma_\eta$ for all such $\eta$. Then $S$ generates a finite index subgroup $\Gamma_S \subset O(\Lambda)$.

**Proof. Step 1:** Let $V = \mathbb{R}^{p,q} := \Lambda \otimes \mathbb{Z} \otimes \mathbb{R}$ be the vector space associated with $\Lambda$, and $X_c \subset V$ the set of all vectors of square $c = (\eta, \eta)$. We prove that $\Gamma_S$ acts on the quadric $X_c$ ergodically for a (unique) $O(V)$-invariant Lebesgue measure.

Let $Y_r$ be the set of all $x \in X_c$ such that $g(x, \eta) = r$. The space $Y_r$ is equipped with a homogeneous action of the group $H := O(\eta^+ \otimes \mathbb{Z} \otimes \mathbb{R}) = O(p-1, q)$, and the stabilizer $H_0$ of a generic point $z \in X_c$ is either $O(p-2, q)$ or $O(p-1, q-1)$, depending on the signature of the space $\langle x, \eta \rangle$. Therefore, $H_0$ is non-compact. Applying Moore’s ergodicity theorem ([Mo, Theorem 7]) to the space $Y_r = H / H_0$, we see that $\Gamma_\eta$ acts ergodically on $Y_r$. Therefore, any $\Gamma_\eta$-invariant measurable function $X_c$ is $H$-invariant almost everywhere. Applying this to two non-collinear vectors $\eta_1, \eta_2$ with positive square, we obtain that any $\Gamma_S$-invariant measurable function on $X_c$ is both $O(\eta_1^+ \otimes \mathbb{Z} \otimes \mathbb{R})$-invariant and $O(\eta_2^+ \otimes \mathbb{Z} \otimes \mathbb{R})$-invariant, hence constant.

**Step 2:** We are going to prove that the group $\Gamma_S$ has finite covolume in $O(V)$. Consider the map $O(V) \to X_c$ taking $g \in O(V)$ to $g(\eta)$, where $\eta \in \Lambda$. This is a locally trivial fibration with fiber $H = O(\eta^+ \otimes \mathbb{Z} \otimes \mathbb{R})$. Choose an open set of finite measure $U \subset X_c$ such that $\Gamma_S U \supset X_c$ (Step 1). Since $\Gamma_\eta \subset H$ is an arithmetic lattice in $H$ ([WM]), there exists a subset $V \subset H$ of finite measure such that $\Gamma_\eta V \supset H$. Choose a section $R \subset O(V)$ of the map $O(V) \to X_c$ over $U \subset X_c$, and let $W \subset O(V)$ be obtained as $V \cdot R$. The set $W = U \times V$ has finite
measure by Fubini’s theorem. To prove that \( \Gamma_S \) has finite covolume in \( O(V) \), it remains to show that \( \Gamma_S W \supset O(V) \). Since \( \Gamma \eta V \supset H \), we have \( \Gamma_S W \supset \pi^{-1}(U) \). Since \( \Gamma_S \supset X_c \), we also have

\[
\Gamma_S W \supset \pi^{-1}(U) = \pi^{-1}(\Gamma_S U) = O(V).
\]

Then \( \Gamma_S \) has finite covolume in \( O(V) \).

**Step 3**: The number \( \frac{\text{Vol}(O(V)/\Gamma_S)}{\text{Vol}(O(V)/O(\Lambda))} \) is equal to the index of \( \Gamma_S \) in \( O(\Lambda) \); Step 2 implies that this number is finite.

## 3 The Torelli group action on the Teichmüller space

In [V1, Remark 1.12] I misquoted a paper [Hu1] of Dan Huybrechts stating that the Teichmüller space of a hyperkähler manifold has finitely many components. This is false, as explained above. The correct version of this statement is as follows.

**Theorem 3.1**: Let \( M \) be a compact hyperkähler manifold, \( \Gamma \) its mapping class group, \( \text{Teich} \) the Teichmüller space of complex structures of hyperkähler type, and \( K \) the Torelli group, that is, the group of all elements \( \gamma \in \Gamma \) acting trivially on \( H^2(M, \mathbb{R}) \). Then

(i) \( K \) acts on the space of connected components of \( \text{Teich} \) with finitely many orbits, and the stabilizer of each component is finite.

(ii) Moreover, for each \( \gamma \in K \) fixing a point \( I \in \text{Teich} \), \( \gamma \) acts trivially on the connected component \( \text{Teich}^I \) of \( I \) in \( \text{Teich} \).

**Proof**: Theorem 3.1 (i) is Theorem 2.6 (ii) and Theorem 3.1 (ii) is Claim 2.1.

**Corollary 3.2**: The Torelli space of complex structures of hyperkähler type on \( M \) has infinitely many connected components if the Torelli group is infinite, and finitely many components if it is finite.

**Remark 3.3**: A similar result is true for the Teichmüller space of complex structures of Kähler type on a compact torus, which also has infinite Torelli group ([Ha]). The Albanese map from a compact Kähler torus to its Albanese space is an isomorphism, and this provides the torus with the canonical flat coordinates. Then the connected component of its Teichmüller space is the set \( GL^+(2n, \mathbb{R})/GL(n, \mathbb{C}) \) of complex structures on an oriented vector space. The Torelli group acts on the set of connected components freely and transitively for the same reason as above. Indeed, an element \( \gamma \) of the Torelli group which stabilizes \( I \in \text{Teich} \) commutes with the Albanese map, and hence acts trivially.
on the whole connected component $\text{Teich}_I$ of the Teichmüller space. Then $\gamma$ defines an automorphism of $(M, J)$ for all $J \in \text{Teich}_I$. For a generic complex torus, all automorphisms are homotopic to identity, hence $\gamma$ is trivial.

4 Errata

The following statements of [V1] are false and should be amended: Remark 1.12, Theorem 1.16, Theorem 3.4, Theorem 3.5 (iv), Theorem 4.26 (ii) and (iii). Correct versions of these results are given in Section 1 (Theorem 3.4, Theorem 3.5, Theorem 1.16), Section 2 (Remark 1.12), Section 3 (Theorem 4.26 (ii) and (iii)). These erroneous claims were used in the proof of [V1, Theorem 4.25, Corollary 4.31, Corollary 7.3]. Theorem 3.1 is sufficient to prove these results.

Remark 4.1: Using this opportunity to update the paper, I want to address a minor gap in the proof of Corollary 7.3, which claims “Using [C, Remark 13], we may assume that there exists a universal fibration $\pi : Z \rightarrow \text{Teich}_I$.” In a more recent paper [M2], E. Markman gives an explicit construction of the universal fibration.

Summing it up: due to my oversight, some claims about the Teichmüller spaces made in [V1] were incorrect, and some results of D. Huybrechts and D. Sullivan were misquoted. Most of the errors can be corrected if we replace the Teichmüller space by the marked moduli space, and the mapping class group $\Gamma$ by its quotient $\Gamma/K_0$, where $K_0$ is a subgroup of all elements acting trivially on $M$, which has finite index in the Torelli group.

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M. Verbitsky  

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Misha Verbitsky  

INSTITUTO NACIONAL DE MATEMÁTICA PURA E APLICADA (IMPA)  

ESTRADA DONA CASTORINA, 110  

JARDIM BOTÁNICO, CEP 22460-320  

RIO DE JANEIRO, RJ – BRASIL  

also:  

LABORATORY OF ALGEBRAIC GEOMETRY,  

NATIONAL RESEARCH UNIVERSITY HSE,  

DEPARTMENT OF MATHEMATICS, 6 USACHEVA STR. MOSCOW, RUSSIA  

verbit@impa.br