Deformations of K3 surfaces and orientation

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Joint work with: E. Macrì (arXiv:0804.2552) and D. Huybrechts and E. Macrì (arXiv:0710.1645)

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1. **Motivations**
   - The setting
   - The problem
   - The analogies

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2. **Infinitesimal Derived Torelli Theorem**
   - The setting
   - The statement
   - Sketch of the proof

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Derived categories and K3 surfaces

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Let X be a smooth projective complex variety. Denote by $\mathbf{Coh}(X)$ the abelian category of coherent sheaves on X.

Derived categories and K3 surfaces

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The main algebraic invariant we are going to study is the **bounded derived category of coherent sheaves**

$$\mathrm{D}^{\mathrm{b}}(X) := \mathrm{D}^{\mathrm{b}}(\mathbf{Coh}(X)).$$

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- X is simply connected.

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A **K3 surface** is a smooth compact Kähler (complex) surface X such that:

- X is simply connected.
- The canonical bundle K_X is trivial.

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Let X be a K3 surface.

Main problem

Describe the group of exact autoequivalences of the triangulated category $\mathrm{D}^{\mathrm{b}}(X)$ or of a first order deformation of it.

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Remark (Orlov)

Such a description is available (in the non-deformed context) when X is an abelian surface (actually an abelian variety).

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Geometry: automorphisms

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Theorem (Torelli Theorem)

Let X and Y be K3 surfaces.

Geometry: automorphisms

Theorem (Torelli Theorem)

Let X and Y be K3 surfaces. Suppose that there exists a Hodge isometry

$$g : H^2(X,\mathbb{Z}) \to H^2(Y,\mathbb{Z})$$

which maps the class of an ample line bundle on X into the ample cone of Y.

Geometry: automorphisms

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Lattice theory

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Lattice theory + Hodge structures

Geometry: automorphisms

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Lattice theory + Hodge structures + ample cone

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Lattice theory + Hodge structures + ample cone

Remark

The automorphism is uniquely determined.

Geometry: diffeomorphisms

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Theorem (Borcea, Donaldson)

Consider the natural map

$$\rho : \mathrm{Diff}(X) \longrightarrow \mathrm{O}(H^2(X, \mathbb{Z})).$$

Then $\mathrm{im}\,(\rho) = \mathrm{O}_+(H^2(X, \mathbb{Z}))$, where $\mathrm{O}_+(H^2(X, \mathbb{Z}))$ is the group of orientation preserving isometries.

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The orientation is given by the choice of a basis for the 3-dimensional positive space in $H^2(X, \mathbb{R})$.

Geometry: diffeomorphisms

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Remark

The kernel of ρ is not known!

Orlov’s result

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Derived Torelli Theorem (Mukai, Orlov)

Let X and Y be smooth projective K3 surfaces. Then the following are equivalent:

Orlov's result

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Let X and Y be smooth projective K3 surfaces. Then the following are equivalent:

1. There exists an equivalence $\Phi : \mathrm{D}^{\mathrm{b}}(X) \cong \mathrm{D}^{\mathrm{b}}(Y)$.

Orlov's result

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1. There exists an equivalence $\Phi : \mathrm{D}^{\mathrm{b}}(X) \cong \mathrm{D}^{\mathrm{b}}(Y)$.
2. There exists a Hodge isometry $\widetilde{H}(X, \mathbb{Z}) \cong \widetilde{H}(Y, \mathbb{Z})$.

Orlov's result

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The equivalence Φ induces an action on cohomology

$$\begin{array}{ccc} \mathrm{D^b}(X) & \xrightarrow{\ \Phi\ } & \mathrm{D^b}(Y) \\ {\scriptstyle v(-)=\mathrm{ch}(-)\cdot\sqrt{\mathrm{td}(X)}}\downarrow & & \downarrow{\scriptstyle v(-)=\mathrm{ch}(-)\cdot\sqrt{\mathrm{td}(Y)}} \\ \widetilde{H}(X,\mathbb{Z}) & \xrightarrow{\ \Phi_H\ } & \widetilde{H}(Y,\mathbb{Z}) \end{array}$$

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Question

Can we understand better the action induced on cohomology by an equivalence?

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Question

Can we understand better the action induced on cohomology by an equivalence?

Orientation: Let σ be a generator of $H^{2,0}(X)$ and ω a Kähler class. Then $\langle \mathrm{Re}(\sigma), \mathrm{Im}(\sigma), 1-\omega^2/2, \omega\rangle$ is a positive four-space in $\widetilde{H}(X,\mathbb{R})$ with a natural orientation.

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Orientation: Let σ be a generator of $H^{2,0}(X)$ and ω a Kähler class. Then $\langle \mathrm{Re}(\sigma), \mathrm{Im}(\sigma), 1-\omega^2/2, \omega\rangle$ is a positive four-space in $\widetilde{H}(X,\mathbb{R})$ with a natural orientation.

Problem

The isometry $j := (\mathrm{id})_{H^0\oplus H^4} \oplus (-\mathrm{id})_{H^2}$ is not orientation preserving. Is it induced by an autoequivalence?

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Motivation

There exists an explicit description of the first order deformations of the abelian category of coherent sheaves on a smooth projective variety (Toda).

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The existence of equivalences between the derived categories of smooth projective K3 surfaces is detected by the existence of special isometries of the total cohomologies.

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Question

Can we get the same result for derived categories of first order deformations of K3 surfaces using special isometries between 'deformations' of the Hodge and lattice structures on the total cohomologies?

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Hochschild homology and cohomology

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For X any smooth projective variety, define the Hochschild homology

$$\mathrm{HH}_i(X) := \mathrm{Hom}_{\mathrm{D^b}(X\times X)}(\Delta_*\omega_X^\vee[i-\dim(X)], \mathcal{O}_{\Delta_X})$$

and the Hochschild cohomology

$$\mathrm{HH}^i(X) := \mathrm{Hom}_{\mathrm{D^b}(X\times X)}(\mathcal{O}_{\Delta_X}, \mathcal{O}_{\Delta_X}[i]).$$

Hochschild homology and cohomology

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and the Hochschild cohomology

$$\mathrm{HH}^i(X) := \mathrm{Hom}_{\mathrm{D^b}(X\times X)}(\mathcal{O}_{\Delta_X}, \mathcal{O}_{\Delta_X}[i]).$$

On the other hand we put

$$\mathrm{H}\Omega_i(X) := \bigoplus_{q-p=i} H^p(X, \Omega_X^q) \quad \mathrm{HT}^i(X) := \bigoplus_{p+q=i} H^p(X, \wedge^q \mathcal{T}_X).$$

Hochschild–Kostant–Rosenberg

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Hochschild–Kostant–Rosenberg

There exist (the Hochschild–Kostant–Rosenberg) isomorphisms

$$I^X_{\mathrm{HKR}} : \mathrm{HH}_*(X) \to \mathrm{H}\Omega_*(X) := \bigoplus_i \mathrm{H}\Omega_i(X)$$

and

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One then defines the graded isomorphisms

$$I^X_K = (\mathrm{td}(X)^{1/2} \wedge (-)) \circ I^X_{\mathrm{HKR}} \qquad I^K_X = (\mathrm{td}(X)^{-1/2} \lrcorner (-)) \circ I_X^{\mathrm{HKR}}.$$

Toda's construction

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Toda's construction

1. Take a smooth projective variety X, $v \in \mathrm{HH}^2(X)$ and write
$$I_X^{\mathrm{HKR}}(v) = (\alpha, \beta, \gamma) \in \mathrm{HT}^2(X).$$

Toda's construction

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2. Define a sheaf $\mathcal{O}_X^{(\beta,\gamma)}$ of $\mathbb{C}[\epsilon]/(\epsilon^2)$-algebras on X depending only on β and γ.

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2. Define a sheaf $\mathcal{O}_X^{(\beta,\gamma)}$ of $\mathbb{C}[\epsilon]/(\epsilon^2)$-algebras on X depending only on β and γ.

3. Representing $\alpha \in H^2(X, \mathcal{O}_X)$ as a Čech 2-cocycle $\{\alpha_{ijk}\}$ one has an element $\widetilde{\alpha} := \{1 - \epsilon\alpha_{ijk}\}$ which is a Čech 2-cocycle with values in the invertible elements of the center of $\mathcal{O}_X^{(\beta,\gamma)}$.

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We get the abelian category

$$\mathbf{Coh}(\mathcal{O}_X^{(\beta,\gamma)}, \widetilde{\alpha})$$

of $\widetilde{\alpha}$-twisted coherent $\mathcal{O}_X^{(\beta,\gamma)}$-modules. Set

$$\mathbf{Coh}(X, v) := \mathbf{Coh}(\mathcal{O}_X^{(\beta,\gamma)}, \widetilde{\alpha}).$$

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One also have an isomorphism $J : \mathrm{HH}^2(X_1) \to \mathrm{HH}^2(X_1)$ such that

$$(I_{X_1}^{\mathrm{HKR}} \circ J \circ (I_{X_1}^{\mathrm{HKR}})^{-1})(\alpha, \beta, \gamma) = (\alpha, -\beta, \gamma).$$

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The Infinitesimal Derived Torelli Theorem

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Theorem (Macrì–S.)

Let X_1 and X_2 be smooth complex projective K3 surfaces and let $v_i \in \mathbb{H}\mathrm{H}^2(X_i)$, with $i = 1, 2$. Then the following are equivalent:

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1. There exists a Fourier–Mukai equivalence

$$\Phi_{\widetilde{\mathcal{E}}} : \mathrm{D}^{\mathrm{b}}(X_1, v_1) \xrightarrow{\sim} \mathrm{D}^{\mathrm{b}}(X_2, v_2)$$

with $\widetilde{\mathcal{E}} \in \mathrm{D}_{\mathrm{perf}}(X_1 \times X_2, -J(v_1) \boxplus v_2)$.

The Infinitesimal Derived Torelli Theorem

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2. There exists an orientation preserving effective Hodge isometry
$$g : \widetilde{H}(X_1, v_1, \mathbb{Z}) \xrightarrow{\sim} \widetilde{H}(X_2, v_2, \mathbb{Z}).$$

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For X a K3, $v \in \mathrm{HH}^2(X)$ and σ_X is a generator for $\mathrm{HH}_2(X)$, let

$$w := I_K^X(\sigma_X) + \epsilon I_K^X(\sigma_X \circ v) \in \widetilde{H}(X, \mathbb{Z}) \otimes \mathbb{C}[epsilon]/(\epsilon^2).$$

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The free $\mathbb{Z}[\epsilon]/(\epsilon^2)$-module of finite rank $\widetilde{H}(X, \mathbb{Z}) \otimes \mathbb{Z}[\epsilon]/(\epsilon^2)$ is endowed with:

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1. The $\mathbb{Z}[\epsilon]/(\epsilon^2)$-linear extension of the generalized Mukai pairing $\langle -, - \rangle_M$.

The structures

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The free $\mathbb{Z}[\epsilon]/(\epsilon^2)$-module of finite rank $\widetilde{H}(X,\mathbb{Z}) \otimes \mathbb{Z}[\epsilon]/(\epsilon^2)$ is endowed with:

1. The $\mathbb{Z}[\epsilon]/(\epsilon^2)$-linear extension of the generalized Mukai pairing $\langle -,-\rangle_M$.
2. A weight-2 decomposition on $\widetilde{H}(X,\mathbb{Z}) \otimes \mathbb{C}[\epsilon]/(\epsilon^2)$

$$\widetilde{H}^{2,0}(X,v) := \mathbb{C}[\epsilon]/(\epsilon^2) \cdot w \qquad \widetilde{H}^{0,2}(X,v) := \overline{\widetilde{H}^{2,0}(X,v)}$$

and $\widetilde{H}^{1,1}(X,v) := (\widetilde{H}^{2,0}(X,v) \oplus \widetilde{H}^{0,2}(X,v))^{\perp}$.

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This gives the infinitesimal Mukai lattice of X with respect to v, which is denoted by $\widetilde{H}(X, v, \mathbb{Z})$.

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An isometry

$$g : \widetilde{H}(X_1, v_1, \mathbb{Z}) \xrightarrow{\sim} \widetilde{H}(X_2, v_2, \mathbb{Z})$$

which is $g = g_0 \otimes \mathbb{Z}[\epsilon]/(\epsilon^2)$, where g_0 is an Hodge isometry of the Mukai lattices is called effective.

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An effective isometry is orientation preserving if g_0 preserves the orientation of the four-space.

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We just sketch of the implication (i)$\Rightarrow$(ii).

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We just sketch of the implication (i)$\Rightarrow$(ii).

- Let $\Phi_{\widetilde{\mathcal{E}}} : \mathrm{D}^{\mathrm{b}}(X_1, v_1) \xrightarrow{\sim} \mathrm{D}^{\mathrm{b}}(X_2, v_2)$ be an equivalence with kernel $\widetilde{\mathcal{E}} \in \mathrm{D}_{\mathrm{perf}}(X_1 \times X_2, -J(v_1) \boxplus v_2)$.

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- One shows that the restriction $\mathcal{E} \in \mathrm{D}^{\mathrm{b}}(X_1 \times X_2)$ of $\widetilde{\mathcal{E}}$ is the kernel of a Fourier–Mukai equivalence $\Phi_{\mathcal{E}} : \mathrm{D}^{\mathrm{b}}(X_1) \xrightarrow{\sim} \mathrm{D}^{\mathrm{b}}(X_2)$.

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- One shows that the restriction $\mathcal{E} \in \mathrm{D}^{\mathrm{b}}(X_1 \times X_2)$ of $\widetilde{\mathcal{E}}$ is the kernel of a Fourier–Mukai equivalence $\Phi_{\mathcal{E}} : \mathrm{D}^{\mathrm{b}}(X_1) \xrightarrow{\sim} \mathrm{D}^{\mathrm{b}}(X_2)$.
- Using Orlov's result, take the Hodge isometry $g_0 := (\Phi_{\mathcal{E}})_H : \widetilde{H}(X_1, \mathbb{Z}) \to \widetilde{H}(X_2, \mathbb{Z})$.

The isometry

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Toda: since $\widetilde{\mathcal{E}}$ is a first order deformation of $\mathcal{E}$,

$$(\Phi_{\mathcal{E}})^{\mathrm{HH}}(v_1) = v_2.$$

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Toda: since $\widetilde{\mathcal{E}}$ is a first order deformation of $\mathcal{E}$,

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Important!

Assume we know that any Hodge isometry induced by an equivalence $\mathrm{D}^{\mathrm{b}}(X_1) \cong \mathrm{D}^{\mathrm{b}}(X_2)$ is orientation preserving.

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Assume we know that any Hodge isometry induced by an equivalence $\mathrm{D}^{\mathrm{b}}(X_1) \cong \mathrm{D}^{\mathrm{b}}(X_2)$ is orientation preserving.

To conclude and prove that

$$g := g_0 \otimes \mathbb{Z}[\epsilon]/(\epsilon^2) : \widetilde{H}(X_1, v_1, \mathbb{Z}) \to \widetilde{H}(X_2, v_2, \mathbb{Z})$$

is an effective orientation preserving Hodge isometry, we need two commutative diagrams.

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Any Fourier–Mukai functor acts on Hochschild homology.

Commutativity I

Any Fourier–Mukai functor acts on Hochschild homology.

Theorem (Macrì–S.)

Let X_1 and X_2 be smooth complex projective varieties and let $\mathcal{E} \in \mathrm{D}^{\mathrm{b}}(X_1 \times X_2)$. Then the following diagram

$$\begin{array}{ccc} \mathrm{HH}_*(X_1) & \xrightarrow{(\Phi_{\mathcal{E}})_{\mathrm{HH}}} & \mathrm{HH}_*(X_2) \\ \downarrow{\scriptstyle I_K^{X_1}} & & \downarrow{\scriptstyle I_K^{X_2}} \\ \widetilde{H}(X_1,\mathbb{C}) & \xrightarrow{(\Phi_{\mathcal{E}})_H} & \widetilde{H}(X_2,\mathbb{C}) \end{array}$$

commutes.

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Commutativity II

Using that for K3 surfaces $H^{0,2}$ is 1-dimensional and the previous result, one get the following commutative diagram (for a Fourier–Mukai equivalence $\Phi_{\mathcal{E}}$):

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$$\begin{array}{ccc}
\mathrm{HH}^*(X_1) & \xrightarrow{(\Phi_{\mathcal{E}})^{\mathrm{HH}}} & \mathrm{HH}^*(X_2) \\
\downarrow {\scriptstyle (-)\circ\sigma_{X_1}} & & \downarrow {\scriptstyle (-)\circ(\Phi_{\mathcal{E}})_{\mathrm{HH}}(\sigma_{X_1})} \\
\mathrm{HH}_*(X_1) & \xrightarrow{(\Phi_{\mathcal{E}})_{\mathrm{HH}}} & \mathrm{HH}_*(X_2) \\
\downarrow {\scriptstyle I_K^{X_1}} & & \downarrow {\scriptstyle I_K^{X_2}} \\
\widetilde{H}(X_1,\mathbb{C}) & \xrightarrow{(\Phi_{\mathcal{E}})_H} & \widetilde{H}(X_2,\mathbb{C}),
\end{array}$$

where σ_{X_1} is a generator of $\mathrm{HH}_2(X_1)$.

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We go back to the original problem of describing the group of exact autoequivalences of the derived category of a K3 surface.

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Remarks

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Remarks

1. To conclude the previous argument involving (first order) deformations, we need to prove that any equivalence induces an orientation preserving Hodge isometry.

The motivation

We go back to the original problem of describing the group of exact autoequivalences of the derived category of a K3 surface.

Remarks

1. To conclude the previous argument involving (first order) deformations, we need to prove that any equivalence induces an orientation preserving Hodge isometry.
2. The (quite involved) proof of this result will use deformation of kernels.

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Main Theorem (Huybrechts–Macrì–S.)

Given a Hodge isometry $g : \widetilde{H}(X,\mathbb{Z}) \to \widetilde{H}(Y,\mathbb{Z})$, then there exists and equivalence $\Phi : \mathrm{D^b}(X) \to \mathrm{D^b}(Y)$ such that $g = \Phi_H$ if and only if g is orientation preserving.

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Szendroi's Conjecture is true: In terms of autoequivalences, this yields a surjective morphism

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Szendroi's Conjecture is true: In terms of autoequivalences, this yields a surjective morphism

$$\mathrm{Aut}\,(\mathrm{D}^{\mathrm{b}}(X)) \twoheadrightarrow \mathrm{O}_+(\widetilde{H}(X,\mathbb{Z})),$$

where $\mathrm{O}_+(\widetilde{H}(X,\mathbb{Z}))$ is the group of orientation preserving Hodge isometries.

The ‘easy’ implication

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The 'easy' implication

The statement: If g is orientation preserving than it lifts to an equivance.

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- A result of Hosono–Lian–Oguiso–Yau (heavily relaying on Mukai/Orlov’s Derived Torelli Theorem) shows that, up to composing with the isometry j, every isometry can be lifted to an equivalence.

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- A result of Hosono–Lian–Oguiso–Yau (heavily relaying on Mukai/Orlov’s Derived Torelli Theorem) shows that, up to composing with the isometry j, every isometry can be lifted to an equivalence.
- Since we know that j is not orientation preserving we conclude using the following:

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Remark (Huybrechts-S.)

All known equivalences (and autoequivalences) are orientation preserving.

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The non-orientation Hodge isometry

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Take any projective K3 surface X.

The non-orientation Hodge isometry

Take any projective K3 surface X.

- Consider the non-orientation preserving Hodge isometry

$$j := (\mathrm{id})_{H^0 \oplus H^4} \oplus (-\mathrm{id})_{H^2}.$$

The non-orientation Hodge isometry

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The non-orientation Hodge isometry

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Take any projective K3 surface X.

- Consider the non-orientation preserving Hodge isometry
$$j := (\mathrm{id})_{H^0 \oplus H^4} \oplus (-\mathrm{id})_{H^2}.$$
- Since one implication is already true, to prove the main theorem, it is enough to show that j is not induced by a Fourier–Mukai equivalence.
- We proceed by contradiction assuming that there exists $\mathcal{E} \in \mathrm{D}^{\mathrm{b}}(X \times X)$ such that $(\Phi_{\mathcal{E}})_H = j$.

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- **Huybrechts–Macrì–S.:** For some particular K3 surfaces we know that j is not induced by any Fourier–Mukai equivalence: K3 surfaces with trivial Picard group.

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- **Huybrechts–Macrì–S.:** For some particular K3 surfaces we know that j is not induced by any Fourier–Mukai equivalence: K3 surfaces with trivial Picard group.
- Deform the K3 surface in the moduli space such that generically we recover the behaviour of a generic K3 surface.

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- Deform the K3 surface in the moduli space such that generically we recover the behaviour of a generic K3 surface.
- Deform the kernel of the equivalence accordingly.
- Derive a contradiction using the generic case.

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Formal deformations

Take $R := \mathbb{C}[[t]]$ to be the ring of power series in t with field of fractions $K := \mathbb{C}((t))$.

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Define $R_n := \mathbb{C}[[t]]/(t^{n+1})$. Then $\mathrm{Spec}\,(R_n) \subset \mathrm{Spec}\,(R_{n+1})$.

Formal deformations

Take $R := \mathbb{C}[[t]]$ to be the ring of power series in t with field of fractions $K := \mathbb{C}((t))$.

Define $R_n := \mathbb{C}[[t]]/(t^{n+1})$. Then $\mathrm{Spec}\,(R_n) \subset \mathrm{Spec}\,(R_{n+1})$.

For X a smooth projective variety, a formal deformation is a proper formal R-scheme

$$\pi : \mathcal{X} \to \mathrm{Spf}(R)$$

given by an inductive system of schemes $\mathcal{X}_n \to \mathrm{Spec}\,(R_n)$ (smooth and proper over R_n) and such that

$$\mathcal{X}_{n+1} \times_{R_{n+1}} \mathrm{Spec}\,(R_n) \cong \mathcal{X}_n.$$

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There exist sequences

$$\mathbf{Coh}_0(\mathcal{X} \times_R \mathcal{X}') \hookrightarrow \mathbf{Coh}(\mathcal{X} \times_R \mathcal{X}') \to \mathbf{Coh}((\mathcal{X} \times_R \mathcal{X}')_K)$$

$$\mathbf{Coh}_0(\mathcal{X}) \hookrightarrow \mathbf{Coh}(\mathcal{X}) \to \mathbf{Coh}((\mathcal{X})_K)$$

where $\mathbf{Coh}_0(\mathcal{X} \times_R \mathcal{X}')$ and $\mathbf{Coh}_0(\mathcal{X})$ are the abelian categories of sheaves supported on $X \times X$ and X respectively.

The categories

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where $\mathbf{Coh}_0(\mathcal{X} \times_R \mathcal{X}')$ and $\mathbf{Coh}_0(\mathcal{X})$ are the abelian categories of sheaves supported on $X \times X$ and X respectively.

In this setting we also have the sequences

$$\mathrm{D}^{\mathrm{b}}_0(\mathcal{X} \times_R \mathcal{X}') \hookrightarrow \mathrm{D}^{\mathrm{b}}_{\mathbf{Coh}}(\mathcal{O}_{\mathcal{X}\times_R\mathcal{X}'}\text{-Mod}) \to \mathrm{D}^{\mathrm{b}}((\mathcal{X} \times_R \mathcal{X}')_K)$$

$$\mathrm{D}^{\mathrm{b}}_0(\mathcal{X}) \hookrightarrow \mathrm{D}^{\mathrm{b}}_{\mathbf{Coh}}(\mathcal{O}_{\mathcal{X}}\text{-Mod}) \to \mathrm{D}^{\mathrm{b}}(\mathcal{X}_K)$$

The key example: the twistor space

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Let us focus now on the case when X is a K3 surface.

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Let us focus now on the case when X is a K3 surface.

Definition

A Kähler class $\omega \in H^{1,1}(X, \mathbb{R})$ is called very general if there is no non-trivial integral class $0 \neq \alpha \in H^{1,1}(X, \mathbb{Z})$ orthogonal to ω, i.e. $\omega^{\perp} \cap H^{1,1}(X, \mathbb{Z}) = 0$.

The key example: the twistor space

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Take the twistor space $\mathbb{X}(\omega)$ of X determined by the choice of a very general Kähler class $\omega \in \mathcal{K}_X \cap \mathrm{Pic}\,(X) \otimes \mathbb{R}$:

$$\pi : \mathbb{X}(\omega) \to \mathbb{P}(\omega).$$

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Remark

$\mathbb{X}(\omega)$ parametrizes the complex structures 'compatible' with ω.

The key example: the twistor space

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Choosing a local parameter t around $0 \in \mathbb{P}(\omega)$ we get a formal deformation $\mathcal{X} \to \mathrm{Spf}(R)$.

The key example: the twistor space

Remark

$\mathbb{X}(\omega)$ parametrizes the complex structures 'compatible' with ω.

Choosing a local parameter t around $0 \in \mathbb{P}(\omega)$ we get a formal deformation $\mathcal{X} \to \mathrm{Spf}(R)$.

More precisely:

$$\mathcal{X}_n := \mathbb{X}(\omega) \times \mathrm{Spec}\,(R_n),$$

form an inductive system and give rise to a formal R-scheme

$$\pi : \mathcal{X} \to \mathrm{Spf}(R),$$

which is the formal neighbourhood of X in $\mathbb{X}(\omega)$.

Equivalences

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As before, given $\mathcal{F} \in \mathrm{D}^{\mathrm{b}}_{\mathbf{Coh}}(\mathcal{O}_{\mathcal{X}\times_R\mathcal{X}'}\text{-Mod})$, we denote by $\mathcal{F}_K$ the natural image in the category $\mathrm{D}^{\mathrm{b}}((\mathcal{X}\times_R\mathcal{X}')_K)$.

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Proposition

Let $\widetilde{\mathcal{E}} \in \mathrm{D}^{\mathrm{b}}(\mathcal{X} \times_R \mathcal{X}')$ be such that $\mathcal{E} = i^*\widetilde{\mathcal{E}}$. Then $\widetilde{\mathcal{E}}$ and $\widetilde{\mathcal{E}}_K$ are kernels of Fourier–Mukai equivalences.

Equivalences

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Here we denoted by $i : X \times X \to \mathcal{X} \times_R \mathcal{X}'$ the natural inclusion.

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The first order deformation

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The equivalence $\Phi_{\mathcal{E}}$ induces a morphim

$$\Phi_{\mathcal{E}}^{\mathrm{HH}} : \mathrm{HH}^2(X) \to \mathrm{HH}^2(X).$$

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$$\Phi_{\mathcal{E}}^{\mathrm{HH}} : \mathrm{HH}^2(X) \to \mathrm{HH}^2(X).$$

Proposition

Let $v_1 \in H^1(X, \mathcal{T}_X)$ be the Kodaira–Spencer class of first order deformation given by a twistor space $\mathbb{X}(\omega)$ as above. Then

$$v_1' := \Phi_{\mathcal{E}}^{\mathrm{HH}}(v_1) \in H^1(X, \mathcal{T}_X).$$

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Let $\mathcal{X}'_1$ be the first order deformation corresponding to v'_1.

The first order deformation

Let $\mathcal{X}_1'$ be the first order deformation corresponding to v_1'.

Using results of Toda one gets the following conclusion

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Let $\mathcal{X}_1'$ be the first order deformation corresponding to v_1'.

Using results of Toda one gets the following conclusion

Proposition (Toda)

For v_1 and v_1' as before, there exists $\mathcal{E}_1 \in \mathrm{D}^{\mathrm{b}}(\mathcal{X}_1 \times_{R_1} \mathcal{X}_1')$ such that

$$i_1^*\mathcal{E}_1 = \mathcal{E}_0 := \mathcal{E}.$$

Here $i_1 : \mathcal{X}_0 \times_{\mathbb{C}} \mathcal{X}_0 \hookrightarrow \mathcal{X}_1' \times_{R_1} \mathcal{X}_1'$ is the natural inclusion.

The first order deformation

Let $\mathcal{X}'_1$ be the first order deformation corresponding to v'_1.

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Proposition (Toda)

For v_1 and v'_1 as before, there exists $\mathcal{E}_1 \in \mathrm{D}^{\mathrm{b}}(\mathcal{X}_1 \times_{R_1} \mathcal{X}'_1)$ such that

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Here $i_1 : \mathcal{X}_0 \times_{\mathbb{C}} \mathcal{X}_0 \hookrightarrow \mathcal{X}'_1 \times_{R_1} \mathcal{X}'_1$ is the natural inclusion.

Hence there is a first order deformation of $\mathcal{E}$.

Higher order deformations

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More generally

We construct, at any order n, a deformation $\mathcal{X}'_n$ such that there exists $\mathcal{E}_n \in \mathrm{D}^{\mathrm{b}}(\mathcal{X}_n \times_{R_n} \mathcal{X}'_n)$, with

$$i_n^* \mathcal{E}_n = \mathcal{E}_{n-1}.$$

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Main difficulties

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More generally

We construct, at any order n, a deformation $\mathcal{X}'_n$ such that there exists $\mathcal{E}_n \in \mathrm{D^b}(\mathcal{X}_n \times_{R_n} \mathcal{X}'_n)$, with

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Main difficulties

1. Write the obstruction to deforming complexes in terms of Atiyah–Kodaira classes (Huybrechts–Thomas).

Higher order deformations

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1. Write the obstruction to deforming complexes in terms of Atiyah–Kodaira classes (Huybrechts–Thomas).
2. Show that the obstruction is zero.

Higher order deformations

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Main difficulties

1. Write the obstruction to deforming complexes in terms of Atiyah–Kodaira classes (Huybrechts–Thomas).
2. Show that the obstruction is zero.

Our approach imitates the first order case (using relative Hochschild homology).

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The generic fiber

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Use the generic analytic case

There exist integers n and m such that the Fourier–Mukai equivalence

$$\Phi^{n}_{(\mathcal{I}_{\Delta_{\mathcal{X}}}[1])_K} \circ \Phi_{\mathcal{E}_K}[m]$$

has kernel $\mathcal{G}_K \in \mathbf{Coh}((\mathcal{X} \times_R \mathcal{X}')_K)$, for $\mathcal{G} \in \mathbf{Coh}(\mathcal{X} \times_R \mathcal{X}')$.

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Remark

This shows that the autoequivalences of the derived category $\mathrm{D}^{\mathrm{b}}(\mathcal{X}_K)$ behaves like the derived category of a complex K3 surface with trivial Picard group (Huybrechts–Macrì–S.).

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Properties of $\mathcal{G}$

The conclusion

Properties of $\mathcal{G}$

1. $\mathcal{G}_0 := i^*\mathcal{G}$ is a sheaf in $\mathbf{Coh}(X \times X)$.

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Properties of $\mathcal{G}$

1. $\mathcal{G}_0 := i^*\mathcal{G}$ is a sheaf in $\mathbf{Coh}(X \times X)$.
2. The natural morphism

$$(\Phi_{\mathcal{G}_0})_H : H^*(X,\mathbb{Q}) \to H^*(X,\mathbb{Q})$$

is such that $(\Phi_{\mathcal{G}_0})_H = (\Phi_{\mathcal{E}})_H = j$.

The conclusion

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1. $\mathcal{G}_0 := i^*\mathcal{G}$ is a sheaf in $\mathbf{Coh}(X \times X)$.
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is such that $(\Phi_{\mathcal{G}_0})_H = (\Phi_{\mathcal{E}})_H = j$.

Lemma

If $\mathcal{G}_0 \in \mathbf{Coh}(X \times X)$, then $(\Phi_{\mathcal{G}_0})_H \neq j$.