Mathematisches Forschungsinstitut Oberwolfach

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Classical Algebraic Geometry

May 26th – June 1st, 2002

The conference was organized by David Eisenbud (Berkeley), Joe Harris (Cambridge) and Frank-Olaf Schreyer (Saarbrücken) and attended by about 45 participants from USA, France, UK, Italia, Japan, Norway, Poland and Germany. There were 18 hours of lectures with a maximum number of four talks per day, allowing plenty of time for questions and many informal discussions among smaller groups. The atmosphere of the meeting seemed particularly lively, perhaps because it was attended by a group of strong young mathematicians. The conference was centered around the three main topics syzygies, toric geometry and moduli spaces of curves. In the area of syzygies Claire Voisin presented her outstanding result on Green's conjecture in her talk "On syzygies of $K3$ surfaces and canonical curves". The interaction between the three main topics was demonstrated in talks given by Gavril Farkas on "Divisors on $M_{g,g+1}$ and the minimal resolution conjecture for points on canonical curves" and Shoetsu Ogata "On the ideals defining projective toric varieties".

Abstracts

On syzygies of $K3$ surfaces and canonical curves

Claire Voisin

For V a vector space, and B a graded $SV=\bigoplus_k S^kV$-module, denote by $K_{p,q}(B,V)$ the cohomology at the middle of the sequence

$$\bigwedge^{p+1}V\otimes B^{q-1}\xrightarrow{\delta}\bigwedge^{p}V\otimes B^{q}\xrightarrow{\delta}\bigwedge^{p-1}V\otimes B^{q+1}$$

$$\delta\left(v_1\wedge\ldots\wedge v_p\otimes b\right)=\sum_i(-1)^i v_1\wedge\ldots\wedge\widehat{v_i}\wedge\ldots\wedge v_p\otimes v_ib$$

If X is a variety, L a line bundle on X, let $K_{p,q}(X,L):=K_{p,q}(B,V)$, $V:=H^0(X,L)$, $B:=\bigoplus_q H^0(X,L^{\otimes q})$. As a generalization of Petri's and Noether's theorems, Green conjectured, that for X a smooth curve

$$\mathrm{Cliff}(X)>\nu\Leftrightarrow K_{l,2}(X,K_X)=0\ \forall l\leq\nu$$

where

$$\mathrm{Cliff}(X):=\min_{\substack{L\\ h^0(L)\geq2,\ h^1(L)\geq2}}\left\{d-2r\mid\deg L=d,\ h^0(L)=r+1\right\}$$

If X is a generic curve, Brill-Noether theory and duality allow to rewrite the conjecture as:

Conjecture. $K_{k,1}(X,K_X)=0$, *X generic of genus $g=2k$ or $2k+1$.*

We show that this is true for curves X which are hyperplane sections of a $K3$ surface S, assuming $L:=\mathcal{O}_S(X)$ generates $\mathrm{Pic}\,S$, and $g(X)=2k$. This follows from:

Theorem. *For S a $K3$ surface as above, $L\cdot\mathbb{Z}=\mathrm{Pic}\,S$ and $L^2=2g-2$, $g=2k$, one has $K_{k,1}(S,L)=0$*

This theorem has the following consequence:

Corollary. *Green's conjecture is true for generic curves of fixed gonality in the range*

$$\frac{g(X)}{3}\leq gon(X)\leq\frac{g(X)}{2}+1$$

Combined with a recent result of Teixidor, which deals with the case $gon(X)\leq\frac{g}{3}$, this shows, that Green's conjecture is true for generic curves of fixed gonality, except may be generic curves of odd genus (which are of gonality $k+2$, $g=2k+1$).

Log canonical thresholds and the birational geometry of hypersurfaces

Mircea Mustata

The talk is based on joint work with Tommaso de Fernex and Lawrence Ein.

Log canonical thresholds are very useful in Mori theory, but they appear in various other settings: they measure the growth of the number of solutions of $f \in \mathbb{Z}[x_1, ..., x_n]$ in $(\mathbb{Z}/p^m\mathbb{Z})^n$, or the growth of the dimension of the jet schemes. We use this last characterization to give a bound for the log canonical threshold of a homogeneous affine hypersurface with fixed dimension of the singular locus.

An other result gives a lower bound for the multiplicity of a zero-dimensional scheme in terms of the log canonical threshold.

Birational cobordisms, factorization of birational maps and stratified toroidal varieties

Jaroslaw Wlodarczyk

We discuss the proof of the Weak Factorization Theorem, which states that any birational map between smooth complete algebraic varieties over an algebraically closed field can be factored into a sequence of blow-ups and blow-downs at smooth centres. The main tool used in the proof is a Morse like theory inspired by Morelli's theory of combinatorial cobordisms. In the above theory the Morse function is replaced by a K^*-action (where K is a base field). The critical points of the Morse function correspond to fixed point components of the action. The homotopy type changes when we "pass through" the critical points. Analogously, in the algebraic setting "passing through" the fixed points of the K^*-action induces some simple birational transformations like blow-ups, blow-downs and flips, which are analogous to spherical modifications. Constructing a smooth cobordism for a given map provides a decomposition into "weighted" blow-ups and blow-downs. In order to obtain a factorization into blow-ups and blow-downs at smooth centres we desingularize geometric quotients of open affine fixed-point free subsets. This is achieved by applying a theory of stratified toroidal varieties, generalizing the theory of toroidal embeddings by Kempf, Knudsen, Mumford and Saint-Donat.

Moduli spaces of curves and the minimal model program: Effective divisors on $\overline{M_{0,n}}$

Brendan Hasset
(joint work with Yuri Tschinkel)

The most obvious divisors on $\overline{M_{0,n}}$ are the boundary divisors, but S. Keel and P. Vermeire have shown, that these do not generate the full effective cone for $n \geq 6$. We compute the effective divisors on $\overline{M_{0,6}}$ by classifying "coextremal rays", which correspond to $\mathbb{Q}$-Fano fibrations on $\overline{M_{0,6}}$. The simplest example arises from the forgetting map $\overline{M_{0,6}} \to \overline{M_{0,5}}$, but many more were not previously known.

Brauer Groups of algebraic surfaces

A.J. de Jong

Let K be a field and let $Br(K)$ denote its Brauer group. The period or exponent of an element $\eta \in Br(K)$ is its order in the torsion group $Br(K)$. The index of η is the degree of the division algebra D over K representing η in $Br(K)$ (i.e. $\mathrm{index}(\eta) = \sqrt{\dim_K(D)}$). Fact: the period divides the index.

Theorem. *Let $k = \bar{k}$ be an algebraically closed field and let $K \supset k$ be a finitely generated field extension of transcendence degree 2. Any element of period prime to $char(k)$ has* period = index.

In the talk we explained the proof of this theorem for unramified classes $\eta \in Br(K)$. An unramified class comes from an Azumaya algebra $\mathcal{A}$ over $\mathcal{O}_X$, where X is a projective nonsingular model of K/k. Whence the title of the talk.

We wish to mention here the following question. If K/k is as above, but now of transcendence degree n, is it true that always index | period^{n-1} ?

The case $n = 1$ is Tsen's theorem and $n = 2$ is the theorem above (for special η's).

A geometric Littlewood-Richardson rule

Ravi Vakil

Littlewood-Richardson numbers are structure coefficients for Schur polynomials, or equivalently structure coefficients of the cohomology of the Grassmannian. A "Littlewood-Richardson rule" is a combinatorial interpretation of these numbers. We describe a geometric Littlewood-Richardson rule, in terms of "checker games". Consequences include, in no particular order:

1. the first effective solution to all Schubert problems (i.e. to any accuracy).
2. an affirmative answer to the classical question "Can solutions to all Schubert problems be real, i.e. defined over $\mathbb{R}$?", and variations to other fields (e.g. finite fields and those satisfying the implicit function theorem)
3. transversality of general translates in characteristic p (hence Schubert problems are enumerative)
4. almost all Schubert problems (over any base) have Galois/monodromy group alternating or full
5. bijection to tableaux and (Knutson-Tao) puzzles, hence the first geometric interpretation of these objects
6. applications to similar questions based in geometry, e.g. K-theory (proof of conjectures of Buch and Tao), equivariant cohomology, and possibly quantum cohomology
7. an approach to the analogous open question for Schubert polynomials ($\equiv$ intersection theory on the flag variety) and for other classical groups (e.g. orthogonal and symplectic Grassmannian).

Flips, Moduli and Derived Categories

DAN ABRAMOVICH
(visiting Hebrew University)

Let $f : X \to Y$ be a birational contraction satisfying

B.1: fibres of f have dim ≤ 1

B.2: $Rf_*\mathcal{O}_X = \mathcal{O}_Y$

Bridgeland defined a moduli space of perverse point sheaves $\mathcal{M}(X/Y)$ with main component $W = \mathcal{W}(X/Y)$ birational to Y. Bridgeland also proved that the Fourier-Mukai type transform $D(W) \to D(X)$ is an equivalence for $X \to Y$ a 3-fold flopping contraction with X smooth. Chen, and the speaker, extended this to some threefold contractions with X singular. This gives a series of examples where the flop $X^+ \to Y$ (or flip) is a moduli space. The talk explains some of the ingredients in the proofs.

Zero-dimensional schemes & families of singular curves

CHRISTOPH LOSSEN
(joint work with G.-M. Greuel and E. Shustin)

We consider the following (classical) problem: Let $V = V_d(S_1, ..., S_r)$ be the variety (ESF) of irreducible, reduced, plane curves of degree d with exactly r singularities of (analytic resp. topological) types $S_1, ..., S_r$. Is V non-empty (=existence problem), resp. T-smooth (=smooth and of the expected dimension), resp. irreducible?

I presented our general approach to these questions, being based on the study of the cohomology of ideal sheaves of zero-dimensional schemes. Following these lines, we obtained the sufficient conditions:

- $\sum_{i=1}^{r} \mu(S_i) \leq \frac{1}{9}(d^2 - 2d + 9) \Rightarrow V_d(S_1, ..., S_r) \neq \emptyset$
- $\sum_{i=1}^{r} \gamma(S_i) \leq (d+3)^2 \Rightarrow V_d(S_1, ..., S_r)$ T-smooth
- $\frac{25}{2} \cdot \#(nodes) + 18 \cdot \#(cusps) + \sum_{i=1}^{r} (\tau'(S_i) + 2)^2 \leq d^2 \Rightarrow V_d(S_1, ..., S_r)$ irreducible

where μ is the Milnor number, τ' the Tjurina number (resp. μ-modality, for topological types) and $\gamma \leq (\tau' + 1)^2$. These conditions are asymptotically proper (existence), expected to be so (T-smoothness), or have at least the best asymptotics of all known universal conditions (irreducibility). In the case of curves with only n nodes and k cusps, the T-smoothness condition $4n + 9k \leq (d+3)^2$ is even optimal up to linear terms.

Finally I discussed two series of reducible ESF of cuspidal curves, resp. curves with only ordinary singularities, whose components cannot be distinguished by considering the fundamental group of the complements.

Divisors on $M_{g,g+1}$ and the minimal resolution conjecture for points on canonical curves

GAVRIL FARKAS
(joint work with M. Mustaţă and M. Popa)

We do global calculations on moduli spaces of pointed curves to prove the Minimal Resolution Conjecture (MRC) for points on any non-hyperelliptic canonically embedded curve. We also show that MRC always fails for curves embedded in projective space by line bundles of high degree.

Our results have surprising connections with moduli spaces of stable bundles on curves and with geometric divisors on moduli spaces of pointed curves. If Q_C denotes the normal bundle of a curve C embedded in its Jacobian, we show that the vector bundles $\bigwedge^i Q_C$ always have a theta divisor, which is identified with the difference variety $C_{g-i-1} - C_i \subseteq Pic^{g-2i-1}(C)$. This answers positively a conjecture of R. Lazarsfeld.

Are minimal degree rational curves determined by their tangent vectors ?

STEFAN KEBEKUS
(joint work with S. Kovács)

Let X be a projective variety which is covered by rational curves, e.g. a Fano manifold over $\mathbb{C}$. In this setup, characterization and classification problems lead to the natural question: "Given two points on X, how many minimal degree rational curves are there, which contain those points ?" A recent answer to this question led to a number of new results in classification theory. As an infinitesimal analogue, we may ask "How many minimal degree rational curves are there on X, which contain a prescribed tangent vector?"

After a review of the earlier results, we give a condition, which guarantees, that every tangent vector at a general point of X is contained in at most one rational curve of minimal degree. As an immediate application we obtain irreducibility criteria for the space of minimal rational curves.

On the ideals defining projective toric varieties

SHOETSU OGATA
(staying at Universität Erlangen-Nürnberg)

Let X be a projective toric variety of dim n and let L be a very ample line bundle on X, whose global sections define an embedding of X as a projectively normal variety. Then it is known that the defining ideal of X is generated by elements of degree $\leq n+1$ and that this bound is the best possible.

On the other hand, Sturmfels conjectured that the ideal defining a nonsingular toric variety is generated by only quadrics, when the variety is embedded as a projectively normal variety. Before he gave the conjecture, Koelman obtained a criterion for projective toric surfaces, when its defining ideal needs an element of degree 3 as its generator. The class of toric surfaces whose defining ideals need a generator of degree 3 is consisting of special singular toric surfaces. We obtain a generalization of the criterion to $n \geq 3$. The criterion is stated in terms of integral convex polytopes defined by global sections of an ample line bundle on the variety.

A toric variety X of dimension n has an action of an algebraic torus $T \cong (\mathbb{C}^*)^n$. Let $M = Hom_{gp}(T, \mathbb{C}^*)$ be the group of characters. We denote $e(m)$ as the character of T defined by $m \in M \cong \mathbb{Z}^n$. Then we have

$$\Gamma(X, L) \cong \bigoplus_{m \in P \cap M} \mathbb{C}e(m)$$

where $P = Conv\{u_0, u_1, ..., u_r\} \subset M_{\mathbb{R}} \cong \mathbb{R}^n$ is an integral convex polytope of dimension n, that is, it is the convex hull of a finite set of points in M.

Theorem. *Let (X, L) be a pair of a projective toric variety X of dimension n and a normally generated ample line bundle L on X. Let P be the integral convex polytope of dimension n corresponding to (X, L). Then the defining ideal of X in $\mathbb{P}(\Gamma(X, L))$ needs a generator of degree $n+1$ if and only if ${}^{\#}\partial P \cap M = n+1$ and $Int P \cap M \neq \emptyset$.*

Generalized Lefschetz hyperplane theorem and rationally connected fibrations

JASON STARR
(joint work with Tom Graber, Joe Harris and Barry Mazur)

One formulation of the Lefschetz hyperplane theorem for π_1 (as formulated by Goresky-MacPherson) is the following:

Given a quasiprojective, normal variety $B \subset \mathbb{P}^n$ and a generically finite morphism $\pi : X \to B$ with no rational section for a general curve $C \subset B$ parametrized by the family $\mathcal{H} := \{[H \cap B] : H \subset \mathbb{P}^n \text{ linear, } \operatorname{codim}(H) = \dim B - 1\}$, the pullback $X \times_B C \to C$ has no section.

Could this be true, if we drop the condition, that π be generically finite? Clearly not as formulated; however we prove the following theorem:

Theorem (GHM–). *Given a normal, projective variety B and an integer $n \geq 0$, there is a family of maps $\mathcal{H}_n = \{[f : C \to B]\}$ with each C a smooth, projective curve such that, for any dominant, projective morphism $\pi : X \to B$ of generic fibre dimension $\leq n$, there is no "pseudo-section" of π – i.e. no subvariety $Z \subset X$ whose general fibre over B is irreducible and rationally connected – iff for a very general $[f : C \to B] \in \mathcal{H}_n$ the pullback $X \times_B C \to C$ has no section.*

We use this theorem to construct a family $\pi : X \to B$ of Enriques surfaces over a smooth curve having no sections, thus providing a counterexample to a question posed by Serre.

Brauer group, torsors and diophantine equations

J.-L. COLLIOT-THÉLÈNE

This is a survey talk on recent developments around the Brauer-Manin obstruction to the Hasse principle. Topics covered:

1. Definition of the Brauer-Manin obstruction
2. The "main theorem of descent" over open varieties over a number field k
3. Application to the equation
$$\alpha (t-\beta)^b (t-\gamma)^c = N_{K/\mathbb{Q}} \left(\sum\nolimits_{i=1}^{n} \omega_i x_i \right)$$
with $\alpha \in \mathbb{Q}^*$, $\beta, \gamma \in \mathbb{Q}$, $b, c \in \mathbb{N}$ and $K = \bigoplus_{i=1}^{n} \mathbb{Q}\omega_i$
(work of Heath-Brown, Skorobogatov, Harari, myself)
4. Fibrations; when does one find a fibre with points in all completions of the base ground field k (a number field); what Schinzel's hypothesis (H) predicts; the example
$$P(t) = N_{K/k} \left(\sum\nolimits_{i=1}^{n} \omega_i x_i \right)$$
with $P(t) \in k[t]$ and $K = \bigoplus_{i=1}^{n} k\omega_i$

5. Pencils of principal homogeneous spaces under an abelian variety: Swinnerton-Dyer's method (using the conjectured finiteness of Tate-Shafarevich groups)
6. Applications: (Swinnerton-Dyer)
   - The diophantine equation $aX^4 + bY^4 + cZ^4 + dT^4 = 0$, where $abcd$ is a square
   - The diophantine equation $\sum_{i=0}^{n} a_i X_i^3 = 0$, $n \geq 3$

Multiplier ideals and jet schemes

LAWRENCE EIN
(joint work with Lazarsfeld & Mustaţă)

Let X be a smooth complex variety and $Y \subseteq X$ be a closed subscheme. Let $Y_m = Mor_{\mathbb{C}}(Spec\mathbb{C}[t]/t^{m+1}, Y)$ be the m-th jet scheme of Y. Let C be an irreducible component of Y_m. We show that C determines an algebraic discrete valuation ring in the function field of X. In general, we describe the various irreducible components of Y_m in terms of a log resolution of the (X, Y).

Hard Lefschetz theorem for non rational polytopes

K. KARU

Given a simple polytope P, let f_i be the number of i-dimensional faces of P. The necessary and sufficient conditions that f_i must satisfy are well-known. R. Stanley's proof of necessity goes as follows: to the polytope P one can associate a quasi-smooth projective toric variety X_P. The face numbers are uniquely determined by the Betti numbers of the cohomology of X_P. Now the conditions on the face numbers correspond to conditions on cohomology of X_P, such as $h_0 = 1$, Poincare duality, Hard Lefschetz theorem. We discuss generalization of these ideas to non-simple nonrational polytopes. In particular we prove the Hard Lefschetz theorem for such polytopes.

Hilbert schemes over exterior algebras

IRENA PEEVA
(joint work with M. Stillman)

Hartshorne proved that the Hilbert scheme, that parametrizes all subschemes of $\mathbb{P}_k^n$ with a fixed Hilbert polynomial, is connected. We show that the Hilbert scheme, that parametrizes all ideals with a fixed Hilbert function in an exterior algebra, is connected. Our construction is entirely different than Hartshorne's, and it provides a new proof of Hartshorne's result. More precisely, we show that every two ideals with the same Hilbert function are connected by a sequence of Gröbner deformations.

Quantum Chow rings of Deligne-Mumford stacks

Tom Graber
(joint work with D. Abramovich and A. Vistoli)

We give an algebro-geometric construction of a quantum Chow ring of a smooth Deligne-Mumford stack with projective coarse moduli scheme. The main ingredient in the construction is Abramovich-Vistoli's moduli space of twisted stable maps. By specializing the quantum parameter we recover the "stringy Chow ring" or the orbifold cohomology ring, which is conjecturally related to the cohomology of crepant resolution of the coarse moduli space of the stack.

Regularity on abelian varieties

Mihnea Popa
(joint work with G. Pareschi)

I introduce a notion of regularity for arbitrary sheaves on abelian varieties, defined by the Fourier-Mukai functor. In a particular case, depending on the choice of a polarization, this strengthens the usual notion of Castelnuovo-Mumford regularity.

M-regularity applies to a large number of questions, ranging from the equations of curves and symmetric products in Jacobians, to linear series and defining equations for abelian varieties, and to effective statements for adjoint line bundles on more general irregular varieties. It can also be used to bound Seshadri constants on abelian varieties, or to a study of moduli spaces of vector bundles.

Edited by Janko Boehm

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