Mathematisches Forschungsinstitut Oberwolfach

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Quadratic Forms and Algebraic Groups

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The conference on quadratic forms and algebraic groups at the Mathematisches Forschungsinstitut Oberwolfach was organized by Detlev W. Hoffmann, Alexander S. Merkurjev and Jean-Pierre Tignol. There were 22 talks, grouped by theme in the schedule, each of 45 minutes in length. The program was designed to offer a sample of the latest techniques, with a special emphasis on geometric methods, and of the cross-breeding which has been developing lately between various aspects of the theory of quadratic forms, linear algebraic groups and Galois cohomology. The organizers took care to give especially to the many young participants the opportunity to present their results. The strict limitation in the number of talks was effective in allowing fruitful interactions to develop between the participants.

Abstracts

Triangular Witt groups

Paul Balmer

Let X be a regular noetherian separated integral scheme such that $\frac{1}{2} \in \Gamma(X, \mathcal{O}_X)$ and let K be its field of fractions. Assume that X has finite Krull dimension d. Then the kernel of the natural map $W(X) \to W(K)$ is nilpotent and more precisely

$$\big(\ \ker(W(X) \to W(K))\ \big)^{\,[\frac{d}{4}]+1} = 0,$$

at least when $W(\mathcal{O}_{X,x}) \hookrightarrow W(K)$ for all $x \in X$ (e.g. when X is defined over a field, by Ojanguren–Panin).

Milnor K-groups and finite field extensions

Karim Johannes Becher

Let E/F be a finite separable field extension and let m denote the integral part of $\log_2[E:F]$. David Leep has shown that, in the case where $\operatorname{char}(F) \neq 2$, the n-th power of the fundamental ideal in the Witt ring of E satisfies the equality $I^nE = I^{n-m}F \cdot I^mE$ $(n \geq m)$. Using the same elementary techniques, I prove an analogous equality for the n-th Milnor K-group of E, that is $K_nE = K_{n-m}F \cdot K_mE$ $(n \geq m)$. An example indicates that m may not be replaced by $(m+1)$ in this formula.

Cohomological invariants and R-triviality of adjoint classical groups

Grégory Berhuy

(joint work with Marina Monsurrò and Jean-Pierre Tignol)

Let F be a field of characteristic different from 2. For G a linear algebraic group defined over F, it is a natural problem to know whether or not G is stably rational.

The aim of this work is to give families of absolutely simple adjoint classical groups of type A_{n-1}, C_n, D_n (n even) which are not stably rational. In fact, our examples satisfy a stronger property: they are not R-trivial, i.e. there is a field extension E/F such that $G(E)/R$ is nontrivial.

To construct these groups, we define a homomorphism $\theta : G(F) \to H^*(F, \mu_2)$, using cohomological invariants, and show then that it induces a map $\bar{\theta} : G(F)/R \to H^*(F, \mu_2)$, using Merkurjev's computation of $G(F)/R$ for G absolutely simple of classical type.

Finally we give examples of groups G for which θ is not identically zero. To do all this, we use extensively the fact that $G \simeq \mathrm{PSim}_+(A, \sigma)$, the connected component of the group of projective similitudes associated to an algebra with involution (A, σ).

Essential dimensions and Killing forms

Vladimir Chernousov

The essential dimension of a linear algebraic group G, denoted by $ed(G)$ is a numerical invariant of G and it is interesting to compute it. For groups of type G_2 (resp. F_4) it is equal to 3 (resp. to 5). For groups of type E_6, E_7, E_8 the answer is unknown.

In the talk we discuss the relation between the essential dimensions of cocycles in a split group and the essential dimensions of the corresponding Killing forms. In the case when the Weyl group of G contains -1 we compute the essential dimensions of all Killing forms coming from elementary abelian subgroups of G of type $\mathbb{Z}/2 \times \cdots \times \mathbb{Z}/2$. This allows us to give lower bounds for the essential dimensions of groups of type E_7, E_8 defined over an arbitrary algebraically closed field of characteristic different from 2.

Indice et exposant en dimension deux, d'après de Jong

Jean-Louis Colliot-Thélène

Soit K le corps des fonctions d'une surface définie sur un corps algébriquement clos. J. A. de Jong vient de montrer que pour toute algèbre simple centrale A sur K, d'exposant premier à la caractéristique, l'indice de A coïncide avec l'exposant de la classe de A dans le groupe de Brauer de K. On a donné les grandes lignes de sa démonstration. (Exposé préparé avec Ojanguren, Parimala et Sridharan)

An invariant of simple algebraic groups

Skip Garibaldi

The Rost invariant is a fantastically useful tool for studying G-torsors for G a simply connected algebraic group. But if one wants to classify simple algebraic groups, it would be preferable to have an invariant of $\mathrm{Aut}(G)$-torsors (equivalently, forms of G). Such a thing can be deduced from the Rost invariant, and in some special cases one obtains invariants which had previously been constructed by ad hoc means. With this invariant at hand, standard restriction/corestriction arguments give analogues of Springer's Theorem for forms of G whenever the Rost invariant has central kernel.

Steenrod operations in the Chow theory of quadrics

Nikita Karpenko

A proof of the following conjecture, due to D. Hoffmann, is given in the talk:
if φ is a quadratic form over a field of characteristic different from 2 and if we write $\dim \varphi = 1 + 2^{n_1} + \cdots + 2^{n_r}$ with $0 \leq n_1 < n_2 < \cdots < n_r$, then the first Witt index $i_1(\varphi)$ is of the form $i_1(\varphi) = 1 + 2^{n_1} + \cdots + 2^{n_s}$ with some $0 \leq s < r$.

The proof uses the Steenrod operations in the modulo 2 Chow theory.

Generic splitting of quadratic forms in characteristic 2

Manfred Knebusch

A generic splitting theory with properties as in characteristic different from 2 is possible over a field k of characteristic 2 for forms φ with anisotropic quasilinear part $QL(\varphi)$ of any dimension, as long as one only admits *"φ-conservative"* field extensions L/k. This means that $QL(\varphi) \otimes_k L$ remains anisotropic.

If $\lambda : K \to L \cup \{\infty\}$ is a place with associated valuation domain $\mathcal{O} = \mathcal{O}_\lambda$, and M is a quadratic $\mathcal{O}$-module, $M = (M, q)$, we call M *nondegenerate* if

1) M is a free $\mathcal{O}$-module of finite rank,
2) the bilinear form $\bar{B}_q$ on $M/QL(M)$ induced by B_q is nondegenerate,
3) every primitive vector $x \in QL(M)$ has unit value $q(x) \in \mathcal{O}^\times$.

A quadratic space (E, q) over the quotient field K of $\mathcal{O}$ has *"good reduction"* under λ, if $E \cong K \otimes_{\mathcal{O}} M$ with M a quadratic $\mathcal{O}$-module which is nondegenerate. In this case, we put $\lambda_*(E) = L \otimes_{\mathcal{O},\lambda} M$, the tensor product taken with respect to $\lambda|_{\mathcal{O}} : \mathcal{O} \to L$. The generic splitting theory is based on this notion of specialisation.

Twisted compositions and cohomological invariants

Max-Albert Knus

Let L be a cubic étale algebra over a field F of characteristic different from 2 and 3. For any $l \in L$, let $l^\# \in L$ be such that $l \cdot l^\# = N_{L/F}(l)$. A twisted composition, as defined by Rost, is a nonsingular quadratic space (V, Q) over L such that for all $v \in V$ and $l \in L$

1) $Q(\beta(v)) = Q(v)^\#$,
2) $\beta(lv) = l^\# \beta(v)$,
3) $b_Q(v, \beta(v)) \in F$,

where b_Q is the polar of the quadratic form Q and β is a quadratic map $V \to V$. Twisted compositions are classified by $H^1(F, \mathrm{Spin}_8 \rtimes S_3)$. They occur in connection with Albert algebras (central simple exceptional Jordan algebras): if J is an Albert algebra ond $L \subset J$ is a cubic étale subalgebra, then $V = L^\perp$ for the trace form is a twisted composition.

In this report we present results of our student R. Engelberger, extending results of Springer–Veldkamp (2000). We describe constructions of twisted compositions which correspond to the Tits construction for Albert algebras. We also discuss cohomological invariants which correspond to the known invariants for Albert algebras. As an application we show that if the invariant f_3 is zero, then the twisted composition is related to a type of composition algebras first described by Okubo.

Hoffmann's theorem in characteristic 2

AHMED LAGHRIBI
(joint work with D. W. Hoffmann)

In 1995, D. W. Hoffmann proved for any field F of characteristic different from 2 that if φ and φ' are anisotropic quadratic forms over F such that $\dim \varphi \leq 2^n < \dim \varphi'$ for some integer $n \geq 0$ then φ stays anisotropic over $F(\varphi')$, the function field of the quadric given by $\varphi' = 0$ over F.

A partial generalization of this result to characteristic 2 had been obtained by me and P. Mammone. In the talk I presented a complete generalization to the case of characteristic 2.

Quadratic forms and Sq^2

FABIEN MOREL

In the talk I explained a connection between the "functorial" extensions

$$(e_n): \qquad 0 \longrightarrow I^{n+1}/I^{n+2}(F) \longrightarrow I^n/I^{n+2}(F) \longrightarrow I^n/I^{n+1}(F) \longrightarrow 0 \qquad (n \geq 0),$$

associated to a field F of characteristic different from 2, and the Steenrod operation Sq^2.

For any $n \geq 1$, let Γ_n be the homotopy fibre of $Sq^2 : K(\mathbb{Z}/2, n) \to K(\mathbb{Z}/2, n+2)$ and let $BGal(F)$ be the classifying space of the profinite group $Gal(F)$.

By the Milnor Conjecture, proved by Voevodsky, one has $k_n(F) = H^n(Gal(F), \mathbb{Z}/2)$.

Theorem: If -1 is a square in F then

$$Sq^2 : H^n(Gal(F), \mathbb{Z}/2) = H^n(BGal(F), \mathbb{Z}/2) \longrightarrow H^{n+2}(BGal(F), \mathbb{Z}/2)$$

vanishes and (e_n) is functorially isomorphic to the extension

$$0 \longrightarrow H^{n+1}(BGal(F), \mathbb{Z}/2) \longrightarrow \pi(BGal(F), \Gamma_n) \longrightarrow H^n(Gal(F), \mathbb{Z}/2) \longrightarrow 0$$

coming from the fibration sequence $K(\mathbb{Z}/2, n+1) \longrightarrow \Gamma_n \longrightarrow K(\mathbb{Z}/2, n)$.

Purity for algebraic groups without transfers

IVAN PANIN
(joint work with M. Ojanguren)

Let A be a regular rocal ring containing a field k, let $m \subset A$ be the maximal ideal, let G be a reductive algebraic group and let T be a torus. Let $\mu : G \to T$ be a group morphism which is surjective locally for the étale topology (on the big étale site over k). Consider the functor

$$R \longmapsto T(R)/\mu(G(R))$$

on the category of commutative k-algebras. This functor satisfies purity, i.e.:

Theorem: Let K be the quotient field of the ring A. Let $a \in T(K)$. Suppose that for every height one prime ideal $\wp$ in A there exist elements $a_\wp \in T(A_\wp), b_\wp \in \mu(G(K))$ such that $a = b_\wp \cdot a_\wp$. Then there exist elements $a_m \in T(A)$, $b_m \in \mu(G(K))$ such that $a = a_m \cdot b_m$.

This result generalizes previous results in this direction proved by Sridharan–Parimala–Colliot-Thélène, Rost–Colliot-Thélène–Ojanguren, Suslin–Panin and Zainoulline.

Classification theorems for hermitian forms and the Hasse principle over function fields of curves over number fields

Raman Preeti
(joint work with R. Parimala)

We discuss a conjecture due to J.-L. Colliot-Thélène. Let K be a function field in one variable over a number field with field of constants k. Let G be a semi-simple simply connected linear algebraic group defined over K. Let Ω_k denote the set of places of k. The conjecture states that the natural map $H^1(K,G) \longrightarrow \prod_{v\in\Omega_k} H^1(K_v,G)$ has trivial kernel.

This conjecture is true if G is of type ${}^1A^*$, i.e. isomorphic to $SL_1(A)$ for a central simple algebra A over K of square-free index, as a consequence of theorems of Merkurjev–Suslin and Kato. P. Gille has proved the conjecture in the case where G is defined over k and $K = k(t)$, the rational function field in one variable over k.

We show that the conjecture is true for groups G defined over k of type ${}^2A^*$ (i.e. isomorphic to $SU(B,\tau)$, where B is a central simple algebra over a quadratic extension k' of k with unitary k'/k-involution τ), B_n, C_n, D_n (non-trialtarian in case of D_4), G_2 or F_4. A sketch of the proof in the case of Spin groups is given in the talk.

Levels of octonion algebras

Susanne Pumplün

To investigate sums of squares is a classical problem in number theory. Traditionally, sums of squares are studied over fields, more recently over commutative as well as over noncommutative rings. Many results on sums of squares and levels can also be extended to nonassociative rings, such as octonion algebras. Moreover, given an octonion algebra C over a ring and an arbitrary involution τ on this algebra, the hermitian level (and sums of hermitian squares $\tau(x)x$ $(x \in C)$) can be investigated. (The results on hermitian levels are joint work with T. Unger.)

Pfister involutions

Anne Quéguiner-Mathieu

In a recent paper, E. Bayer and R. Parimala raised the following question: could one consider tensor products of quaternion algebras with involution as a generalization of the classical Pfister quadratic forms? According to a conjecture of D. Shapiro, such a tensor product should give rise to a Pfister form as soon as the algebra is split. This is proved only in the case where the number of quaternion algebras in the product is less or equal to five.

Cohomological invariants are a useful tool to treat this question, at least when the degree is small. But one may prove that the e_3-invariant in the theory of quadratic forms cannot be extended to orthogonal involutions. This enables us to produce elements in the unramified cohomology of the function field of some Severi–Brauer varieties which do not come from the base field.

Trace forms of Galois field extensions in the presence of roots of unity

Zinovy Reichstein
(joint work with D.-S. Kang)

My talk centered around the following question: given a finite group G and a field K, which quadratic forms over K are (up to Witt equivalence) trace forms of G-Galois field extensions L/K? This is a rather delicate question in general, however, if on assumes that K contains certain roots of unity, the situation simplifies considerably.

The main result I presented says that under this assumption the trace form is split (i.e. hyperbolic) whenever the Sylow 2-group G_2 of G is non-abelian. I also discussed the (simpler) case where G_2 is abelian; in this case trace forms are Pfister forms.

Self-dual normal bases and unitary groups in characteristic 2

Jean-Pierre Serre

Let k be a field of characteristic 2 and let L/k be an étale Galois G-algebra (i.e. a G-torsor over k). Denote by $\varphi : \mathrm{Gal}(\bar{k}/k) \to G$ the corresponding homomorphism.

Theorem 1: The following are equivalent:

a) L/k has a self-dual normal basis (à la Bayer–Lenstra),

b) the image of φ is contained in the subgroup of G generated by the elements of order 2 and by the elements of odd order.

The proof relies on the following result, applied to $R = k[G]$:

Theorem 2: Assume k is perfect. Let R be a k-algebra with involution, of finite rank; let U_R be the corresponding unitary group and U_R° its connected component. Then $H^1(k, U_R^\circ) = 0$.

Variations on a theme of Lazard

Ramadorai Sujatha

A result of Lazard in the theory of p-adic analytic groups is applied to two different contexts: (1) Congruence subgroup problem, (2) Vanishing of arithmetic p-adic local representations and description of image of local Galois groups (for representations coming from abelian varieties or smooth projective varieties with good reduction). The result of Lazard that is applied is the following: Let G be a compact p-adic Lie group, and let $L(G)$ be the Lie algebra of G. Let V be a continuous p-adic representation (finite dimensional) of G. Then $H^i(G, V) \subseteq H^i(L(G), V)$ for all $i \geq 0$. This result can be used to prove finiteness of congruence kernel in certain cases very simply.

A local–global principle for hermitian forms

THOMAS UNGER
(joint work with David W. Lewis)

Pfister's well-known local–global principle states that a nonsingular quadratic form q over a field k (assumed to be of characteristic different from 2) is a torsion element in the Witt ring $W(k)$ of k if and only if the signature of q is zero for all orderings of k. Furthermore, every torsion element of $W(k)$ has 2-power order.

If $W(A, \sigma)$ is the Witt group of hermitian forms over some central simple k-algebra A with involution σ (of any kind), then W. Scharlau showed in 1970 that the torsion elements of $W(A, \sigma)$ have 2-power order.

We complement Scharlau's result by showing that $h \in W(A, \sigma)$ is a torsion element if and only if h has signature zero for all orderings of the ground field k, thus obtaining an analogue of Pfister's local–global principle for hermitian forms. In fact, this follows from our main theorem which states that if (A, σ) is a central simple k-algebra with involution (of any kind), then the signature of σ is zero for all orderings of k if and only if (A, σ) is weakly hyperbolic.

Discrete invariants of quadrics

ALEXANDER VISHIK

We introduce the following so-called *generic discrete invariant* of a quadric, which contains such well-known discrete invariants as *splitting type* and *motivic decomposition type* as particular cases.

Definition: $DGI(j, Q) := \text{image}(\mathrm{CH}^*(G(j, Q))/2 \to \mathrm{CH}^*(G(j, Q)|_{\overline{k}})/2)$, where $0 \leq j \leq [\dim(Q)/2]$ and $G(j, Q)$ is the Grassmannian of j-dimensional projective subspaces on Q.

Most of the results obtained concern the case $j = [\dim(Q)/2]$. Without loss of generality we can assume that $\dim(Q) = 2n - 1$ is odd. Then, due to the results of Hiller-Boe, Stembridge and Pragacz-Ratajski, the Chow ring of the Grassmannian has the following description: $\mathrm{CH}^*(G(n-1, Q)|_{\overline{k}})/2 = \otimes_{\text{odd } d \leq n} \mathbb{Z}/2[z_{(d)}]/(z_{(d)}^{2^{m_d}})$, where $m_d = [\log_2(n/2)] + 1$, and $z_{(l)}$ is a cycle of $j = (n-1)$-dimensional projective planes on Q, intersecting a given $(n - l)$-dimensional plane.

Our main result is the following:

Theorem 1: Let Q be smooth projective quadric of dimension $2n-1$. Then $GDI(n-1, Q)$ as a subring of $\mathrm{CH}^*(G(n-1, Q)|_{\overline{k}})$ is generated by the set of *elementary cycles* $z_{(l)}$ which are defined over the base field $(\mathit{mod}\, 2)$.

In particular, $GDI(n-1, Q)$ carries the same information as $JDI(Q) \subset \{1, 2, \ldots, n\}$, the subset of the natural numbers l for which the cycle $z_{(l)}$ $(\mathit{mod}\, 2)$ is defined over the base field.

The severe restrictions on the possible values of $JDI(Q)$ comes from the action of the Steenrod algebra on the Chow groups (constructed by Voevodsky in the general context of motivic cohomology, and by Brosnan in the classical context of Chow groups).

Theorem 2: $S^{\bullet}(z_{(i)}) = \sum_{m=i}^{\min(2i,n)} \binom{i}{m-i} z_{(m)}$.

In particular, if $i \in JDI(Q)$ and if $\binom{i}{m-i}$ is odd $(i \leq m \leq n)$ then $m \in JDI(Q)$.

Question: Do we have other restrictions on the set $JDI(Q)$?

Applying the above results to the question about the possible values for the dimension of anisotropic forms in I^n, we get:

Theorem 3: Let $q \in I^n$ be anisotropic form. Suppose that $\dim(q) > 2^n + 2^{n-1}$. Then $\dim(q)$ is either divisible by 4 or is $\geq 2^n + 2^{n-1} + 2^{n-2}$.

I remind, that currently it is known that $\dim(q)$ is either 0 or 2^n or $\geq 2^n + 2^{n-1}$, and it is conjectured that the possible values are: $2^{n+1} - 2^{i+1}$ $(0 \leq i \leq n)$ or even $\geq 2^{n+1}$ (examples for all these values are constructed). In particular, our Theorem 3 implies that for anisotropic forms q in I^4 one has $\dim(q) \neq 26$, which together with the results of Arason–Pfister and Hoffmann gives the complete list of possible dimensions for I^4 (for I^3 the problem was solved long ago by Pfister).

Grothendieck–Witt and Witt groups of projective bundles

Charles Walter

If X is a scheme, F an algebraic vector bundle of rank $r+1$ on X, and $P := \mathbb{P}(F) \to X$ the associated projective bundle, then it is well known that $K_0(P) \cong K_0(X)^{\times(r+1)}$. Many "oriented cohomology theories" satisfy this formula. In the work that I am reporting on I show that Grothendieck – Witt and Witt groups do not. Namely, under certain technical hypotheses one has

$$\begin{aligned} \mathrm{GW}^{\mathrm{tot}}(P) &\cong \mathrm{GW}^{\mathrm{tot}}(X)_{\{0\}} \times \prod_{i=1}^{r} K_0^{\mathrm{tot}}(X)_{\{i\}} \times \mathrm{GW}^{\mathrm{tot-r}}(X, \det F^\vee)_{\{r+1\}} \ , \\ \mathrm{W}^{\mathrm{tot}}(P) &\cong \mathrm{W}^{\mathrm{tot}}(X)_{\{0\}} \times \mathrm{W}^{\mathrm{tot-r}}(X, \det F^\vee)_{\{r+1\}} \ . \end{aligned}$$

The Purity for algebraic groups with Norm Principle

Kirill Zainoulline

Let G be a group over a local regular ring R and let T be a torus over R. Let $\mu : G \to T$ be a surjective morphism of group schemes over R. We prove that if the Norm Principle holds for μ, i.e. $N_{S/R}(\mu(G(S))) \subset \mu(G(R))$ where $N_{S/R}$ is the norm map for a finite projective extension S/R, then the Purity holds for μ, i.e. the sequence

$$1 \longrightarrow \frac{T(R)}{\mu(G(R))} \longrightarrow \frac{T(K)}{\mu(G(K))} \longrightarrow \bigoplus_{\mathrm{ht}\, p=1} \frac{T(K)}{\mu(G(K))T(R_p)}$$

is exact. We give examples of G, T and μ for which the Norm Principle holds.

Edited by Karim Johannes Becher

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