MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

T a g u n g s b e r i c h t 22/1989

Formal and Rigid Geometry and Applications to Moduli Spaces

20.5. bis 25.5.1989

Tagungsleiter: S. Bosch, Münster
W. Lütkebohmert, Münster
M. Raynaud, Paris

Ein Hauptziel der Tagung war das Studium arithmetischer Kompaktifizierungen des Modulraumes A_g prinzipal polarisierter abelscher Varietäten der Dimension g nach Manuskriptvorlagen von Chai und Faltings. In einer Serie von 11 im voraus geplanten Vorträgen haben wir uns darum bemüht, die Details dieser Konstruktion, die auf Ideen der formellen und rigiden Geometrie aufbaut, zu verstehen. Daneben wurden von den Teilnehmern auch noch einige freie Vorträge gehalten, in welchen über eigene Forschungsarbeit berichtet wurde.

Die Notwendigkeit, arithmetische Kompaktifizierungen von Modulräumen abelscher Varietäten zu betrachten, ergab sich in zwingender Weise beim Beweis der Mordell-Vermutung durch Faltings. Inzwischen gibt es weitere interessante Anwendungen, und wir haben den Eindruck, daß insbesondere auf dem Gebiet der Modulformen die Tragweite der Existenz solcher Kompaktifizierungen noch gar nicht hoch genug eingeschätzt wird. Auf der Konferenz wurden auch Felder sichtbar, die noch offen sind: etwa eine analoge Theorie für d-fach polarisierte abelsche Varietäten oder die Konstruktion von Kompaktifizierungen unter Einbeziehung nicht notwendig semi-abelscher Degenerierungen.

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Vortragsauszüge

S. Bosch, Münster:

Introduction to the compactification of A_g

We gave an introduction to the construction of arithmetic compactifications à la Chai and Faltings of the moduli stack A_g of principally polarized abelian schemes of dimension g. Relating the problem of compactifying A_g to the valuative criterion of properness, the strategy is to add semi-abelian schemes with abelian generic fibre at the boundary of A_g. Such schemes can be parametrized in terms of Mumford's construction and Faltings' improvement of it (mixed case). Using M. Artin's approximation theorem and working relatively to a polyhedral cone decomposition of the cone of positive semi-definite symmetric bilinear forms, it was indicated how to obtain the toroidal compactification $\bar{A}_g$ of A_g together with its stratification.

U. Stuhler, Wuppertal:

Toroidal embeddings

In this talk a short introduction to the theory of torus-embeddings was given. Let S be an arbitrary scheme, $M \cong \mathbb{Z}^n$ an abelian group, free of rank n; $T := \operatorname{Spec} \mathcal{O}_S[M]$ the split torus with character group $\operatorname{Hom}_S(T; \mathbb{G}_m) = M(T)$ ($\cong M$ of course) and $N(T) = \operatorname{Hom}_S(\mathbb{G}_m; T)$, the group of 1-parameter subgroups, with t[he] canonical pairing $M \times N \longrightarrow \mathbb{Z}$ resp. $M_{\mathbb{R}} \times N_{\mathbb{R}} \longrightarrow \mathbb{R}$. Associated with any rational convex polyhedral cone $\sigma \subseteq N_{\mathbb{R}}$, $\sigma = \{\sum_{i=1}^{s} \lambda_i \nu_i \mid \lambda_i > 0\}$, where $\nu_1, \ldots, \nu_s \in N$, is a torus embedding $T \longrightarrow X_\sigma = \operatorname{Spec} \mathcal{O}_S[\check{\sigma} \cap M]$, where $\check{\sigma} = \{y \in M_{\mathbb{R}} \mid \langle y, \sigma \rangle \geq 0\}$. This is open, if σ contains no full lines through the origin. The action of T

can be extended to an action of T on X_σ. If $\tau \leq \sigma$ is a face of σ there is an open T-equivariant embedding $X_\tau \hookrightarrow X_\sigma$. This allows to generalize the construction above to the following situation. A rational partial polyhedral cone decomposition is a set $C = \{\sigma_\alpha\}$ of cones $\sigma_\alpha \subseteq N_{\mathbb{R}}$ as above, such that 1) any face $\tau \leq \sigma_\alpha$ is a σ_β and 2) some local finiteness conditions (for example finiteness itself or something weaker) hold. Then one can associate a torus embedding $T \hookrightarrow X_C$ by gluing the X_{σ_α}. One can discuss then, as was done in the talk, various properties of X_C such as normality, properness over S, smoothness and also the orbit structure under the T-action.

F. Vogel, Münster:

Cubical invertible sheaves and biextensions

In this talk we were considering for a G-torsor L over A (A,G commutative groups in a topos E) a G-torsor

$$\mathcal{D}_n L := \bigotimes_{\substack{I\subset\{1,\dots,n\}\\ I\neq\emptyset}} (m_I{}^*L)^{\otimes(-1)^{n+\mathrm{card}\, I}} \quad (m_I(\underline{x}) = \sum_{i\in I} x_i) \text{ over } A^n (n=2,3).$$

A symmetric section σ (fulfilling a cocycle condition) of $\mathcal{D}_2 L$ over A^2 corresponds to a structure of a commutative extension of A by G on L, compatible with the structure as a G-torsor.

Such a section τ of $\mathcal{D}_3 L$ over A^3 is called a cubical structure on L and corresponds to a structure of a symmetric biextension of $A \times A$ by G on $\mathcal{D}_2 L$. E.g. each rigidified line bundle on an abelian scheme $|_S$ carries a cubical structure.

One has a descent theory of cubical torsors that gives in the case of an exact sequence $0 \to T \to A \to B \to 0$ of smooth group schemes with connected fibres (T a torus) the following result for a cubical $\mathbb{G}_m$-torsor L over A:

i) $L \otimes [-1]_A^* L$ descends canonically to a cubical $\mathbb{G}_m$-torsor over B.

ii) L descends after étale surjective basechange to a cubical $\mathbb{G}_m$-torsor over B.

M. Rapoport, Bonn:

<u>Degenerating abelian varieties</u>

Let R be a noetherian normal ring, complete w.r.t. an ideal I. Let $G/\mathrm{Spec}\, R$ be a semi-abelian group scheme, whose restriction to $\mathrm{Spec}(R/I)$ is an extension of an abelian variety A_o by a (split) torus T_o and whose generic fibre is an abelian variety. We indicated the construction of the Raynaud extension

$$0 \to T \to \tilde{G} \to A \to 0$$

whose restriction to $\mathrm{Spec}(R/I)$ is the given extension. Using (principal) polarization on G_η , we indicated the construction of a lattice $Y \subset \tilde{G}(\mathrm{Quot}(R))$, as well as an action of Y on the line bundle $\tilde{\mathcal{L}}$ on $\tilde{G}$ which arises through the Raynaud construction from the principal polarization. The proof, which is presented in the manuscript of Chai and Faltings, is based on addition formulae which exist in case R is a discrete valuation ring.

N. Schappacher, Bonn:

<u>Mumford's Construction</u>

Inverting, in a way, the procedure described in the talk before, it was sketched how Mumford obtains a semi-abelian group scheme G over R as above, from a (split) torus $\tilde{G}$ over $\mathrm{Spec}(R)$ and a lattice $Y \hookrightarrow \tilde{G}(K)$, K = the quotient field of R . The idea - very roughly - is to first pass to a "relatively complete model" $\tilde{P}$ of $\tilde{G}$. This notion is axiomatized which allows for a certain amount of flexibility when carrying out the construction in special examples. Then the successive infinitesimal thickenings of $\tilde{P}$ over the R/I^n are divided by the action of Y . The resulting formal proper scheme P_{for} can be algebrised to a proper scheme P/S in which the desired G is found as an open subscheme. - The main features of this construction were presented, following Mumford's original paper: Compositio Mathematica <u>24</u> (1972), 239-272. - Faltings' and Chai's generalisation to semi-abelian $\tilde{G}$, as well as the categorial interpretation of Mumford's construction - to wit, it gives an equivalence of categories between the $\tilde{G}$'s (with certain additional structures) and the G's (dito) - in Chai-Faltings was briefly discussed.

R. Weissauer, Mannheim:

Kodaira - Spencer Map

Let be the situation as in the last talk. In order to control the Kodaira-Spencer map $\rho_{G_\eta} : \omega_{G'_\eta} \otimes \omega_{G_\eta} \longrightarrow \Omega^1_{S_\eta/\Sigma_\eta}$ for degenerating semiabelian $G \to S \to \Sigma$ with $G_\eta \to S_\eta$ abelian and $S_\eta \to \Sigma_\eta$ smooth, it is explained how Chai-Faltings introduce a Kodaira-Spencer map for semiabelian (split) extensions $0 \to T \to G \to A \to 0$ over S with a map $i : Y = \mathbb{Z}^r \to G(S)$. This is done via commutative vector extensions of (G,i). This allows (partially) the computation of ρ_{G_η} in terms of the data of degeneration.

G. Laumon, Orsay:

Stacks and moduli

Let g be an integer and for any affine scheme U let $A_g(U)$ be the category of principally polarized abelian schemes of pure relative dimension g over U. Then A_g is in a natural way a fibered category over the category (Aff) of all affine schemes. We explained that A_g is in fact a stack when we endow (Aff) with the fppf-topology and even an algebraic stack in the sense of Deligne and Mumford. We gave some properties of this algebraic stack. We explained the relation between algebraic stacks and algebraic groupoids $X_1 \rightrightarrows X_o$. We explained how to stratify A_g by gerbs over algebraic spaces.

M. Knebusch, Regensburg:

The cone of positive semidefinite forms

Let $\mathcal{B}$ denote the vector space of real symmetric $n \times n$-matrices, $\mathcal{P}$ the open cone in $\mathcal{B}$ consisting of all positive definite $S \in \mathcal{B}$ and $\mathcal{C}$ the cone of all positive semidefinite $S \in \mathcal{B}$ with rational radical. The group $\Gamma = GL(n,\mathbb{Z})$ operates on $\mathcal{P}$ and $\mathcal{C}$ by $(U,S) \mapsto {}^tUSU$. By Minkowski's reduction theory a rational polyhedral cone $\bar{\mathcal{R}}$ in $\mathcal{B}$ is constructed (= set of "reduced" quadratic forms) such that $\bar{\mathcal{R}}$ is a nice fundamental domain of Γ in $\mathcal{C}$ and $\mathcal{R} := \bar{\mathcal{R}} \cap \mathcal{P}$ is a very nice fundamental domain of Γ in $\mathcal{P}$. I mainly followed Siegel's arguments (cf. Siegel, Einheiten quadratischer Formen, Ges. Werke II). Some extra work is needed to describe not only $\mathcal{R}$ in $\mathcal{P}$ but also its closure $\bar{\mathcal{R}}$ in $\mathcal{B}$ by finitely many linear inequalities.

M. Raynaud, Orsay:

Construction of $\bar{A}_g$: Formal part

As a first approximation of $\bar{A}_g$, Chai and Faltings construct formal charts of $\bar{A}_g$ along the strata given by the rank of the torus part.

Fix $X = \mathbb{Z}^g$, $S^2(X) = \mathrm{Sym}^2(X)$, C the cone in $\mathrm{Hom}(S^2(X),\mathbb{R})$ consisting of positive quadratic forms with rational kernel. Then we choose a polyhedral decomposition of C, rational, invariant under $GL(X)$, finite modulo $GL(X)$ and smooth with respect to the integral structure given by $\mathrm{Hom}(S^2(X),\mathbb{Z})$. Let E be the corresponding toroidal embedding, $E(\sigma)$ the affine cell corresponding to the simplex σ.

When σ lies in the interior C^o of C and after completion of $E(\sigma)$ along the closed orbit, we get a completely degenerate semi-abelian group scheme G.

When σ lies in the boundary we have to modify the construction to parametrize the extension of the abelian part by the torus.

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R. Elkik, Orsay:

Compactification of A_g

Once one has "good" semi-abelian schemes over complete rings (by Mumford's construction), we get "good" semi-abelian schemes over rings of finite type over $\mathbb{Z}$ by approximation methods (Artin's Theorem and approximation of degeneration data).

Then we define a scheme U, equipped with a semi-abelian G which is abelian over a dense open set U_o etale over A_g. This U will be an etale atlas of A_g. Let $R_o = \mathrm{Isom}(p_1^* G, p_2^* G)$ over U_o and take R = normalization of R_o over $U \times U$. We prove R is etale over U via the two projections and define $\bar{A}_g$ as the "quotient of U by R".

L. Moret-Bailly, Rennes:

The minimal compactification

If $f: G \to S$ is a semiabelian scheme, put $\omega_G = (\Lambda^g \mathrm{Lie}\,(G/S))^{-1}$ ($g = \dim S$). In particular, if $\bar{A}_g$ is an arithmetic toroidal compactification of A_g, and $B_g \longrightarrow \bar{A}_g$ the natural semiabelian scheme, put $\omega_g = \omega_{B_g}$ and define Siegel modular forms of weight $k \geq 0$ and genus g as elements of $H^\circ(\bar{A}_g, \omega^{\otimes k})$.

This is seen to be independent of the choice of $\bar{A}_g$ and in fact, if $g \geq 2$, equal to $H^\circ(A_g, \omega^{\otimes k})$ (Koecher's principle).

One proves that $\omega^{\otimes m}$ is generated by global sections for some $m \geq 1$. This reduces to the analogous statement for ω_G with $G \to S$ as above, generically abelian. One proves this by relating ω_G to "theta constants", suitably extended to the semiabelian case, and then constructing enough linear forms on these theta constants by evaluation of sections of finite order.

The preceding result now implies that we have a morphism

$$\bar{\pi} : \bar{A}_g \longrightarrow A_g^* = \mathrm{Proj} \bigoplus_{k \geq 0} \Gamma(\bar{A}_g, \omega^{\otimes k})$$

and that the ring on the right-hand side is finitely generated $/\mathbb{Z}$.

One then checks that A_g^* has a stratification $A_g^* = \coprod_{0 \leq i \leq g} [A_i]$ where $[A_i]$ = coarse moduli scheme of A_i, compatible with the natural stratification of $\bar{A}_g$ by torus rank; the map $\bar{\pi}$ associates to a geometric point x of $\bar{A}_g$ the isomorphism class of the abelian part of $(B_g)_x$.

J.P. Wintenberger, Orsay:

P-adic Hodge theory for families of abelian varieties

For $G \to R$ a semi-abelian scheme with R complete with respect to an I-adic topology, R normal, integral, noetherian, such that $G[1/p] \longrightarrow R[1/p]$ is an abelian scheme, G with L rigidified and L ample on the generic fiber, one constructs a pairing

$$H^1_{DR}(G[1/p]/R[1/p]) \times T_p(G(\bar{F})) \longrightarrow B_{DR}(\bar{R}/R)$$

that is functorial with respect to $R \to R'$ not necessarily continous with I-adic topology. As an application, using compactification of the modular scheme and its semi-abelian scheme over it, one gives a proof that de Rham and etale p-adic components of a Hodge cycle on an abelian variety are compatible with p-adic comparison theorem. One cites a proof of Don Blasius using the spectral sequence of the morphism of an abelian scheme.

J.-F.Boutot, Strasbourg:

Drinfeld's and Cherednik's theorems

Let D be a quaternion algebra over $\mathbb{Q}_p$ and $\mathcal{O}_D$ its ring of integers. We explained Drinfeld's description of $\hat{\Omega}^2 \hat{\otimes} \hat{\mathbb{Z}}_p^{nr}$ (where $\hat{\Omega}^2$ is the formal model over $\mathbb{Z}_p$ of the "p-adic upper half space") as a moduli space for quasi-isogenies of height zero $\rho : \Phi \to X$ of special formal $\mathcal{O}_D$-modules (where Φ is a fixed one over $\bar{\mathbb{F}}_p$).

Let Δ be a quaternion algebra over $\mathbb{Q}$ unramified at ∞, $\mathcal{O}_\Delta$ a maximal order in Δ and S_n the Shimura curve over $\mathbb{Z}[1/n]$

parametrizing special abelian schemes of dimension 2 with an action of $\mathcal{O}_\Delta$ and level n structure. Let p be a prime, not dividing n, where Δ is ramified and $\hat{S}_n$ the formal completion of S_n along the fiber at p. We explained how to deduce Cherednik's p-adic uniformization of $\hat{S}_n$ from Drinfeld's description of $\hat{\Omega}^2$.

W. Lütkebohmert, Münster:

Properness in rigid geometry

Let R be a discrete valuation ring with uniformizing parameter π and with field of fractions K. An R-model of a rigid space X is a formal scheme $\mathcal{X}$ over Spf R which is topologically of finite type and flat over R satisfying $\mathcal{X} \otimes_R K = X$. Due to Raynaud, any morphism $f: X \to Y$ of quasi-compact rigid spaces is induced by a morphism $\mathfrak{f}: \mathcal{X} \to \mathcal{Y}$ of suitable R- models $\mathcal{X}$ of X resp. $\mathcal{Y}$ of Y which are quasi-compact.

Theorem. $f: X \to Y$ is proper in the sense of Kiehl if and only if $\mathfrak{f}: \mathcal{X} \to \mathcal{Y}$ is proper in the formal sense.

Corollary. The composition of proper rigid morphisms is proper.

A key tool of the proof is the following

Proposition. Let S be an affine noetherian scheme which is of finite type over an artinian ring and let $f: X \to S$ be a separated morphism of finite type. Assume that, for any coherent sheaf $\mathcal{F}$ on X, the first direct image $R^1 f_* \mathcal{F}$ is coherent on S. Then f can be factored into $f = g \circ h$ where $g: Y \to S$ is affine and of finite type and where $h: X \to Y$ is proper satisfying the conditions

(a) $h_* \mathcal{O}_X = \mathcal{O}_Y$

(b) $\{y \in Y \mid \dim h^{-1}(y) \geq 1\}$ is finite over S.

B. Edixhoven, Utrecht:

On the Manin constants of strong Weil curves

Let $\phi : X_0(M)_{\mathbb{Q}} \longrightarrow E$ be a strong Weil parametrization, ω a Néron differential on E and $\sum_{n\geq 1} a_n q^n \frac{dq}{q}$ the normalised newform on $X_0(M)_{\mathbb{Q}}$ corresponding to E. Then one has:

$\phi^*\omega = c \cdot \sum_{n\geq 1} a_n q^n \frac{dq}{q}$ with $c \in \mathbb{Q}^*$. Manin has conjectured that $c = \pm 1$.

Using the model over $\mathbb{Z}$ of $X_0(M)_{\mathbb{Q}}$ as constructed by Katz and Mazur it is easy to show that $c \in \mathbb{Z}$. Mazur has shown that $p \neq 2$, $v_p(M) \leq 1 \Rightarrow p \nmid c$. In this talk it was shown that if $p > 7$, then $p \nmid c$ unless the Kodaira symbol of E at p is II, III or IV and E has potentially ordinary reduction at p. In the last case one knows that $v_p(c) \leq 1$. This result was proved by applying the method of Mazur to a model of $X_0(M)$ that has stable reduction at p. Of course, one then has to work over some extension of $\mathbb{Q}$. All the details can be found in my thesis.

P. Schneider, Köln:

The cohomology of p-adic symmetric spaces and their quotients

This was a report on joint work with U. Stuhler. Let K be a local field with finite residue class field of char p. We consider Drinfeld's p-adic symmetric space

$$\Omega^{(d+1)} := \mathbb{P}^d_K \setminus \text{all K-rational hyperplanes.}$$

Our main result computes the cohomology of $\Omega^{(d+1)}$ in any reasonable cohomology theory, e.g., etale or de Rham cohomology, on the category of smooth separated K- analytic varieties: If A is the coefficient ring of the given cohomology theory, then $H^s(\Omega^{(d+1)})$ is the A-dual of a certain generalized (integral) Steinberg representation for $G := PGL_{d+1}(K)$ if $0 \leq s \leq d$ and is zero if $s > d$.

Now let $\Gamma \subseteq G$ be a discrete cocompact subgroup which acts fixed-point free on $\Omega^{(d+1)}$. According to Drinfeld and Mustafin the quotient $X_\Gamma := \Gamma \setminus \Omega^{(d+1)}$ is a smooth projective variety. Under very weak assumptions one has the spectral sequence $H^r(\Gamma, H^s(\Omega^{(d+1)}) \Rightarrow H^{r+s}(X_\Gamma)$. Using the above result one can interprete the E_2-terms as Ext-groups in the category of smooth G-representations. Extending ideas and results of Casselman we computed this Ext-groups in the case that A is a field of characteristic 0 (e.g. de Rham or $\mathbb{Q}_\ell$-adic cohomology). It turns out that, apart from the hyperplane section, only $H^d(X_\Gamma)$ is interesting: It has a filtration whose subquotients are $\cong A^\mu$ where μ is the multiplicity of the Steinberg representation in Ind_Γ^G. In the case of $\mathbb{Q}_\ell$-adic cohomology this filtration is pure.

Berichterstatter: Ferdinand Vogel, Münster

Tagungsteilnehmer

Prof. Dr. F. Baldassarri
Dipartimento di Matematica
Universita di Padova
Via Belzoni, 7

I-35131 Padova

Prof. Dr. P. Berthelot
Departement de Mathematiques
Universite de Rennes I
Campus de Beaulieu

F-35042 Rennes Cedex

Prof. Dr. S. Bosch
Mathematisches Institut
der Universität Münster
Einsteinstr. 62

4400 Münster

Prof. Dr. J. F. Boutot
Institut de Mathematiques
Universite Louis Pasteur
7, rue Rene Descartes

F-67084 Strasbourg Cedex

H. Carayol
Institut de Mathematiques
Universite Louis Pasteur
7, rue Rene Descartes

F-67084 Strasbourg Cedex

Prof. Dr. O. Debarre
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

F. Ducrot
Dept. de Mathematiques
Faculte des Sciences
Universite d'Angers
2, Boulevard Lavoisier

F-49045 Angers Cedex

Prof. Dr. S. J. Edixhoven
Mathematisch Instituut
Rijksuniversiteit te Utrecht
P. O. Box 80.010

NL-3508 TA Utrecht

Prof. Dr. R. Elkik
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

J. Y. Etesse
Departement de Mathematiques
Universite de Rennes I
Campus de Beaulieu

F-35042 Rennes Cedex

Prof. Dr. M. Flexor
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

Prof. Dr. L. Gerritzen
Institut f. Mathematik
der Ruhr-Universität Bochum
Gebäude NA, Universitätsstr. 150
Postfach 10 21 48

4630 Bochum 1

Prof. Dr. J. M. Fontaine
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

W. Heinen
Opferfelder Str. 9

5650 Solingen 19

Prof. Dr. J. Fresnel
Mathematiques et Informatique
Universite de Bordeaux I
351, cours de la Liberation

F-33405 Talence Cedex

Dr. F. Herrlich
Institut f. Mathematik
der Ruhr-Universität Bochum
Gebäude NA, Universitätsstr. 150
Postfach 10 21 48

4630 Bochum 1

Prof. Dr. G. Frey
Fachbereich 9 - Mathematik
Universität des Saarlandes
Bau 27

6600 Saarbrücken

Dr. R. Huber
Fakultät für Mathematik
der Universität Regensburg
Universitätsstr. 31
Postfach 397

8400 Regensburg

Dr. E.-U. Gekeler
Max-Planck-Institut für Mathematik
Gottfried-Claren-Str. 26

5300 Bonn 3

Dr. A.J. de Jong
Mathematisch Instituut
Katholieke Universiteit Nijmegen
Toernooiveld

NL-6525 ED Nijmegen

Dr. E. Kani
Department of Mathematics and
Statistics
Queen's University

Kingston, Ontario K7L 3N6
CANADA

Prof. Dr. M. Matignon
Mathematiques et Informatique
Universite de Bordeaux I
351, cours de la Liberation

F-33405 Talence Cedex

Prof. Dr. M. Knebusch
Fakultät für Mathematik
der Universität Regensburg
Universitätsstr. 31
Postfach 397

8400 Regensburg

Prof. Dr. L. Moret-Bailly
U. E. R. Mathematiques
I. R. M. A. R.
Universite de Rennes I
Campus de Beaulieu

F-35042 Rennes Cedex

Prof. Dr. G. Laumon
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

Prof. Dr. H.-J. Nastold
Mathematisches Institut
der Universität Münster
Einsteinstr. 62

4400 Münster

Prof. Dr. Qing Liu
Mathematiques et Informatique
Universite de Bordeaux I
351, cours de la Liberation

F-33405 Talence Cedex

Prof. Dr. J. Oesterle
12, rue Lucien Sampaix

F-75010 Paris 10e

Prof. Dr. W. Lütkebohmert
Mathematisches Institut
der Universität Münster
Einsteinstr. 62

4400 Münster

Prof. Dr. M. Rapoport
Mathematisches Institut
der Universität Bonn
Beringstr. 1

5300 Bonn 1

Prof. Dr. M. Raynaud
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

Prof. Dr. R. Remmert
Mathematisches Institut
der Universität Münster
Einsteinstr. 62

4400 Münster

Prof. Dr. M. Reversat
Analyse sur les Varietes
Universite Paul Sabatier
118, route de Narbonne

F-31062 Toulouse Cedex

Dr. N. Schappacher
Max-Planck-Institut für Mathematik
Gottfried-Claren-Str. 26

5300 Bonn 3

Prof. Dr. P. Schneider
Mathematisches Institut
der Universität Köln
Weyertal 86-90

5000 Köln 41

Prof. Dr. U. Stuhler
Fachbereich 7: Mathematik
der Universität/Gesamthochschule
Wuppertal, Gaußstr. 20
Postfach 10 01 27

5600 Wuppertal 1

Prof. Dr. L. Szpiro
29, rue de Vaugirard

F-75006 Paris

F. Vogel
Mathematisches Institut
der Universität Münster
Einsteinstr. 62

4400 Münster

Prof. Dr. R. Weissauer
Fakultät für Mathematik und
Informatik
der Universität Mannheim
Seminargebäude A 5

6800 Mannheim 1

Prof. Dr. J. P. Wintenberger
Mathematiques
Universite de Paris Sud (Paris XI)
Centre d'Orsay, Bat. 425

F-91405 Orsay Cedex

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