Mathematisches Forschungsinstitut Oberwolfach

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Endlichdimensionale Lie-Algebren

10.2. bis 16.2.1991

This meeting was organized by Prof. M. Goze (Mulhouse) and Prof. O.H. Kegel (Freiburg). It was the first conference on finite dimensional Lie algebras at the Oberwolfach Institute taking into account the recent progress in this topic.

Several talks were devoted to new results in classification theory. In prime characteristic, a complete classification of the finite dimensional simple Lie algebras over algebraically closed fields of characteristic $p > 7$ was given and thereby proving the modified Kostrikin-Shafarevich conjecture. In addition, some decisive steps toward a solution of this problem in characteristic $p = 5,7$ were announced. Some results concerning the difficult problem of the classification of finite dimensional nilpotent Lie algebras in zero characteristic are presented, including a complete classification in the 7-dimensional case, some insights for 8-dimensional algebras and a proof of Vergne's conjecture on the reducibility of the variety of nilpotent Lie algebras of dimension ≥ 7.

A number of lectures were given on the deformation theory of Lie algebras. In particular, a non-standard approach was presented, which has been quite useful as a new tool in the above mentioned classification of finite dimensional nilpotent Lie algebras. The participants also got a survey of Lie algebras with nondegenerate invariant bilinear forms and an impression of cohomological methods in the representation theory of modular Lie algebras. Moreover, some connections to Kac-Moody algebras, group theory, differential geometry and computer algebra were pointed out.

The conference was attended by 23 participants from Australia, France, Greece, Hungary, Spain, USA, USSR, Vietnam and the Federal Republic of Germany. Apart from many interesting lectures, the discussions during the breaks and in the evening were an invaluable part of the meeting.

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J.M. ANCOCHEA-BERMUDEZ: Rigid Lie algebras and classification

We use non-standard tools, as the perturbations, to study the solvable rigid complex Lie algebras. This non-standard approach leads us to the study of the linear system of roots of a rigid Lie algebra defined by a regular vector. More precisely, we give necessary conditions for the rigidity in terms of the rank of this system. Namely, if g is rigid, the rank is equal to the dimension of the nilradical minus one. We apply this criterion to the classification of 8-dimensional rigid solvable algebras and the classification of rigid algebras whose nilradical is filiform.

YU. BAHTURIN: Automorphisms and derivations of abelian extensions of Lie algebras

Let L be a free Lie algebra over an arbitary commutative ring K with unit and R an ideal of L such that L/R is a free K-module. Denote by U the enveloping algebra of L/R and by IAut L/R^2 the group of those automorphisms of L/R^2 which are identical modulo R/R^2. Using the notion of the wreath product and an embedding theorem due to A.L. Shmel'kin (1973), we single out the subgroup in $(U_n)^*$ isomorphic to IAut L/R^2, where n = rank L. We also indicate the subalgebra in $[U_n]$ which is isomorphic to IDer L/R^2, the similarly defined derivation algebra. Analogous results hold for algebras of the form L/S where $R \supset S \supset R^2$ if $S/R^2 = J(R/R^2)$, J being a two-sided ideal of U. As an application, we prove the non-tameness of inner automorphisms of free metabelian algebras and the non-finiteness generator property for the derivation algebra of free metabelian algebras of rank ≥ 3 (with S. Nabiyev). The existence of non-tame automorphisms (they are also inner) is also shown for algebras of the form L/R^m, $m \geq 2$ if $R \subset L^2$ and $m \geq 3$ otherwise, in the case where K is a field of characteristic 0 (with V. Shpilrain). Here we have used R. Fox's free differential calculus.

M. BORDEMANN: Lie algebras carrying a nondegenerate derivation invariant bilinear form

Let A be a finite-dimensional Lie algebra over a field K of characteristic ≠ 2. A is called *D-metrizable* if there is a nondegenerate bilinear form $f: A \times A \to K$ invariant under all derivations of A. After presenting some structural properties for arbitary fields, we obtain the following result:

THEOREM 1: Let A be a perfect Lie algebra over an algebraically closed field of characteristic 0. Then A is D-metrizable if and only if there exists an nondegenerate invariant symmetric bilinear form on A which is invariant under all derivations in the nilradical of Der(A) and every derivation of A has trace zero.

CONJECTURE: Every D-metrizable Lie algebra over a field of characteristic 0 is semisimple.

In prime characteristic, we construct a counterexample by means of a so-called T_w^*-extension. This is applied to B = W(1,1) over a field of characteristic 5 using the following result:

THEOREM 2: Let B be a finite dimensional Lie algebra over an algebraically closed field K of characteristic $\neq 2$. Suppose B satisfies the following conditions:
a) B is simple and nonabelian,
b) every invariant bilinear form on B vanishes,
c) B has only inner derivations,
d) $H^3(B,K) \neq 0$.
Then T_w^*B is D-metrizable and nonsemisimple.

R. CARLES: Deformations in the schemes of Lie algebras

A deformation of a Lie algebra law Φ_0, parametrized by a local ring A, is a morphism $O \rightarrow A$, where O is the local ring at the point Φ_0 in the scheme defined by Jacobi's identities. If A is complete, this deformation is equivalent to the one where the structure constants, inducing a local parametrization of the orbit under the canonical action of the full linear group, are fixed. This applies to the universal deformation defined by the identity map. Thus we obtain deformations, where only appear parameters which express the varieties of the orbit as well as nilpotent elements in the completion of O. A non-null obstruction in the theory of M. Gerstenhaber of formal deformations which blocked the lifting to an order for a tangent vector, corresponds here to a relation $\varepsilon^p = 0$ for the parameter ε. The local study of Lie algebras $g = sl(2,\mathbb{C}) \oplus \mathbb{C}^n$, where $\mathbb{C}^n$ is the irreducible $sl(2,\mathbb{C})$-module with $n = 4p + 3$, gives an example of deformations of this type with a nilpotent element of order 2. Moreover, g is rigid and $H^2(g,g) \neq 0$ (G. Rauch, R.W. Richardson).

R. FARNSTEINER: Ordinary and restricted cohomology of modular Lie algebras

In this talk we shall be concerned with extension functors of ordinary and restricted enveloping algebras of modular Lie algebras. Their behaviour can be studied by considering indecomposable coefficients. In default of a classification of indecomposables we introduce a certain class of induced modules that unifies several known concepts from modular representation theory. In particular, we shall provide conditions implying indecomposability.

The second part of the talk employs these modules in order to establish cohomological reduction theorems that illustrate the peculiarities of modular cohomology theory. For restricted Lie algebras the ordinary and restricted cohomology theories are shown to be linked via a spectral sequence.

J. FELDVOSS: Restricted Lie algebras with bounded cohomology

In our talk we consider the problem of determining the restricted Lie algebras for which the dimensions of their indecomposable restricted modules are bounded. Since this property is not inherited by subalgebras and homomorphic images, we consider the (in general) larger class of restricted Lie algebras with bounded cohomology. According to Shapiro's lemma, this class is invariant under restriction to subalgebras but not under projection to arbitrary factor algebras. In the last step, we show that it is sufficient to classify restricted Lie algebras L of the following type:

(*) Every proper restricted subalgebra K of L is solvable and satisfies $\dim K/C(K) \leq 2$ and every nilpotent restricted subalgebra N is abelian with $\dim N/\langle N^{[p]}\rangle \leq 1$.

By means of the complete classification of finite dimensional restricted Lie algebras of type (*) over an algebraically closed field of arbitrary prime characteristic $p > 0$, we show the equivalence of the following statements:

1) Every finite dimensional restricted L-module has a unique composition series.
2) There are at most finitely many non-isomorphic finite dimensional indecomposable restricted L-modules.
3) The dimensions of the finite dimensional indecomposable restricted L-modules are bounded.
4) L has periodic cohomology.
5) L has bounded cohomology.
6) $L \cong (T \oplus \langle x\rangle_p) \oplus \langle t\rangle$, where T is a central torus, x is p-nilpotent, t is toral and $[t,x] = x + z$ with $z \in T$.

The above results are proved in joint work with H. Strade.

A. FIALOWSKI: Lie algebra cohomology and deformations

The cohomology of nilpotent Lie algebras is very hard to study. Even the low dimensional cohomology is complicated to study, although it is important as it has a nice geometric interpretation. In my talk I concentrated on the deformation problem. The classical definition of a formal deformation has to be generalized, considering deformations parametrized by a complete local algebra, in order to be able to define the versal deformation. A sufficient condition for the existence of a versal deformation is the finiteness of the space $H^2(L,L)$. There is a conjecture that nilpotent Lie algebras are never rigid, but the deformations are only known in some special cases, e.g. for the maximal nilpotent subalgebras of simple finite dimensional Lie algebras.

In my talk I arouse a question on finite dimensional 1-graded Lie algebras with 2 generators, and on the cohomology of these nilpotent algebras. The examples I gave come from my classification theorem in infinite dimension. I also presented my results on the cohomology of the maximal nilpotent subalgebra of the Virasoro and affine Kac-Moody algebras with coefficients in the adjoint representation, pointing out the basic differences between finite and infinite dimensional cases. For these algebras I described a versal deformation as well, using Massey operations and obstruction theory.

J.R. GOMEZ-MARTIN: Characterization of filiform Lie algebras which are derived from another Lie algebra

We give a neccesary and sufficient condition on the Maurer-Cartan structure constants relative to a given basis of a filiform Lie algebra L for the fact that L is the derived algebra of a solvable Lie algebra M.

Moreover, we prove that in this case the dimension of the filiform Lie algebra L can be of exactly one dimension less than M.

M. GOZE: On the variety of nilpotent Lie algebras

We present a new tool for the local study of the variety of complex Lie algebras based on the theory of infinitesimals. We compare this notion (called *perturbation*) to the classical ones: *deformations* and *contractions*. This concept of perturbation permits to understand (or solve) the "duality" between deformations and contractions. It also permits to prove that the obstructions of the classical deformations can be interpreted by a finite number of conditions (and we solve these conditions).

The classification of 7-dimensional nilpotent Lie algebras is obtained by using characteristic sequences as invariants. These invariants are well suited for the study of the contractions and perturbations. This permits to determine some irreducible algebraic components of the variety of nilpotent Lie algebras and we prove Vergne's conjecture: "The variety of nilpotent Lie algebras is reducible for $n \geq 7$."

YU.B. HAKIMJANOV: The variety of nilpotent Lie algebra laws

Let N_n be the variety of n-dimensional nilpotent complex Lie algebra laws. For $n \geq 12$, two irreducible components in the variety N_n are described. The characteristically nilpotent filiform Lie algebras are studied.

J. HELMSTETTER: Hausdorff series and related problems of projections in enveloping algebras

The main purpose is to calculate the coefficient of each monomial $a_{i_1}^{q_1}a_{i_2}^{q_2}......a_{i_n}^{q_n}$ in the Hausdorff series log((exp a_1) (exp a_2)...(exp a_m)); here $a_1, a_2, ..., a_m$ are taken in a Lie algebra A and the series is calculated in its enveloping algebra UA. This leads to the problem of studying the projection of UA onto A along the subspace spanned by the powers b^p, where $b \in A$ and p is an integer $\neq 1$. The first results of L. Solomon about this projection are revisited.

O.H. KEGEL: A problem on "factorized" Lie algebras

Let L be a Lie algebra with subalgebras A and B such that L = A + B. To what extent does the structure of A and B influence that of L?

I reported on recent results of Petravchuk and of Panjukov-Zsmanovic. Parallels in Group theory are pointed out.

E.I. KHUKHRO: Almost fixed-point-free automorphisms

G. Higman (1956) proved that if a Lie ring admits an automorphism of prime order p which has no non-trivial fixed elements, then it is nilpotent of class $\leq h(p)$. Later Kreknin and Kostrikin (1963) provided a new proof giving an explicite upper bound for h(p) and Kreknin (1963) also proved the solubility of a Lie ring with a fixed-point-free automorphism of any finite order.

We generalize Higman's theorem by proving the following

THEOREM. If a Lie ring (Lie algebra) $\mathfrak{L}$ satifying $p\mathfrak{L} = \mathfrak{L}$ admits an automorphism φ of prime order p with exactly $m < \infty$ fixed elements (with $\dim C_{\mathfrak{L}}(\varphi) = m < \infty$), then it contains a subring (subalgebra) of (p,m)-bounded index (codimension) which is nilpotent of degree $\leq g(p)$, where g(p) depends only on p.

LE NGOC CHUYEN: Lie algebras and involutive functions

Deep relations between Hamilton systems and algebraic geometry, Lie algebras and Lie groups are discovered in many new results: in this problem V.I. Arnol'd constructed the Euler equation of the geodetic flow in terms of Kirillov's Hamilton structure on the orbits of the coadjoint representation of the Lie group SO(3). This concept is developed by P. Lax for Korteweg - De Vries type equations. Lax's representation with spectral parameters is received by S.P. Novikov. By the displacement method, S.P. Manakov found the first integral of the Euler equation on SO(n). This method was developed by A.X. Misenko and A.T. Fomenko for arbitary semi-simple Lie algebra.

Completely involutive sets of polynomial functions for algebras of the type $G \otimes A$, where G is a Lie algebra and A is a Frobenius algebra are constructed.

L. MAGNIN: Verification of the Riemann hypothesis for 7-dimensional nilpotent Lie algebras

The zeta function for a finite dimensional nilpotent Lie algebra has been introduced by Deninger and Singhof (Bull. Soc. Math. Fr. 116, 1988, 3-14) in the form dictated by Deligne's definition in the L-adic cohomology. For 7-dimensional nilpotent Lie algebras without zero roots, the following two types of root systems can occur: Either there exists only one algebra or there is a continous one-parameter family and some limit points corresponding to the root system. We investigate the analogue of the Riemann hypothesis in the Weil conjectures, which asserts that the various factors of the zeta function are relatively prime. We are able to verify the Riemann hypothesis for the first type and for the continuous series of the second type except for some singular values. The limit points may or may not satisfy the hypothesis. We also discuss some higher dimensional examples. The verification relies on the computer-calculation of the whole trivial and adjoint cohomology of 7-dimensional nilpotent Lie algebras given in L. Magnin: "Cohomology tables for nilpotent 7-dimensional Lie algebras." Preprint, Univ. Dijon, 1991.

PHAM HYU TIEP: Irreducible orthogonal decompositions of complex simple Lie algebras and associated Euclidian lattices

Let L be a simple complex Lie algebra. An *orthogonal decomposition (OD)* of L is a decomposition $L = \bigoplus_j H_j$ of L into the direct sum of Cartan subalgebras H_j which are pairwise orthogonal with respect to the Killing form.

CONJECTURE: Lie algebras of type A_n (n+1 is non-primary) and C_n ($n \neq 2^n$) have no OD.

An OD is called *irreducible (IOD)* if the group $Aut_{OD}(L) = \{\varphi \in Aut(L) : \forall\, i\ \exists\, j\ \varphi(H_i) = H_j\}$ acts absolutely irreducibly on L.

THEOREM 1: A Lie algebra L of type A_n admits IOD iff $n + 1$ is primary, i.e. $n = p^m - 1$.

THEOREM 2: A Lie algebra L of B_n admits IOD iff $n = [\frac{p^m - 1}{2}]$ for some prime power p^m.

A.A. PREMET: The generalization of Wilson's theorem on Cartan subalgebras of simple Lie algebras

Let g be a finite-dimensional simple Lie algebra over an algebraically closed field k of characteristic p > 0, h a Cartan subalgebra in g, $\overline{h}$ the p-closure of h in Der(g) and $\overline{g} = \overline{h} + \mathrm{ad}\, g$. Let T be the unique maximal torus in $\overline{h}$ and Γ the root system associated with T. Define $\overline{g}(\alpha,\beta) = \overline{h} \oplus \sum_{i,j \in GF(p)} \overline{g}_{i\alpha+j\beta}$, where (α,β) is a pair of roots such that dim $[GF(p)\alpha + GF(p)\beta] = 2$ and $\overline{g}_\gamma$ is the root space corresponding to $\gamma \in \Gamma$. We shall say that h is a *triangulable subalgebra* if ad h can be represented by upper triangular matrices.

THEOREM: (i) If char(k) > 5, then h is a triangulable subalgebra.

(ii) If char(k) = 5 and h is nontriangulable, than there exist a pair $(\alpha,\beta) \in \Gamma^2$ such that dim $[GF(5)\alpha + GF(5)\beta] = 2$ and a maximal ideal $\overline{I}(\alpha,\beta) \subset \overline{g}(\alpha,\beta)$ such that the quotient algebra $\overline{g}(\alpha,\beta)/\overline{I}(\alpha,\beta)$ is isomorphic to the Melikyan algebra $\mathfrak{L}(1,1)$ of dimension 125.

(iii) $\mathfrak{L}(1,1)$ contains nontriangulable Cartan subalgebras of maximal toral rank. They are conjugate under the group of automorphism of $\mathfrak{L}(1,1)$.

P. REVOY: Lie algebras with invariant scalar products

It is well known that simple or abelian Lie algebras have an invariant scalar product. We may also construct direct products, with orthogonal sums, of such algebras. As $I^\perp$ is an ideal for every ideal I, every algebra can be split as a direct product of mutually orthogonal indecomposable ideals. Such indecomposables can be described by means of the following construction. Let I be a minimal ideal of A. Then I is totally isotropic (i.e. $I \subset I^\perp$), $I^\perp$ is a maximal ideal and we have the following two short exact sequences:

$$(1) \quad 0 \to I \to I^\perp \to I^\perp/I \to 0 \quad \text{central extension}$$
$$\qquad\qquad\qquad\qquad\qquad \| $$
$$\qquad\qquad\qquad\qquad\qquad W$$
$$(2) \quad 0 \to I^\perp \to A \to A/I^\perp \to 0 \quad \text{semidirect product}$$

Since $A/I^\perp$ is simple, (2) splits and W is a "reduction" of A. Consequently, A is called a *double extension* of W by an antisymmetric derivation (cf. A. Medina and Ph. Revoy, Ann. Sc. ENS, Paris 1985).

We present some results concerning A-modules equipped with an invariant scalar product and also the set of all invariant bilinear forms on A. Using ideas of M. Bordemann, we can show that there are only "few" alternating invariant forms and that this set is a ring which under the assumption D(A) ⊃ Z(A) is a finite product of local "almost commutative" rings, reflecting the decomposition of A as a product of indecomposables. We also give examples of neither solvable nor semisimple algebras with such an invariant space structure.

L.J. SANTHAROUBANE: Kac-Moody cohomological resolutions for nilpotent Lie algebras

For any nilpotent Lie algebra $\mathbf{g}$ there is a unique Kac-Moody Lie algebra L(A) such that we have the exact sequence

$$(\xi): \ 0 \to \mathbf{a} \to L_+(A) \to \mathbf{g} \to 0,$$

where $L_+(A)$ is the positive part of L(A) and $\mathbf{a}$ an ideal of $L_+(A)$. One can view (ξ) as a 2-resolution of $\mathbf{g}$. Starting from a cocycle c of the relative cohomology $H^2(L_+(A), \mathbf{g}; M)$, one can extend (ξ) to a 3-resolution of $\mathbf{g}$:

$$(\xi'): \ 0 \to M \to \mathbf{m}_c \to L_+(A) \to \mathbf{g} \to 0,$$

where $\mathbf{m}_c$ is a Lie algebra on which $L_+(A)$ acts. In order to recover c from (ξ'), one uses concepts from differential geometry like connection, curvature, structure equation and Bianchi identities. Finally, to (ξ) one can associate Chern classes and Chern-Simmons classes which form a subring of $\coprod_{n\geq 0} H^{2n}(\mathbf{g}, \mathbb{C})$ and $\coprod_{n\geq 0} H^{2n+1}(\mathbf{g}, \mathbb{C})$, respectively.

C. SEELEY: A component of non-filiform nilpotent Lie algebras

Let N^8 denote the variety of 8-dimensional nilpotent Lie algebras over $\mathbb{C}$. We consider the subvariety $\mathcal{G} \subset N^8$ containing the Lie algebra structures L_α defined as follows:

L_α has a basis $\{e_1, e_2, e_3, f_1, f_2, f_3, g_1, g_2\}$ with products given by $[e_i, e_j] = \sum_{k=1}^{3} \alpha_{ij}^k f_k$ such that $\alpha_{12}^3 + \alpha_{23}^1 = 0 = \alpha_{12}^3 + \alpha_{31}^2$, $\alpha_{ij}^k = -\alpha_{ji}^k$ and $[e_1, f_1] = g_1$, $[e_2, f_2] = g_2$, $[e_3, f_3] = g_1 + g_2$.

It is shown that there is an open set of (α)'s for which the isomorphism class of L_α intersects $\mathcal{G}$ in a 3-dimensional space. $\mathcal{G}$ has dimension 7, so there is a 4-parameter family of isomorphism classes in a neighborhood of L_α. Computation of the derivation algebra of L_α shows that generically the isomorphism class of L_α has dimension 51 in N^8. Thus locally there is an at most 55-dimensional component in N^8. The two filiform components are 55-dimensional, so that the $\mathcal{G}$-component is distinct from these.

H. STRADE: A survey on the classification of simple modular Lie algebras + Methods in the classification theory of simple modular Lie algebras

We investigate finite dimensional simple Lie algebras over an algebraically closed field of characteristic $p > 7$. There are two big classes of these known. The *classical* Lie algebras are obtained by a Chevalley construction from the finite dimensional simple Lie algebras over $\mathbb{C}$, and the *Cartan type* Lie algebras are constructed by a suitable reduction mod p from the infinite dimensional Lie algebras over $\mathbb{C}$ arising in the theory of pseudo-groups due to Cartan. We announce a proof of the following generalization of the Kostrikin-Shafarevich Conjecture:

THEOREM: Let L be a finite dimensional simple Lie algebra over an algebraically closed field of characteristic $p > 7$. Then L is classical or of Cartan type.

We indicate some of the ideas of the proof, as the consideration of p-envelopes, switching of tori, sections, Lie-type theorems and the representation theory of some Cartan type Lie algebras.

GR. TSAGAS: Classification of nilpotent Lie algebras of dimension 8

Let g be a nilpotent Lie algebra of dimension 8 over a field F of characteristic 0. We denote by g_0 the maximal abelian ideal of g. It is known that dim $g_0 = 4,5,6,7$. Therefore to classify the nilpotent Lie algebras of dimension 8, we must consider each case seperately. If dim $g_0 = 7$, we have four nilpotent Lie algebras of dimension 8. If dim $g_0 = 6$, we have determined 231 nilpotent Lie algebras of dimension 8.

Berichterstattung: Jörg Feldvoss

Tagungsteilnehmer

Prof.Dr. Jose Maria Ancochea-Bermudez
Facultad de Matematicas
Dpto. Geometria y Topologia
Universidad Complutense de Madrid

E-28040 Madrid

Dr. Jörg Feldvoss
Mathematisches Seminar
Universität Hamburg
Bundesstr. 55

2000 Hamburg 13

Prof.Dr. Yuri Bahturin
Dept. of Mathematics
Chair of Algebra
Moscow State University
Mehmat

119899 Moscow
USSR

Prof.Dr. Alice Fialowski
Villanyi ut. 103

H-1118 Budapest

Dr. Martin Bordemann
Fakultät für Physik
Universität Freiburg
Hermann-Herder-Str. 3

7800 Freiburg

Prof.Dr. Jose Ramon Gomez-Martin
Departamento de Matematica Aplicada
Facultad de Informatica y
Estadistica
Virgen de Africa 7

E-41011 Sevilla

Prof.Dr. Roger Carles
100, allee de la Vervoliere

F-86000 Poitiers

Prof.Dr. Michel Goze
Mathematiques
Universite de Haute Alsace
4, rue des Freres Lumiere

F-68093 Mulhouse Cedex

Prof.Dr. Rolf Farnsteiner
Dept. of Mathematics
University of Wisconsin-Milwaukee
P.O. Box 413

Milwaukee , WI 53201
USA

Prof.Dr. Yousoupdjan Hakimjanov
1-Kutuzova 25

700057 Tashkent - 57
USSR

Prof.Dr. Jacques Helmstetter
Mathematiques
Universite de Grenoble I
Institut Fourier
Boite Postale 74

F-38402 Saint Martin d'Heres Cedex

Prof.Dr. Louis Magnin
Laboratoire de
Physique - Mathematique
Universite de Dijon
B. P. 138

F-21004 Dijon

Prof.Dr. Otto H. Kegel
Mathematisches Institut
Universität Freiburg
Albertstr. 23b

7800 Freiburg

Prof.Dr. Pham Huu Tiep
Dept. of Mathematics
Moscow State University

119899 Moscow
USSR

Prof.Dr. Eugene I. Khukhro
c/o Prof. Kegel
Mathematisches Institut
Universität Freiburg
Albertstr. 23b

7800 Freiburg

Prof.Dr. Aleksander Premet
Institute of Mathematics
Academy of Sciences BSSR
ul. Surganova 11

Minsk 220604
USSR

Prof.Dr. Apostolos Kobotis
Dept. of Mathematics
School of Technology
University of Thessaloniki

Thessaloniki 54 006
GREECE

Prof.Dr. Philippe Revoy
Departement de Mathematiques
Universite de Montpellier II
Place Eugene Bataillon

F-34060 Montpellier Cedex 5

Dr. Le Ngoc Chuyen
Institute of Mathematics
VIEN TOAN HOC
P. O. Box 631, Bo Ho

10000 Hanoi
VIETNAM

Prof.Dr. Louis Santharoubane
Mathematiques, Batiment 425
Universite de Paris Sud (Paris XI)
Centre d'Orsay

F-91405 Orsay Cedex

Prof.Dr. Craig D. Seeley
Mathematics Research Section
IAS
Australian National University
GPO Box 4

Canberra ACT 2601
Australia

Prof.Dr. Helmut Strade
Mathematisches Seminar
Universität Hamburg
Bundesstr. 55

2000 Hamburg 13

Prof.Dr. Grigorios Tsagas
Department of Mathematics
Aristoteles University of
Thessaloniki

54006 Thessaloniki
GREECE