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Mathematisches Forschungsinstitut Oberwolfach

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Group Actions on Manifolds
22.2.-28.2.1998

The present meeting is the latest of a series of conferences on group actions. Starting from the 1967 meeting on Transformation Groups at Tulane, there have been similar conferences in the last three decades under perhaps slightly different headings such as "Transformation Groups" or "Group Actions on Manifolds", but always within the same theme. For example, at Oberwolfach in the 80's there was a meeting organized by tom Dieck, Hanspeter Kraft, and Ted Petrie on "Algebraic Group Actions".

Some 26 lectures were delivered on topics of current interest: differentiable and topological group actions, geometric structures on manifolds, symplectic, algebraic and holomorphic actions. Clearly progress has been made on many fronts. For example, surgery theory has bypassed the formidable restriction on "Gap Hypothesis" and has made effective use of control topology techniques as in the talks by Connolly, Schultz, Pawałowski, and Pedersen. In addition there is also the renewed interest in the Seifert manifold construction which is evident in the work of F. Raymond, K.B. Lee, P. Igodt, W. Malfait, P. Mazaud, and others.

Sören Illman
Ronnie Lee
Frank Raymond

(Organizers of the conference)

The following abstracts are in chronological order.

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Seifert fiberings
(Frank Raymond)

Seifert fiberings are a generalization of the classical Seifert 3-dimensional fiberings $f : M^3 \to B$, B a surface, where $f^{-1}(b) = S^1$, for every $b \in B$. Locally f is the orbit mapping

$$f^{-1}(N(b)) = (S^1, S^1 \times_{\mathbb{Z}_n} D^2) \to N(b),$$

where $N(b)$ is a disk neighborhood of b. The generalization replaces S^1 with a connected Lie group G modulo a lattice Γ in G, (i.e., $S^1 = \mathbb{R}/\mathbb{Z} \leftrightarrow G/\Gamma$). $\pi_1(M)$ is replaced by a discrete group π acting properly on a principal G-bundle P over a space W. The group π normalizes the left translational action $\ell(G)$ on P, and contains Γ as a normal subgroup. There is induced a Q action ($Q = \pi/\Gamma$) on W which we assume to be proper. These assumptions imply that the projection $P \to W$ defines a map $f : P/\pi \to W/Q$. The G fibers of P descend to "fibers" of the map f. Each fiber $f^{-1}(b)$ is the quotient of G/Γ by the action of a finite group acting affinely (in a natural way) on G/Γ. When the finite group is trivial, $f^{-1}(b)$ is called a typical fiber, otherwise a singular fiber. The entire construction is called a Seifert Construction.

Theorem (P. Conner, K.B. Lee, Y. Kamishima, D. Wigner, F. Raymond). *Let $1 \to \Gamma \to \pi \to Q \to 1$ be any extension where Γ is a lattice in a connected completely solvable Lie group G or a lattice in a semi-simple Lie group without normal compact or 3-dimensional factors. Suppose Q acts properly on a reasonable space W. Then we can construct a proper action of π on $G \times W$ which normalizes the left translations of G on $G \times W$. The induced map*

$$f : (G \times W)/\pi \to W/Q$$

is a Seifert fibering. Furthermore, the construction, called an injective Seifert Construction, satisfies a strong uniqueness and rigidity properties.

Some typical applications developed by P. Conner, K.B. Lee and F. Raymond are:

1. a) All infra-nilmanifolds are obtained this way (Γ a lattice in G, W a point, and π torsion free).

b) Any two infra-nilmanifolds with isomorphic fundamental groups are affinely diffeomorphic.

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2. *Geometric realization of group actions*: Let M be an infra G-manifold where G is completely solvable. Suppose $\psi : F \to \mathrm{Out}(\pi_1(M))$ is a homomorphism. Then there exists a lift $\tilde{\psi} : F \to \mathrm{Aff}(M)$ such that ψ is the composite $F \to \mathrm{Aff}(M) \to \mathrm{Out}(\pi_1(M))$ if and only if there is an extension $1 \to \pi_1(M) \to E \to F \to 1$, which realizes the abstract kernel ψ.

3. Restricting $\rho : Q \to \mathrm{TOP}(W)$ to more geometrically defined subgroups of $\mathrm{TOP}(W)$ still yields injective Seifert Constructions. But now $(G \times W)/\pi$ inherits some of the geometry from the subgroup of $\mathrm{TOP}(W)$. For example, if ρ defines a smooth action on a smooth W, then the construction can be done smoothly and the theorem holds in the smooth category. Various versions also exist for the Riemannian and holomorphic categories.

Affine structures on nilmanifolds
(Dietrich Burde)

In this talk we gave an overview of the questions and problems in the theory of affinely and projectively flat manifolds and affine crystallographic groups. In particular we discussed questions of J. Milnor and L. Auslander on fundamental groups of complete affine manifolds. We started with examples of affine manifolds and the question of existence of affine structures. We discussed some well known conjectures, among them the following ones:

Chern-Conjecture (1955) *The Euler characteristic of a closed affine manifold vanishes.*

Markus-Conjecture (1962) *A compact affine manifold is complete if and only if it is unimodular.*

Auslander-Conjecture (1964) *The fundamental group of a complete compact affine manifold is virtually polycyclic.*

All conjectures are open, including Gromov's question on the L_2-Betti numbers, except for a few special cases. In 1977 Milnor asked the following question:

Milnor's Question (1977) *Does every solvable Lie group G admit a complete left-invariant affine structure?*

If yes, then G/Γ with Γ discrete would be a complete affine manifold with fundamental group Γ. The question became a famous conjecture. It had a

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very interesting history with many "proofs". Finally, Benoist gave a counterexample, as well as Grunewald and myself. There are filiform nilpotent Lie groups without any left-invariant affine structure. The only known examples are of dimension 10 and 11. This implies that there are nilmanifolds with no affine or projective structures.

The counterexamples rely on the fact that a sharper version of Ado's theorem does not hold: there are nilpotent Lie algebras $\mathfrak{g}$ which do not have any faithful $\mathfrak{g}$-module of dimension $\dim \mathfrak{g} + 1$. A positive result holds for classes of filiform nilmanifolds of dimension $n \geq 12$ which corresponds to certain irreducible components of the variety of nilpotent Lie algebras. The affine structure in this case is induced by a certain extension property. Let $\mathfrak{g}$ be the Lie algebra of the filiform nilpotent Lie group G. If there is a central extension $0 \to \mathfrak{z}(\mathfrak{h}) \xrightarrow{\iota} \mathfrak{h} \xrightarrow{\pi} \mathfrak{g} \to 0$ with a higher-dimensional filiform Lie algebra $\mathfrak{h}$, then G/Γ is an affine nilmanifold. The extension exists iff there is a 2-cocycle $\omega \in H^2(\mathfrak{g}, \mathbb{C})$ which is nonzero on $\mathfrak{z}(\mathfrak{g}) \wedge \mathfrak{g}$.

Equivariant Chow rings of SL(2)-embeddings

(Lucy Moser-Jauslin)

The equivariant Chow ring was introduced by Edidin and Graham as an algebraic analogue of the equivariant cohomology ring. More speicifically, consider an algebraic smooth complex variety X endowed with an action of a reductive group G. One can study the equiviariant cohomology of X, but this can be difficult, since it is not necessarily generated by algebraically defined objects. The equivariant Chow ring is generated by classes of closed subvarieties of an algebraic variety, and it is therefore algebraically defined. In this talk, I discuss two cases in which the two rings are isomorphic: (1) smooth compact toric varieties, and (2) smooth compact $L(2, \mathbb{C})$-embeddings. I discuss some general results about Chow groups for torus actions due to M. Brion. Then for the 2 cases above, I discuss how the equivariant Chow ring can be calculated.

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Rigidity and classification of actions of semisimple Lie groups and their lattices

(Ralf Spatzier)

This is a survey of recent progress on actions of a semisimple Lie group G without compact factors and its lattices $\Gamma \subset G$ on compact manifolds. While general actions of such groups are impossible to classify, such actions seem to be rare under fairly weak additional topological, geometric or dynamical assumptions.

Low dimensions: Conjecturally, all actions of lattices in low dimensions are via finite groups. Witte for the circle, Farb-Shalen for real analytic actions on the circle, surfaces and 3-manifolds and Weinberger for actions of $SL(n, \mathbb{Z})$ on tori have partial results.

Volume preserving actions: Zimmer shows that such actions always admit measurable framings which essentially transform according to a linear representation for the ambient group. Katok-Lewis and later Benveniste construct examples which are not affine algebraic, are Gromov rigid and admit deformations.

Topological obstructions: For engaging actions, Lubotzky and Zimmer show that the image of the fundamental group of the manifold under a linear representation is s-arithmetic.

Local rigidity: Margulis and Qian show that the affine algebraic actions are locally rigid provided the linear part of the action does not split off the trivial representation as a factor. Kanai and Katok-Spatzier prove local rigidity of the projective actions of uniform lattices. Cartan actions: Goetze and Spatzier show that they are always affine algebraic.

Affine structures: Zimmer, Feres and Zeghib show that all low dimensional affine actions are affine algebraic. For complete affine connections on compact connected manifolds, Szaro shows that a non-trivial affine $SL(2, \mathbb{R})$ action cannot fix a point.

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A controlled end theorem for stratified spaces
(Frank Connolly)

Let X be a locally compact ANR, finitely filtered by closed sets

$$X = X^n \supset \cdots \supset X^0 \supset X^{-1} = \emptyset.$$

Let A be a closed set in X, which is tame (in a stratified sense). Assume that $X - A$ is a manifold-stratified space in the sense of F. Quinn (essentially this assumes that each stratum $X_k := X^k - X^{k-1}$ is a k-dimensional manifold, and that strata fit together neatly). Then A admits a stratified mapping cylinder neighbourhood in X iff a single obstruction $\gamma_*(X, A)$ vanishes. $\gamma_*(X, A) = \sum_{i=1}^{n} \gamma_i(X, A)$ and $\gamma_i(X, A)$ lies in a localization of the controlled $\tilde{K}_0$-group, $\tilde{K}_0(X^{i-1} \cup A^i, p)_{(A^i)}$, where $p : Holink(X^i, X^{i-1} \cup A^i) \to X^{i-1} \cup A^i$ is projection.

An almost immediate corollary of this result is a good theory of open regular neighbourhoods in manifold stratified spaces.

Holomorphic actions of compact Lie groups on $\mathbb{C}^n$
(Frank Kutzschebauch)

The talk was centered around the following problem:

Holomorphic Linearization Problem: Let $K \hookrightarrow \mathrm{Aut}(\mathbb{C}^n)$ be a compact subgroup of the holomorphic automorphism group of $\mathbb{C}^n$. Can one conjugate this subgroup by a single automorphism into the general linear group $GL_n(\mathbb{C}) \subset \mathrm{Aut}(\mathbb{C}^n)$, i.e., is every holomorphic action of a compact group on $\mathbb{C}^n$ linearizable?

Besides a short introduction about holomorphic automorphisms of $\mathbb{C}^n$ and an overview over the positive results concerning holomophic linearization I sketched the main idea for the proof of the following theorem which is a joint work with Harm Derksen.

Theorem. *Let K be a compact Lie group (not the trivial group). Then there exists an N such that for all $n \geq N$ there is a nonlinearizable effective action of K on $\mathbb{C}^n$ by holomorphic transformations.*

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Torus bundles over lens spaces
(Jim Davis)

This is joint work with W. Lück. Let $T \to E \xrightarrow{\pi} L$ be a torus bundle over a lens space, so that $|\pi_1 L|$ is an odd prime and π has a section. (For example, given an action of $\mathbb{Z}_p$ on $\mathbb{Z}^n$, let $E := T^n \times_{\mathbb{Z}_p} S^k$.) We classify all closed manifolds in the homotopy type of E, assuming the isomorphism conjecture of Farrell-Jones. We classify h-cobordisms with fundamental group $\Gamma = \pi_1 E$ and stable isomorphism classes of finitely generated projective $\mathbb{Z}\Gamma$-modules. We prove the stable positive curvature conjecture for manifolds with fundamental group Γ.

Polynomial structures for polycyclic-by-finite groups
(Karel Dekimpe and Paul Igodt)

A group G has a polynomial structure if it admits a faithful representation $\rho : G \to \mathrm{P}(\mathbb{R}^n)$ making it acting properly discontinuously and with compact quotient $_G\backslash\mathbb{R}^n$. $\mathrm{P}(\mathbb{R}^n)$ stands for the group of all polynomial diffeomorphisms of $\mathbb{R}^n$. We prove the following theorems:

Theorem 1 (Main Cohomology Vanishing Theorem). *Let Γ be polycyclic-by-finite and $\rho : \Gamma \to \mathrm{P}(\mathbb{R}^K)$ a polynomial structure, which is compatible to a given torsion-free filtration $\Gamma_0 = 1 \subset \Gamma_1 \subset \Gamma_2 \subset \cdots \subset \Gamma_c \subset \Gamma_{c+1} = \Gamma$ of characteristic subgroups such that $\Gamma_i/\Gamma_{i-1} \cong \mathbb{Z}^{k_i}$ $(1 \le i \le c)$ and Γ/Γ_c is finite ($K = \sum_{i=1}^{c} k_i$). Then, for every morphism $\phi : \Gamma \to \mathrm{Gl}(k, \mathbb{Z})$, and, for all $i \ge 1$,*

$$H^i_{\phi\times\rho}(\Gamma, \mathrm{P}(\mathbb{R}^K, \mathbb{R}^k)) = 0.$$

($\mathrm{P}(\mathbb{R}^K, \mathbb{R}^k)$ is the vectorspace of polynomial mappings $\mathbb{R}^K \to \mathbb{R}^k$ and becomes a Γ-module by: $\forall x \in \Gamma : \forall \lambda \in \mathrm{P}(\mathbb{R}^K, \mathbb{R}^k) :^x \lambda = \phi(x) \circ \lambda \circ \rho(x)^{-1}$.)

Corollary. *Every polycyclic-by-finite group admits a polynomial structure, taking its image in a blocked Joncquière group J.*

Definition. *For fixed n-tuples of positive integers, $\kappa = (k_1, \dots, k_n)$ and $\omega = (\omega_1, \dots, \omega_n)$, we define the (κ, ω)-weight of a monomial $x_{1,1}^{\alpha_{1,1}} \dots x_{1,k_1}^{\alpha_{1,k_1}} \dots \dots x_{n,1}^{\alpha_{n,1}} \dots x_{n,k_n}^{\alpha_{n,k_n}}$ as $\sum_{i=1}^{n} \sum_{j=1}^{k_i} \omega_i \alpha_{i,j}$. The (κ, ω)-weight of a polynomial is the maximum of the weights of its monomials.*

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Theorem 2. *Fix $\kappa = (k_1, \ldots, k_n)$ and $\omega = (\omega_1, \ldots, \omega_n)$. Let $\mathrm{P}_{\kappa,\omega}$ be the subset of J, consisting of the diffeomorphisms of $\mathbb{R}^{k_1+\cdots+k_n}$ being of the form*

$$\begin{pmatrix} x_{n,k_n} \\ \vdots \\ x_{n,1} \\ \vdots \\ x_{1,k_1} \\ \vdots \\ x_{1,1} \end{pmatrix} \mapsto \begin{pmatrix} p_n(x_{1,1}, \ldots, x_{n,k_n}) \\ p_{n-1}(x_{1,1}, \ldots x_{n-1,k_{n-1}}) \\ \vdots \\ p_2(x_{1,1}, \ldots, x_{2,k_2}) \\ p_1(x_{1,1}, \ldots, x_{1,k_1}) \end{pmatrix}$$

such that, for all i, $1 \leq i \leq n$

$$p_i(x_{1,1}, \ldots, x_{i,k_i}) = A_i \begin{pmatrix} x_{i,k_i} \\ \vdots \\ x_{i,1} \end{pmatrix} + q_i(x_{1,1}, \ldots, x_{i-1,k_{i-1}})$$

with $A_i \in \mathrm{Gl}(k_i, \mathbb{Z})$ and q_i of (κ, ω)-weight $\leq \omega_i$. Then, $\mathrm{P}_{\kappa,\omega}$ is a finite dimensional Lie-subgroup of J.

Theorem 3. *For every finitely generated subgroup Γ of a blocked Jonquière group J of type $(k_1, \ldots, k_n)$ there exist $\omega = (\omega_1, \ldots, \omega_n)$ such that Γ is contained in $\mathrm{P}_{\kappa,\omega}$. This implies that Γ is of bounded degree.*

Corollary. *Every polycyclic-by-finite group Γ admits a bounded degree polynomial structure $\rho : \Gamma \to \mathrm{P}_{\kappa,\omega}$, for some κ and ω.*

Now that it is known that polycyclic-by-finite groups do not always admit an affine structure (a problem originally posed by John Milnor in 1977 (Adv. Math.), and for which even nilpotent counter-examples have been found in the early 90's), this $\mathrm{P}_{\kappa,\omega}$-setting states the best general type positive answer so far for this problem.

We present several elements giving evidence for the fact that the groups $\mathrm{P}_{\kappa,\omega}$ might be good alternatives for the group of affine transformations.

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Group actions, genus inequalities and 4-dimensional surgery

(Dariusz Wilczynski)

A genus inequality, such as the adjunction inequality for example, provides a lower bound for the genus of an embedded surface in a 4-dimensional manifold. In this talk, we discussed certain generalized Rokhlin inequalities and related them to the topological surgery problem in dimension 4. The latter asks if the topological surgery sequence is exact for a (compact) 4-manifold with any (finitely presented) fundamental group.

Dimension theory over finite von Neumann algebras and applications

(Wolfgang Lück)

We define for arbitrary modules over a finite von Neumann algebra $\mathcal{A}$ a dimension taking values in $[0, \infty]$ which extends the classical notion of von Neumann dimension for finitely generated projective $\mathcal{A}$-modules and inherits all its useful properties such as Additivity, Cofinality and Continuity. This allows to define L^2-Betti numbers for arbitrary topological spaces with an action of a discrete group Γ extending the well-known definition for regular coverings of compact manifolds. We show for an amenable group Γ that the p-th L^2-Betti number depends only on the $\mathbb{C}\Gamma$-module given by the p-th singular homology. Using the generalized dimension function we detect elements in $G_0(\mathbb{C}\Gamma)$, provided that Γ is amenable. We investigate the class of groups for which the zero-th and first L^2-Betti numbers resp. all L^2-Betti numbers vanish. We study L^2-Euler characteristics and introduce for a discrete group Γ its Burnside group extending the classical notions of Burnside ring and Burnside ring congruences for finite Γ.

Invariant measure and the Euler characteristic of projectively flat manifolds

(Kyeonghee Jo and Hyuk Kim)

Let M be a projectively flat manifold. Then it has a developing pair which is an equivariant map from its universal covering with fundamental group action into $\mathbb{R}P^n$ with the corresponding holonomy action. Suppose

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that there is a probability measure λ on $\mathbb{R}P^n$ which is invariant under the holonomy action. Then we can show that a measure μ is induced on M from λ by the holonomy invariance of λ, and the following theorem holds:

Theorem. *Let M be an even dimensional closed projectively flat manifold and λ be a holonomy invariant finitely additive probability Borel measure on $\mathbb{R}P^n$. Then the Euler characteristic of M is equal to $\mu(M)$, where μ is the measure on M induced from λ.*

Our study has been motivated from the effort to resolve Chern's conjecture: "Closed affinely flat manifolds have vanishing Euler characteristic." As a corollary of the theorem we show that the conjecture is true if the holonomy group of the affinily flat manifold has an invariant probability measure. This generalizes the earlier results for the amenable case and the radiant case.

Fixed point sets of smooth actions of finite Oliver groups on spheres

(Krzysztof Pawałowski, joint work with Masaharu Morimoto)

A finite group G is called an Oliver group if there is no sequence of normal subgroups $P \subseteq H \subseteq G$ such that P is a p-group, H/P is cyclic, and G/H is a q-group for two primes p and q. A finite nilpotent group is an Oliver group if and only if G has three or more noncyclic Sylow subgroups. Every finite nonsolvable (in particular, nontrivial perfect) group is an Oliver group. For a finite group G, let $\mathcal{P}(G)$ denote the family of all prime power order subgroups of G.

Theorem A. *Let G be a finite nilpotent Oliver group. Let M be a closed smooth manifold. Then there exists a smooth action of G on a sphere S such that $S^G = M$ and $S^P \neq M$ for each $P \in \mathcal{P}(G)$ if and only if M is stably complex, if and only if there exists a smooth action of G on a disk D such that $D^G = M$.*

Theorem B. *Let G be a finite nontrivial perfect group. Let M be a closed smooth manifold. Then there exists a smooth action of G on a sphere S such that $S^G = M$ and $S^P \neq M$ for each $P \in \mathcal{P}(G)$ if and only if there exists a smooth action of G on a disk D such that $D^G = M$.*

The question of which smooth manifolds occur as the G-fixed point sets for smooth actions of G on disks has been answered completely by Bob Oliver

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[Topology **35** (1996), pp. 583–615] in the case where G is a finite group not of prime power order. In the case where G is of prime power order, the answer goes back to Lowell Jones [Ann. Math. **94** (1971), pp. 52–68].

Homeomorphic representations

(Erik Pedersen, joint work with Ian Hambleton)

Let $G := C_n$ be a cyclic group of order n and consider 2 G-representations written as $V_1 \oplus W_1$ and $V_2 \oplus W_2$ that are equivariantly homeomorphic. It is elementary that we then have $V_1 \oplus W_1 \sim_+ V_2 \oplus W_1$, and the problem can be translated to a problem in bounded surgery. We do get $S(V_1)/G \simeq S(V_2)/G$ so this determines an element $\alpha \in J(S(V_2)/G)$. Consider the diagram:

$$\begin{array}{ccccccc} \to & L_0^h(\mathbb{Z}G) & \to & S^h(S(V_2)/G) & \to & [S(V_2)/G, F/Top] & \to \\ & \downarrow & & \downarrow & & \downarrow & \\ \to & L^h_{|W|}(C_{W,G}(\mathbb{Z})) & \to & S^h_b((S(V_2)\times W)/G) & \to & [(S(V_2)\times W)/G, F/Top] & \to \end{array}$$

where the lower sequence is the bounded surgery exact sequence due to Ferry, Pedersen and Hambleton. This shows that if the transfer on L-groups is 0 we get a similarity. Using this technique we recover and sometimes correct all known facts on homeomorphic representations in the literature. The ultimate result we obtain is that homeomorphisms of representations of finite cyclic groups are determined by the Reidemeister Torsion.

Topological models and cohomology of Galois groups

(Alejandro Adem)

We compute the cohomology of certain Galois groups which are determined by the Witt ring of a field F of characteristic $\neq 2$. Properties and explicit computations were discussed. This is joint work with J. Minac and D. Karagueuzian.

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Multiplicity-free Hamiltonian actions and spherical varieties

(Dominique Luna)

Let G be a complex reductive group and K a maximal compact subgroup. I tried to explain the relations which exist between Hamiltonian actions of K and algebraic actions of G (in particular between multiplicity-free Hamiltonian actions and spherical varieties). I mentioned briefly the definition (and role) of wonderful varieties.

See also: *"Toute variété magnifique est sphérique"*, Transformation Groups, Vol. 1, no 4 (1996)

Manifolds with little symmetry

(Volker Puppe)

The relation - obtained from P. A. Smith theory - between the multiplicative structure of the cohomology of a manifold and the possible fixed point sets of $\mathbb{Z}/p$-actions on it can be used to show the existence of closed simply connected manifolds, which do not admit effective orientation preserving actions of finite groups. Furthermore, for a certain class of 6-dimensional manifolds (i.e. closed simply connected spin-manifolds with $H^3(-) = 0$) it is shown that the subset consisting of those manifolds which admit effective $\mathbb{Z}/p$-actions for infinitely many primes p, has density zero (with respect to a certain density function). Similar arguments can be applied to prove that 'most' $\mathbb{Z}_2$-cohomology types of closed 3-dimensional manifolds are represented by manifolds, which do not admit any non trivial involution.

The further aim is to get analogous results for higher dimensional manifolds. One might expect that the following holds. Let $\bar{\mathcal{M}}^{2k}$ be the class of rational cohomology types of closed simply connected 2k-dimensional manifolds, such that $H^{even}(-;\mathbb{Q})$, as an algebra, is generated by $H^2(-;\mathbb{Q})$. Then for 'most' elements in $\bar{\mathcal{M}}^{2k}$ a representing manifold does admit an effective $\mathbb{Z}/p$-action for at most finitely many primes p; in particular, it does not admit an effective S^1-action. Certain steps in this direction are done.

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Expanding maps on homogeneous infra-nilmanifolds

(HyunKoo Lee and Kyung Bai Lee)

Let M be a compact differentiable manifold. A C^1-endomorphism $f : M \to M$ is expanding if for some Riemannian metric on M there exist $c > 0$, $\lambda > 1$ such that $\|Df^m v\| \geq c\lambda^m \|v\|$ for all $v \in TM$ and all integers $m > 0$. It is known [Gromov] that any expanding endomorphism of an arbitrary compact manifold is topologically conjugate to an expanding endomorphism of an infranilmanifold.

We are concerned with the converse. It is known that every flat manifold admits an expanding endomorphism. There are counter examples of nilpotent Lie algebras which do not admit an expanding endomorphism, showing that the existence of expanding endomorphisms does not hold for general (infra)nilmanifolds.

We say that $\mathfrak{L}$ is a *free Lie algebra of rank* r if there exist r elements $X_1, X_2, \cdots, X_r \in \mathfrak{L}$ which generate $\mathfrak{L}$ as algebra, and which enjoy the following universal mapping property: any function from the set $\{X_1, X_2, \cdots, X_r\}$ to any algebra $\mathfrak{G}$ extends to a unique algebra homomorphism $\mathfrak{L} \to \mathfrak{G}$.

Define the ideal $\mathfrak{L}^i$, $i = 1, 2, \cdots$ of $\mathfrak{L}$ as follows:

$$\mathfrak{L}^1 = \mathfrak{L}, \qquad \mathfrak{L}^{i+1} = [\mathfrak{L}^i, \mathfrak{L}].$$

An ideal $\mathfrak{J}$ of $\mathfrak{L}$ is *homogeneous* if the vector space $\mathfrak{J}$ is isomorphic to the direct sum of $(\mathfrak{J} \cap \mathfrak{L}^i)/(\mathfrak{J} \cap \mathfrak{L}^{i+1})$, $i = 1, 2, \cdots$. We shall say that a *Lie algebra* $\mathfrak{G}$ *is homogeneous* if $\mathfrak{G}$ is isomorphic to $\mathfrak{L}/\mathfrak{J}$ with $\mathfrak{L}$ free and $\mathfrak{J}$ homogeneous. A nilpotent Lie algebra is called *free* if $\mathfrak{J} = \mathfrak{L}^r$ for some r; this is, it is of the form $\mathfrak{L}/\mathfrak{L}^r$. A nilpotent Lie group is homogeneous if its Lie algebra is homogeneous.

An infra-nilmanifold is the quotient of a connected, simply connected nilpotent Lie group G by a discrete cocompact subgroup π of $G \times C$, where C is a maximal compact subgroup of $\mathrm{Aut}(G)$. It is known that a Riemannian manifold M is almost flat if and only if it is homeomorphic to an infra-nilmanifold.

An infra-nilmanifold $\pi \backslash G$ is *of homogeneous type* if G is of homogeneous type. It is known that: *any homogeneous Lie algebra admits expanding automorphisms.* We generalize this to infra-homogeneous spaces.

Theorem. *(1) Every 2-step infra-nilmanifold admits an expanding map.*

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(2) Every infra-nilmanifold of homogeneous type, with freely generated lattice, whose holonomy group has prime order greater than the nilpotency, admits an expanding map.

Spin(4)-actions on 8-dimensional manifolds
(Philippe Mazaud)

We study smooth, effective $Spin(4)$-actions on closed, orientable, 8-dimensional manifolds. We further assume that the principal orbits are free. $spin(4)$-manifolds make-up a rich class of spaces, that are parametrized by orbit data over a surface.

Equivariantly, one distinguishes between three general situations. (1) The action is principal; these bundles are trivial, so that the interesting situations are the following two. (2) "Seifert-like manifolds" over closed surfaces: the action is free away from exceptional orbits ($E \neq \emptyset$). (3) comprises all the cases where singular orbits are present. The quotient space M^* is a surface with boundary. The singular orbits occur over this boundary. The isotropy structure determines a partition of each connected component of $\mathrm{Bd}(M^*)$ into vertices and edges, and must satisfy fairly strict local conditions. The interior of M^* consists entirely of free orbits, and possibly a finite number of E orbits.

We obtain the following equivariant classification of $Spin(4)$-actions: if $Spin(4)$ acts on M according to the conditions given above, and $E = \emptyset$, then, up to equivalence, the action is completely characterized by: (a) the homeomorphism type of the orbit space M^*, (b) the isotropy weights, and (c) An element $o \in \mathbb{Z}_2^b$, where b is the number of boundary components of M^*. Given some fixed ordering of the components of the boundary, to the j^{th} boundary circle is associated an element in $\mathbb{Z}_2$, and this is the j^{th} coordinate of o.

The invariant o is directly interpreted as an obstruction to the "uniformization" of a global section to the action (section that is shown to always exists). We discuss the question pertaining to whether the invariant also encodes topological information, or whether it is strictly equivariant.

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Catesian products of 3-manifolds
(Slawomir Kwasik)

The following problem of S. Ulam was discussed

Problem. *Let A and B be topological spaces such that* $A^2 := A \times A$ *and* $B^2 := B \times B$ *are homeomorphic. Are A and B homeomorphic?*

The case of 3-manifolds was considered. For closed, connected irreducible 3-manifolds which are geometric the equation $M^n = N^n$ for some $n \geq 2$ was solved completely. It turns out that the above equation in general can have many solutions, however all these solutions can be classified.

Homologically trivial group actions on 4-manifolds
(Allan Edmonds)

This talk outlined a proof of the following theorem: If a finite group G acts pseudofreely, locally linearly, and homologically trivially on a closed, simply connected 4-manifold X, with $b_2(X) \geq 3$, then G is cyclic and the action is semifree.

This contrasts with the rich families of symmetries of smaller 4-manifolds, such as S^4, $S^2 \times S^2$, and $\mathbb{C}P^2$.

The proof involves group cohomology and the integral spectral sequence of the Borel fibering $X \to X_G \to B_G$. One first deals with special cases where G is an elementary abelian p-group or a nonabelian metacyclic group. The argument then proceeds by induction on the order of the group.

Circle actions in symplectic geometry and Lusternik-Schnirelmann category
(John Oprea)

Recently, the methods of homotopy theory have found use in symplectic geometry. In particular, the theory of Hamiltonian actions has proven especially amenable to this approach. Furthermore, recent work by Rudyak and Rudyak-Oprea shows that homotopy theory also has a place in studying more analytic symplectic problems such as the Arnold Conjecture. This talk

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discusses the relation of homotopy methods to Hamiltonian actions and the Arnold Conjecture. More specifically, the following results are discussed in this framework.

Theorem (Lupton-Oprea). *For a symplectic manifold* (M^{2n}, ω), *if* $c_1(M) = r \cdot \omega$ *with* $r > 0$, *then every symplectic* S^1*-action on* M *is Hamiltonian.*

Theorem (Rudyak-Oprea). *For a symplectic manifold* (M^{2n}, ω), *if* $\omega|_{\pi_2(M)} = 0$, *then* $\mathrm{cat}(M) = \dim(M)$, *where* $\mathrm{cat}(M)$ *denotes the Lusternik- Schnirelmann category of* M.

Together with powerful results of Rudyak, the latter theorem proves the original conjecture of Arnold that the number of fixed points of a Hamiltonian diffeomorphism is at least as great as the number of critical points of any smooth function on M for manifolds satisfying $\omega|_{\pi_2(M)} = 0 = c_1(M)|_{\pi_2(M)}$ (i.e. Floer's original hypothesis). The second theorem also shows that manifolds satisfying $\omega|_{\pi_2(M)} = 0$ *cannot* give positive solutions to the

Contractible Orbit Problem (McDuff-Salamon). *Does there exist a free symplectic circle action on a symplectic manifold* M *such that all orbits are contractible in* M?

Thus, positive solutions cannot be obtained from Hamiltonian actions (e.g. M simply connected), since such actions have fixed points or from non-simply connected manifolds with $\omega|_{\pi_2(M)} = 0$. In fact, a positive solution cannot be obtained for any symplectic manifold having $\mathrm{cat}(M) = \dim(M)$.

Normal surfaces and G-equivariant minimal Seifert surfaces of links

(Jeffrey L. Tollefson)

Let L be an oriented polyhedral link in a homology 3-sphere Σ where $M_L = \Sigma - \mathrm{int}(N)$ has a triangulation $\mathcal{T}$. Suppose that G is a finite group of simplicial homeomorphisms of M_L such that the set $\mathrm{Fix}(G) = \{x | g(x) = x \text{ for some nontrivial } g \in G\}$ is a subcomplex. One can find a least weight, taut normal surface S such that $[S]$ represents the homology class of a Seifert surface for L.

Theorem. *Let* $\alpha \in H_2(M_L, \partial M_L; \mathbb{Z})$ *be a homology class such that* $g(\alpha) = \pm\alpha$ *for all* $g \in G$. *If* S *is a lw-taut normal surface representing* α *then every*

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intersection curve between images of S is regular and the geometric sum $\sum_{g \in G} g(S)$ is a disjoint union of lw-taut G-equivariant normal surfaces S_g such that S_g is homologous to $g(S)$.

Corollary. *Let L be an oriented link in a triangulated homology 3-sphere Σ. Let G be a finite group of simplicial homeomorphisms of Σ such that $\mathrm{fix}(G)$ is a subcomplex and for each element $g \in G$ either $g(L) = L$ or $g(L) = -L$. Then there exists an equivariant minimal Seifert surface for L.*

A link L in a homology 3-sphere Σ has *period* n if there is a PL rotation g of order n about an axis A disjoint from L which leaves the link invariant. Using the existence of equivariant minimal Seifert surfaces one can find a bound N_L on the period for any nontrivial oriented link by applying the Riemann-Hurwitz formula (as is done by A. Edmonds for knots). This gives another proof of J. Hillman's result that only trivial links can have infinitely many periods.

Stabilized fixed point neighbourhoods in 4-manifolds
(Reinhard Schultz)

A basic question about group actions is the classification of neighbourhood germs of fixed points. For orientation preserving involutions on 4-manifolds, results from the 1980s answer this question in the case of isolated fixed points, and for nonisolated fixed points recent work of S. Kwasik and myself describes the stabilized germs obtained by taking products with suitable linear representations. Analogous results and problems for actions of larger finite groups and S^1 on 4-manifolds are considered in the present work. In particular, one has the following results:

Theorem 1. *Given a semifree S^1-action on a 4-manifold M, its product with the standard S^1-action on $\mathbb{C}$ is locally linear.*

Theorem 2. *Given an isolated fixed point of an S^1-action on a 4-manifold such that the nearly isotropy subgroups are $\{1\}$, $\mathbb{Z}/2$ and S^1, for each odd integer $m > 1$, the neighbourhood germ for the restriction of the action to $\mathbb{Z}/m$ has a weakly conelike structure (i.e. the formal collaring obstruction on $\widetilde{K}_0(\mathbb{Z}[\mathbb{Z}/m])$ is zero).*

The proofs rely on the classification of neighbourhood germs in homotopy stratified sets (in Quinn's sense) due to Hughes, Taylor, Williams and Weinberger. The preceding is joint work with Slawomir Kwasik.

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The classification of radiant affine 3-manifolds

(Suhyoung Choi)

This talk has two parts:

1. We try to understand the geometric properties of n-manifolds with geometric structure modeled on $(\mathbb{R}P^n, PGL(n+1,\mathbb{R}))$, i.e. real projective n-manifolds. Given a real projective n-manifold M, we show that the failure of $(n-1)$-convexity of M implies an existence of a particular type of real projective submanifolds in M. We give a decomposition of M into simpler real projective manifolds, some of which are $(n-1)$-convex and others are affine. We get a consequence for Lie-groups with left-invariant affine structure.

2. A topologist's definition of an affine manifold is a manifold with an atlas of charts to the affine space with transition functions which are affine maps. A radiant affine manifold is an affine manifold with holonomy consisting of affine transformations fixing a common point. We decompose an orientable closed radiant affine 3-manifold into radiant 2-convex affine manifolds and radiant concave affine 3-manifolds along mutually disjoint totally geodesic tori or Klein bottles using the $(n-1)$-decomposition of real projective n-manifolds developed earlier. Then we decompose a 2-convex radiant affine manifold into convex radiant affine manifolds and concave-cone affine manifolds. To do this, we will show the existence of certain nice geometric objects in the projective completion of holonomy cover. The equivariance and local finiteness property of the collection of such objects will show that their union covers a compact submanifold of codimension zero, the complement of which is convex. Finally, using the results of Barbot, we will show that a closed radiant affine 3-manifold admits a total cross section, confirming a conjecture of Carrière, and hence every radiant affine 3-manifold is homeomorphic to a Seifert fibred space with trivial Euler number, or a virtual bundle over a circle with fiber homeomorphic to a torus.

Symmetry of model aspherical manifolds

(Wim Malfait)

Model aspherical manifolds are those aspherical manifolds M arising from a Seifert fiber space construction. We think of symmetry of such a manifold M in terms of finite groups of fiber preserving homeomorphisms acting effectively on M. In [3], we describe a subclass of model aspherical manifolds

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M for which the realization of a finite abstract kernel $\psi : G \to \mathrm{Out}(\pi_1(M))$, as a group of fiber preserving homeomorphisms acting effectively on M, is equivalent to realizing ψ as the abstract kernel of an admissible group extension of $\pi_1(M)$ by G. This approach allows to convert the study of symmetry of M into a pure group-theoretical problem (partially solved in [2]).

An interesting subtopic is the study of model aspherical manifolds with no periodic maps. A theorem of Borel ([1]) states that if the fundamental group of an aspherical manifold M is centerless and $\mathrm{Out}(\pi_1(M))$ is torsion-free, then M admits no finite effective actions. In [4], we investigate to what extent the converse of this result holds for model aspherical manifolds. In particular, if there is a total lack of symmetry on a flat Riemannian manifold, on an infra-nilmanifold or on an infra-solvmanifold of type (R), then its fundamental group is centerless and there are no outer automorphisms of finite order. We pose the problem of finding examples of such manifolds with no periodic maps.

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Counterexamples of equivariant s-cobordism theorems and Lefschetz rings

(Katsuo Kawakubo)

A lot of people are concerned with a sort of equivariant s-cobordism theorems. They mainly dealt with isovariant case and finite group actions. On the other hand, we got equivariant s-cobordism theorems for any compact Lie group actions under gap hypothesis. Here we do not consider orbit space and stratification. Instead we handle G-manifolds themselves and make use of the technics of decomposition of G-manifolds which I exploited in studying $J_G(X)$. On the contrary, we get the following theorem.

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Theorem. *Let G be an arbitrary non trivial compact Lie group. Then there exists a G-s-cobordism $(W; X, Y)$ such that X is not G-homeomorphic to Y. In particular, W is not G-homeomorphic to $X \times I$.*

The second part of the talk is a joint work with the late E. Laitinen. We introduce induction and restriction homomorphisms in Lefschetz rings, and show that Frobenius reciprocity and Mackey property formulae hold. Idempotents and prime ideals of Lefschetz rings are also discussed.

Representation spheres and stably linear homotopy representations

(Gesa Ott)

For a compact Lie group G, the notion of a G–homotopy representation (given by tom Dieck and Petrie in 1982) summarizes the most important homotopy theoretical properties of the unit spheres SV of (finite-dimensional) orthogonal G-representations V: Essentially, a G–homotopy representation is a homotopy sphere X with G acting on it s. t. the fixed point set X^H of any $H \subset G$ is a homotopy sphere $S^{n(H)}$ of topological dimension $n(H)$.

In general, the dimension function $\dim_G X : H \mapsto n(H) + 1$ does not classify sufficiently the G-homotopy type of X. If X is stably linear, we describe how to get further invariants by means of equivariant K–theory: If X is stably complex linear, $K_G(CX, X)$ is a free $R(G)$–module of rank one. Using this analogon to the Bott periodicity, we define certain class functions $\lambda(X)_H : NH/H \to \mathbb{C}^*$ which help to describe the G-homotopy type sufficiently. Remarkably, if G is a p-group ($p \neq 2$), this description can be simplified (tom Dieck 1987): SW and SV are oriented equivalent iff the quotient $\lambda(V)_1/\lambda(W)_1$ is an element of $R(G)^*$. (For $p = 2$, probably the same is true.)

If G is finite, using results of Tornehave and KO_G–theory, a similar description for stably linear G-homotopy representations can be obtained.

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Relations among characteristic classes and fixed point sets

(Arthur G. Wasserman)

The first example of a relation between characteristic classes and fixed point sets of group actions is Hopf's theorem relating the zeroes of a vector field on a manifold (fixed points of an action of $\mathbb{R}$) to the Euler characteristic of the manifold. Residue theorems or localization theorems relate a global invariant of a manifold to local invariants of the fixed point sets. A more general approach to characteristic classes helps to explain such relations.

Definition. *A natural class in dimension k is a function z that assigns to each G-manifold M a cohomology class $z(M) \in H^k(M, \mathbb{Z}_2)$ such that*

a) if A is diffeomorphic to an open submanifold of B, $i : A \subset B$, then $i^*(z(B)) = z(A)$ and

b) $z(M \times \mathbb{R}) = z(M) \in H^*(M) = H^*(M \times \mathbb{R})$, i.e., natural classes are stable.

Fixed point sets of an action give rise to such classes. Let Fixed(M, H, ρ) denote the union of the components of the fixed point set having normal representation ρ. Note that the codimension of any component of Fixed(M, H, ρ) is just the dimension of ρ and hence, $D(\text{Fixed}(M, H, \rho)) \in H^k(M, \mathbb{Z}_2)$ is defined where k =dimension of ρ. I then prove a recocnition theorem for finding relations among natural classes of G-manifolds for G abelian. I illustrate the use of the theorem by exhibiting some relations among natural classes for 3-manifolds with involution. For example, $\omega_1 F_1 = F_2$ and $\omega_1^2 F_1 + F_1^3 = F_3$ where F_i denotes the Poincaré dual of the component of the fixed point set of codimension i and the ω's are the Stiefel-Whitney classes of the manifold.

Siegel modular varieties of degree two

(Steven H. Weintraub, joint work with J. W. Hoffman)

Let S_d denote Siegel space of degree d, $S_d := \{\tau | \tau$ is a d-by-d complex symmetric matrix, $\tau = X + iY$, X, Y real and Y positive definite$\}$. Let $Sp(2d, \mathbb{R})$ be the symplectic group

$$Sp(2d, \mathbb{R}) = \{M = \begin{pmatrix} A & B \\ C & D \end{pmatrix} | MJ^tM = J\},$$

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where J is the $2d$-by-$2d$ matrix $\begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$. Note that $Sp(2d, \mathbb{R})$ acts on $\mathcal{S}_d$ by

$$M(\tau) := (A\tau + B)(C\tau + D)^{-1}.$$

For an arithmetic subgroup Γ of $Sp(2d, \mathbb{R})$, set

$$M_\Gamma := \Gamma \backslash \mathcal{S}_d.$$

M_Γ is a quasi-projective variety of complex dimension $d(d+1)/2$. We let M_Γ^* denote a suitable compactification.

These varieties are natural to consider as they arise as moduli spaces of d-dimensional abelian varieties. When $d = 1$ they are Riemann surfaces (note $\mathcal{S}_1$ is the usual upper half plane) and their topology was understood in the nineteenth century. The situation for $d = 2$ is only beginning to be understood.

Let $\Gamma = \Gamma(3)$ be the principal congruence subgroup of level 3 in $Sp(4, \mathbb{R})$. Let $M_3 = \Gamma \backslash \mathcal{S}_2$, M_3^* its Igusa compactification.

Theorem. *a) $H^i(M_3^*)$ is free of rank $1, 0, 61, 0, 61, 0, 1$ for $i = 0, ..., 6$.*

b) $H^{p,q}(M_3^*) = 0$ for $p \neq q$.

c) $H^{1,1}$ is spanned by fundamental classes of boundary components and Humbert surfaces.

d) $H^i(\Gamma(3), \mathbb{Q})$ has dimension $1, 0, 21, 139, 81$ for $i = 0, ..., 4$ and is 0 for $i > 4$.

In fact, $G = PSp(4, \mathbb{F}_3)$ (the group of even automorphisms of the configuration of 27 lines on the cubic surface) acts on M_3 and M_3^*, and we can describe all of these cohomology groups as representation spaces of G.

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