MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

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The chairmen of this conference were V. Bangert (Freiburg) and U. Pinkall (TU Berlin). Besides the western European countries and the USA also the countries of eastern Europe were well represented.

The talks covered a wide field of differential geometry — the main emphasis was on the theory of surfaces and submanifolds in Riemannian resp. Euclidean geometry. The subjects included also topics from Riemannian as well as affine differential geometry.

Besides the talks the exchange of ideas in conservations and informal discussions was an important part of the success of this conference.

Abstracts:

The trapping property of totally geodesic hyperplanes in Hadamard manifolds

U. Lang

Let (X, g_0) be an n-dim. Hadamard manifold containing a totally geodesic hyperplane G. Given a riem. metric g_1 on X which is Lischitz equivalent to g_0, we are interested in the question whether there exists a complete hypersurface S in X minimizing area w. r. t. g_1 and lying within finite distance from G.

So far, most of the results relevant to this problem deal with the cases where the sectional curvature of (X, g_0) is constant or strictly negative. We focus on varying, somewhere vanishing curvature and answer the above question in the affirmative for totally geodesic hyperplanes $G \cong \mathbb{H}^{k-1} \times \mathbb{R}^{n-k}$ in $X = \mathbb{H}^k \times \mathbb{R}^{n-k}$. Further we present a partial result for all Hadamard manifolds splitting off a hyperbolic factor and discuss a new phenomenon in $\mathbb{H}^2 \times \mathbb{H}^2$.

Discrete groups of isometries of Riemannian manifolds

P. Ghanaat

Consider a discrete group Λ of isometries of a complete Riemannian manifold M^n with bounded sectional curvature $|K| \leq 1$. Fix $p \in M$ and some orthogonal frame u at p. For $\delta \leq const(n)$, we give a fairly detailed description of the action of $\Lambda_\delta = \langle \lambda \in \Lambda | dist(\lambda u, u) \leq \delta \rangle$ near p in terms of standard actions on nil-and infra-nil-manifolds, extending the classical Margulis-Lemma as well as the theorem on almost flat manifolds. When lifted to the bundle P of orthonormal frames, Λ preserves an $O(n)$-equivalent fibration of $P|_u$ by nilmanifolds, for some Λ-invariant neighborhood U of p. The subgroup Λ_δ preserves each fiber N and acts cocompactly and by left translations on N. The fibration induces a decomposition of U into infra-nilmanifolds that interpolate the orbits of Λ_δ. We give an application to discrete parabolic groups acting on Hadamard manifolds with negatively pinched sectional curvature, using a finiteness result of Bowditch and extending the description of parabolic cusps for manifolds of finite volume.

Metrics of nonpositive curvature on infinite graph-manifolds

S. Buyalo

This is a joint work with V. Kobelskii.

We consider a class $\mathfrak{M}$ of connected orientable graph-manifolds whose maximal blocks M_v are homeomorphic to $F_v \times S^1$, where F_v is a compact orientable surface with boundary and different from D^2. A criterion for infinite $M \in \mathfrak{M}$ (i. e., M with infinite graphs) to carry a complete metric of bounded nonpositive curvature ($\equiv$ to have a geometrization) with finite volume is given. Such a criterion is similar to the criterion for closed $M \in \mathfrak{M}$ to carry a non positively curved metric given in a previous work. However, on contrast to the case of closed graph-manifolds there are several new geometrical effects for infinite $M \in \mathfrak{M}$.

First, every infinite $M \in \mathfrak{M}$ admits a complete metric of bounded nonpositive curvature. Secondly, there is an effect of the volume collapse for infinite $M \in \mathfrak{M}$ carrying a geometrization of finite volume. This means the existence of a geometrization whose fiber length function $\mathfrak{L}$ decreases with an arbitrary given speed at infinity. Thirdly, for infinite $M \in \mathfrak{M}$ without geometrization of finite volume the fiber length function $\mathfrak{L}$ is never square-summable on the vertex set V of the graph Γ of M for any geometrization of M. Several results relating the existence and behaviour of geometrizations of M with Laplace operator on its graph Γ are given.

Geometric Relativization

I. Sterling

We study Martin's nonlinear model for electrodynamics. Martin's model is formally similar to the Born-Infeld type models and has its origins in the formulation of classical electrodynamics described by Souriau. Recently it has been shown that this model predicts quark-like structures.

In this model the cotangent bundle of space-time is replaced with an eight- dimensional M endowed with a neutral metric g. The metric g induces a bundle isomorphism $h : TM \mapsto T^*M$. The dynamical structure determines non-degenerate 2-vector fields Λ on M that satisfy $C(\Lambda, h(\Lambda)) = -1$ where C denotes the contraction of the the last index of Λ with the last index of $h(\Lambda)$. These equations linearize to the classical Maxwell equations along Lagrangian submanifolds.

Once an Artinian ambient metric is chosen the generalized Maxwell PDE determines a pair of totally null distributions that can be parameterized by four three- component vector fields which can be identified as electric and magnetic fields.

Using equivariant geometry (and computers) we find solutions to these PDE's and study their behavior. Integrals of these solutions would in theory correspond to particles.

Constant mean curvature foliations and 2 + 1 + 1-dynamics in General Relativity

G. Huisken

This is a joint work with S. T. Yau.

The classical (3 + 1)-space-time decomposition of Lorentzian manifolds is refined in the asymptotically flat case by constructing a unique radial constant mean curvature foliation by 2-spheres in each 3-dimensional time-slice. It is studied how this foliation moves from one time slice to the next inside the 4-manifold, and it is shown that the construction yields a consistent geometric description for the physical concepts "center of mass" and "linear momentum" for isolated systems

Harmonic Spinors and Topology

C. Bär

Klassische Hodge-deRham-Theorie liefert einen bemerkenswerten Zusammenhang zwischen Analysis und Topologie einer geschlossen Mannigfaltigkeit: die Dimension des Kernes des Laplace-Operators (auf p-Formen) ist eine topologische Invariante, die p-te Bettizahl. Es stellt sich die Frage, ob ähnliches auch für andere natürliche Operatoren richtig ist, wie etwa den Dirac-Operator. Der Atiyah-Singer-Indexsatz liefert erste Beziehungen zwischen harmonischen Spinoren und Topologie, ferner gibt es spezielle Phänomäne in Dimension 2. Andererseits zeigen wir:

Satz. *In Dimension $n \equiv 3 \mod 4$ sind harmonische Spinoren nicht topologisch obstruiert, d. h. auf jeder geschlossen Spin-Mannigfaltigkeit existiert eine Riem. Metrik mit nichttrivialen harmonischen Spinoren.*

Ähnliche Aussagen lassen sich auch für $Spin^c$, $Spin^h$, und ähnliche Mannigfaltigkeiten machen. Im Spin-Fall hat Hitchin das entsprechende Resultat für Dimension $n \equiv 0, \pm 1 \mod 8$ bewiesen.

Isoperimetric inequalities for lattices in Lie groups

E. Leuzinger

This is a joint work with C. Pittet

Let $\Gamma =< S, R >$ be a finitely presented group. Let $\omega \in F(s)$ be a word in the free group generated by S which is trivial in Γ, i. e. $\omega = \prod_{i=1}^{N} n_i r_i n_i^{-1}$ with $r_i \in R$ and $n_i \in F(S)$.

Let $A(\omega)$ be the minimum value of N in such expressions. Let $|\omega|$ be the number of letters of ω. The *Dehn-function* of $\Gamma =< S, R >$ is defined as

$$\delta_\Gamma(n) = \max_{|\omega| \leq n} A(\omega)$$

and is a quasi-isometry invariant of Γ.

Theorem. *Let G be a semi-simple non-compact Lie group with finite center. Let Γ be an irreducible lattice in G. If the real rank of G is 2, then the Dehn-function of Γ is exponential.*

(This was proved for the special case of quadratic Hilbert-modular groups by Gromov and for $SL_3(\mathbb{Z})$ by Thurston-Epstein.)

Uniqueness of horospheres and geodesic cylinders in hyperbolic space

P. Kohlmann

The following theorem is proved:

Theorem. *Let M be a complete, properly embedded hypersurface in the hyperbolic space $\mathbb{H}^{n+1}$ ($n \geq 2$) with nonnegative sectional curvature and $E_r \equiv const.$ for $1 \leq r \leq n$. Then M is a horosphere or a geodesic cylinder.*

The proof uses arguments based on the comparison with certain spindle surfaces inside M and the behaviour of M at infinity. The case $E_r \equiv \binom{n}{r}$ is easily settled. In case $E_r > \binom{n}{r}$ it is proved indirectly that M cannot be diffeomorphic to $\mathbb{R}^n$ having only one infinity point. Eigenvalue estimates for a certain eigenvalue problem for caps cut off by suitable horospheres are considered for a Voss operator, which is associated to E_r.

On the other hand we obtain an inequality for the Rayleigh quotient by volume estimates for the caps, which contradict the eigenvalue estimates. Then the geodesic cylinder is the only possible choice for M. Many algebraical problems are solved by a frequent use of the Newton inequalities $H_s^2 \geq H_{s-1}H_{s+1}$.

On characterizations of spheres and ellipsoids and a problem of Firey

K. Leichtweiß

1967 U. Simon proved some characterizations of a hypersphere in $\mathbb{R}^n$ as an ovaloid fulfilling the condition $H_k = G(h)$ or $\frac{H_k}{H_l} = G(h)$ for a special C_1-function G with $\frac{dG}{dh} \leq 0$ ($1 \leq l < k \leq n-1$) where H_k is the k-th normalized elementary symmetric function of the principal curvatures and h is the support function. It is the aim of the lecture to present some results for such equations with $\frac{dG}{dh} > 0$, especially for the case $k = n-1$ and $G =$ identity, closely related to a problem of W. Firey about worn stones. A known characterization of an ellipsoid also fits into this context. The method of proofs consists in the application of the theory of evolutions of ovaloids with respect to the time t as solutions of the heat equation $\frac{\partial h}{\partial t} = -F(H_k)$ or $\frac{\partial h}{\partial t} = -F(\frac{H_k}{H_l})$ with the inverse function F of G.

On G_2-Structures

Thomas Friedrich

This is a joint work with I. Kath, A. Moroianu, U. Semmelmann.

A (nearly) parallel G_2-structure on a 7-dimensional Riemannian manifold is equivalent to a spin structure with Killing spinors. During the last 10 years these special Einstein manifolds appeared as Einstein spaces where the Dirac operator has the smallest possible eigenvalue and many compact examples are known since this time. We

- construct new with nearly parallel G_2-structures.
- investigate the automorphism group of a compact nearly parallel G_2-structure.
- classify all these manifolds with a "large" automorphism group (dim but ≥ 9)
- in particular, all homogeneous compact nearly parallel G_2-manifolds are described.

Harmonic maps and Morse theory on the loop group

Francis E. Burstall

This is joint work with Martin Guest.

Harmonic maps of a 2-sphere in a compact Lie group G are projections of certain holomorphic curves into the based loop group ΩG called *extended solutions*. Each extended solution takes its values in polynomial loops of a fixed degree and this degree is called the *uniton number* of the extended solution. The *minimal uniton number* of a harmonic map $\phi : S^2 \to G$ is the minimum among the uniton numbers of all the extended solutions which cover ϕ.

When $G = \mathrm{U}(n)$, Uhlenbeck proved that the minimal uniton number of any harmonic map $\phi : S^2 \to G$ does not exceed $n - 1$.

We consider the case when G is a compact simple group (of adjoint type) and prove that the minimal uniton number does not exceed n_G given by the following table:

G	n_G
SU(n)	$n-1$
SO($2n+1$)	$2n-1$
Sp(n)	$2n-1$
SO($2n$)	$2n-3$
G_2	5
F_4	11
E_6	11
E_7	17
E_8	28

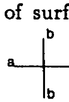
Moreover, these estimates are sharp.

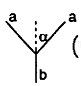
Our method uses the Morse theory of the energy function on the loop group: the algebraic loop group decomposes into unstable manifolds for the energy flow and, off a divisor, any extended solution has image in a single unstable manifold. Further, the uniton number is controlled by easily computed algebraic invariants of the corresponding critical manifold. Finally, one shows that the extended solution can be chosen so that this critical submanifold has low index and the result follows.

On the moduli space of constant mean curvature surfaces with three or four embedded ends

K. Grosse-Brauckmann

In previous works I constructed constant mean curvature surfaces with $n \geq 3$ embedded ends in dihedral symmetry. Their ends are asymptotic to Delaunay undoloids, and their minimal radius cannot exceed $1/n$. Kapouleas had constructed similar surfaces before, but without any symmetry assumption. For technical reasons he obtained those surfaces only with small necks, and it can be asked: what is the maximal neck size for the extension of this families?

In my talk, I want to report on work in progress, joint with R. Kusner (Amherst), which gives the answer for two families of surfaces with some symmetry: surfaces with four ends, which look like 

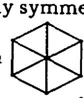
, and surfaces with 3 ends looking as 

($0 < \alpha < 90°$).

Compact Constant Mean Curvature Surfaces

K. Polthier

This is a joint work with K. Grosse-Braukmann.

In the talk we present new examples of compact constant mean curvature (cmc) surfaces. The surfaces are highly symmetric and have low genus. They are based on a graph of the the form , where bubbles are placed at the vertices and connected with Delaunay necks along the edges. In contrast to the results of Kapouleas the Delaunay necks do not have to contain further bubbles.

The construction involves a two-parameter period problem which was solved numerically. The algorithm of Oberknapp/Polthier to compute discrete cmc-surfaces was used and will be explained in the talk. The surfaces arise in families with varying genus but are isolated otherwise. Their genus ranges from 3 to 11.

Invariants for Weyl Geometries

U. Simon

From a Weyl geometry we construct a "canonical" projective class (which, in general, is not Ricci-symmetric) and show that the projective invariants are gauge invariants of the Weyl geometry. We extend this procedure including the conformal class. Finally, we study a class of second order differential operators and gauge invariants within the asymptotic spectrum of these operators.

Homogeneous submanifolds of affine 4-space

R. Walter

Continuing the lecture on the preceding Geometrie-Tagung, we determine all 2-dimensional subgroups of the special affine group in $\mathbb{R}^4$. Similarly all 3-dimensional subgroups in Lie's list of abstract Lie groups are determined in the cases I,I' (semi-simple groups) and V,VI,VII, where for example VII is the totally commutative case. In order to reduce the number of sub-cases, suitable regularity assumptions on the orbits are made. But the method applies as well more generally. Also, the full affine group can be handled. The middle cases II-IV are in current preparation.

Flat equiaffine homogeneous surfaces in $\mathbb{R}^4$

C. Wang

We give a complete classification of flat equiaffine homogeneous surfaces in $\mathbb{R}^4$.

If the Burstin-Mayer metric is definite and flat, then there are only three types of homogeneous surfaces. They are orbits of commutative equiaffine subgroups. If the Burstin-Mayer metric is indefinite and flat, then there are 32 types of homogeneous surfaces. We determine all of them and their corresponding equiaffine subgroups. Some of these groups are non-commutative, and may have three types of orbits which are not affinely equivalent.

A method is presented to determine the corresponding equiaffine subgroups from a given homogeneous space.

Affine Gauss-Kronecker curvature

A.-M. Li

Classification of complete hyersurfaces with constant affine Gauss-Kronecker curvature.

Let M be a euclidean complete hypersurface represented by the convex function $X_{n+1} = f(x_1, \cdots, x_n)$. Denote by U and Ω the Legendre transformation function and the Legendre domain of f respectively. If the affine Gauss-Kronecker curvature is constant and the Weingarten form B is negative definite and $-B$ is complete, then Ω is a bounded convex domain, and U satisfies the PDE:

$$\det(U_{ij}) = (-U^*)^{-n-2},$$

where U^* is the solution of the PDE:

$$\begin{cases} \det(U^*_{ij}) = (-U^*)^{-n-2} & \text{in } \Omega \\ U^* = 0 & \text{on } \partial\Omega. \end{cases}$$

Conversely, given a C^∞ convex domain Ω and $\rho \in C^\infty(\partial\Omega)$, one can solve the above PDE with $U|_{\partial\Omega} = \rho$. From U we can construct a hypersurface M with constant affine Gauss-Kronecker curvature, and M is both euclidean and affine complete and $-B$ is also complete.

Introducing projective billiards

S. Tabachnikov

Given a closed smooth convex plane curve γ equipped with a smooth traverse line field n one defines a transformation T of he set L^2 of rays in the the plane that intersect γ: the incoming ray, the outgoing ray, the tangent line and the transversal n constitute a harmonic quadruple. One also defines a transformation F of the set M^3 of inward vectors with the footpoints on γ: a vector moves freely until it hits γ; there the vector is decomposed into the tangential and the transverse components, and the latter instantaneously changes its sign. We have a commutative diagram:

$$\begin{array}{ccc} M & \xrightarrow{F} & M \\ \downarrow{\scriptstyle \pi} & & \downarrow{\scriptstyle \pi} \\ L & \xrightarrow{T} & L \end{array}$$

Theorem. *There exists a T-invariant area form ω on L if and only if there exits a section $i : L \mapsto M$ such that $F \circ i = i \circ T$. The form is then given by $\omega = |i(\alpha, p)|^3 dp \wedge d\alpha$, where (α, p) are the natural coordinates in L.*

Theorem. *If ω is smooth in a vicinity of ∂L then there exists a parameterization $\gamma(t)$ such that $n(t)$ is generated by $\gamma''(t)$ for all t's.*

Theorem. *If γ is a circle and a T-invariant form ω exists then T is integrable.*

Cohomogeneity one Einstein metrics

C. Böhm

We consider a compact Riem. manifold $(\hat{M}, \hat{g})$ and a compact Lie group G acting on $(\hat{M}, \hat{g})$ by isometries. We assume that one orbit is a hypersurface $P = G/K$ and one orbit Q is a singular one. Close to Q one can show the existence of cohomogeneity one Einstein metrics, if the isotropy representation of K is not to difficult (J.-H. Eschenburg, McKenzie, Y. Wang, 95 to appear). We put a tubular neighbourhood M of Q and get a compact manifold $\hat{M} \dot{\cup}_{\partial M} M$. For special examples - there is an explicit cone solution which is an attractor - one can find a solution of the Einstein equations (an ODE), such that $\hat{M} \dot{\cup}_{\partial M} M$ becomes a C^∞-Einstein manifold. For instance, on $\mathbb{H}P^2 \# \mathbb{H}P^2$ there is an inhomogeneous Einstein metric, on $S^2 \times S^3$, $S^2 \times S^4$, $\cdots$, $S^3 \times S^6$, $\mathbb{C}P^2 \times S^3, \cdots, \mathbb{C}P^3 \times S^3$ there exists infinitely many inhomogeneous Einstein metrics.

On smoothness and singularities of convex hypersurfaces

Y. Burago

This is a joint work with my student B. Kalinin.

Convex hypersurfaces with bounded densities of one of the curvature measures are studied. It turns out that if (low) densities are not separated from zero the hypersurface can even have point-wise singularities. Dependence between curvature restrictions and possible types of singularities is established. The following theorem is proved:

Theorem. *Let F be a convex hypersurface in $\mathbb{R}^{n+1}$ and let (upper) densities of its p-th curvature measure be uniformly bounded. Let at a point $x \in F$ the tangent cone be l-splitted. Then either $l > n - p/2$ or $n - p/2 \geq l \geq s \geq n - p + 1$, where s is the dimension of the maximal face $A \subset F$ such that $x \in \operatorname{relint} A$, and if a face $B \subset \operatorname{relbd} A$ when $\partial B \subset \partial F$. Examples show that all these inequalities are sharp.*

Also a gap in Pogorelov's proof on smoothness of convex hypersurfaces with smooth metrics of positive curvature is filled up.

Asymptotic geometry of rank one manifolds

G. Knieper

The aim of this talk is to extend certain asymptotic properties of negatively curved manifolds (which were obtained by Marjulis and Bawen) to rank one spaces of non-positive curvature.

Definition. *A manifold (M, g) of non-positive curvature is called a rank one manifold if there exists one hyperbolic geodesic, i. e. a geodesic with no perpendicular parallel Jacobi fields.*

Let (M, g) be a compact manifold of non-positive curvature, then

$$h = \lim_{r \mapsto \infty} \frac{\log \operatorname{vol} B(p,r)}{r}$$

(where $B(p,r)$ is a geodesic ball of radius $r > 0$ on the universal cover) is called the volume entropy.

Denote by

$$P(t) = \#\{\text{primitive free homotopy classes in } M \text{ containing a closed geodesic of } period \leq t\}$$

Then we obtain

Theorem. *Let $M = X/\Gamma$ be a compact rank one manifold, X the universal cover. Then there exists $a > 1$ such that*

- $\frac{1}{a} \leq \frac{\operatorname{vol} S_r(p)}{e^{hr}} \leq q$
- *there exists $b > 1$ such that $\frac{e^{ht}}{bt} \leq P_{hyp}(t) \leq P(t) \leq be^{ht}$ where P_{hyp} contains only hyperbolic closed orbits.*

The result follows from an investigation of the Bussemann densities (conf. densities) at infinity.

Flows on surfaces and related topics

D. V. Anosov

"Surface" means a closed 2-dimensional manifold M. "Flow" means a continuous 1-parameter transformation group $\{\varphi_t\}$ (practically such a group is usually generated by a vector field V, but for the problems considered below no "regularity" of $\{\varphi_t\}$ is needed and one need not to assume that $\{\varphi_t\}$ is generated by V).

For $M = S^2$ or $M = \mathbb{R}P^2$ there exists a Poincare-Bendixon theory describing possible types of limiting behaviour of the trajectories. This talk is devoted to other M. The general idea (due to Weil) is to "lift" a (semi-)trajectory to the universal covering of M. Under rather general assumptions (although not always) a lifted semi-trajectory $\{\tilde{\varphi}_t(\tilde{x})\}, t \geq 0$ is either bounded or "goes to infinity". In the latter case there exists an "asymptotic ray at infinity" $\tilde{l}$ which is a limit of rays $\tilde{a}\tilde{\varphi}_t(\tilde{x})$ with a fixed $\tilde{a}$. One can ask whether $\tilde{\varphi}_t(\tilde{x})$ remains (for all t) a bounded distance from $\tilde{l}$. Related geometric questions arise when we start from the (semi)infinite curve $\{z(t); 0 \leq t < \infty\} \subset M$ having no self-intersections and "lift" it to $\tilde{M}$. One can also consider the intermediate case when instead of the flow on M one starts with a 1-parameter foliation with singularities on M. Finally, if the covering semi-trajectory (curve; semi-leaf) "oscillates", i. e. is unbounded but returns from time to time to some compact set, one can ask about the "set of its asymptotic directions at infinity" (defined in a natural way).

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