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Geometric and Analytic Methods in 3-Dimensional Topology

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In the late 1970's William Thurston came up with a stunning conjecture which completely changed the landscape of 3-dimensional topology:

Geometrization Conjecture: Every compact orientable 3-manifold can be decomposed along spheres and incompressible tori into *geometric* 3-manifolds.

This conjecture is supported by the work of Thurston (who proved it in the case of Haken manifolds), and of many other people. The Geometrization Conjecture includes the Poincaré Conjecture as a special case. The Seifert Fibered Space Conjecture/Theorem, the Orbifold Geometrization Theorem and the Geometrization Theorem for irreducible manifolds homotopy-equivalent to hyperbolic manifolds are relatively recent examples of success in proving various special cases of the Geometrization Conjecture.

The goal of this conference was to bring together people from different areas of mathematics – Riemannian geometry, 3-dimensional topology, geometric analysis, geometric group theory, theory of hyperbolic 3-manifolds – whose work in one way or another is related to Thurston's Geometrization Conjecture. The appearance of Perelman's preprints on Ricci flow and Geometrization was a major source of interest and excitement during the meeting, and led one of the organizers (Bruce Kleiner) to give a series of expository lectures on Perelman's work.

The meeting was organized by Misha Kapovich (University of Utah), Bruce Kleiner (University of Michigan) and Bernhard Leeb (LMU München). The participants enjoyed the wonderful atmosphere at the institute.

Abstracts

Cannon's Conjecture and metric 2-spheres

Mario Bonk

Cannon's conjecture predicts that for every Gromov hyperbolic group G whose boundary at infinity $\partial_\infty G$ is homeomorphic to $\mathbb{S}^2$ there exists an isometric action of G on hyperbolic 3-space $\mathbb{H}^3$ which is discrete and cocompact. This is equivalent to showing that $\partial_\infty G$ is quasisymmetrically equivalent to the standard 2-sphere $\mathbb{S}^2$. In my talk I discussed joint work with B. Kleiner related to this problem.

The geometry of the curve complex

Brian Bowditch

We describe a simplified proof of the result of Masur and Minsky, that the Harvey complex associated to a compact surface is hyperbolic in the sense of Gromov. We can obtain certain refinements, for example the hyperbolicity constant is bounded by a logarithmic function of the complexity.

Geometric inflexibility of hyperbolic 3-manifolds

Ken Bromberg

(joint work with Jeff Brock)

McMullen's geometric inflexibility theorem describes how the bilipschitz constant of a map between hyperbolic 3-manifolds decays exponentially deep in the convex core. His original version only applied to manifolds whose convex core had injectivity radius bounded above and below. We described some new versions of this theorem that didn't require this lower bound on injectivity radius.

The Orbifold Theorem

Daryl Cooper

(joint work with Craig Hodgson and Steve Kerckhoff)

We discuss part of the proof of Thurston's orbifold theorem. The case that the orbifold fundamental group is finite involves different arguments to the other case. We show how to define a notion of complexity for such orbifolds and show that a counter-example to the orbifold theorem with finite orbifold fundamental group and minimal complexity must be a relabelling of one of the 18 spherical 3-orbifolds which do not admit an orbifold Seifert fibering. The proof in this case is completed by examining these finitely many cases.

Amalgamated product and negative curvature

Gilles Courtois

(joint work with G. Besson and S. Gallot)

A theorem of Y. Shalom says if a lattice $\Gamma \subset \mathrm{PO}(n,1)$ is an amalgamated product, $\Gamma = A *_C B$, then the critical exponent δ_C of C satisfies $\delta_C \geq n-2$. We give a geometric proof of this inequality and settle the equality case, namely $\delta_C = n-2$ if and only if there exists a separating compact totally geodesic hypersurface embedded in $\Gamma\backslash\mathbb{H}^n$. Our proof extends to variable curvature.

Homotopy and isotopy finiteness of tight contact structures

Emmanuel Giroux

The goal of the talk is to discuss the proof of the following result:

i) On a closed 3-manifold, only finitely many homotopy classes of plane fields contain tight contact structures.

ii) On a closed atoroidal 3-manifold, there exist only finitely many isotopy classes of tight contact structures.

Monotone quantities, singularities and surgery for mean curvature flow

Gerhard Huisken
(joint work with Carlo Sinestrari)

Consider a smooth closed n-dimensional hypersurface of Euclidean space and let $H = \Sigma\lambda_i$ be the mean curvature, i.e. the sum of the principal curvatures of the surface. We study how an initial surface evolves under mean curvature flow $\frac{d}{dt}F = H\nu$ and show that in certain cases the flow decomposes an initial surface into pieces while allowing complete control of topology changes. One major consequence is the following result:
Theorem (G. Huisken and C. Sinestrari): *Suppose that on the closed, smoothly immersed hypersurface $F_0 : M^n \to R^{n+1}$ the sum of any two principal curvatures is positive at each point of the surface. Then M^n is diffeomorphic to either S^n or to a connected sum of finitely many copies of $S^{n-1} \times S^1$.*
The result follows from an explicit algorithm, that deforms the given initial surface by mean curvature flow, interrupted by finitely many surgeries taking place at instances where the curvature blows up. Crucial steps of the proof are new a priori estimates for the curvature and its derivatives allowing complete control of all possible singularities. There is a quantitatively explicit surgery procedure replacing cylindrical necks just before a singularity occurs, preserving the a priori estimates and reducing the maximum curvature by a fixed factor. This allows control of the number of surgeries necessary and guaranties the finiteness of the algorithm. In case $n = 3$ the assumption of the theorem is equivalent to positive scalar curvature, in case $n = 4$ to positive isotropic curvature; thus the result is analogous to the results obtained by Hamilton and Perelman for the Ricci flow in those cases.

Strong convergence of Kleinian groups

Gero Kleineidam

If (ρ_i) is a sequence of discrete and faithful representations of a finitely generated torsion-free non-abelian group Γ into $PSL_2(\mathbb{C})$, then one can study several types of convergence. The sequence (ρ_i) converges *algebraically* if $\rho_i(\gamma)$ converges in $PSL_2(\mathbb{C})$ for every $\gamma \in \Gamma$. The algebraic limit $\rho : \Gamma \to PSL_2(\mathbb{C})$ defined by $\rho(\gamma) = \lim \rho_i(\gamma)$ is then a discrete and faithful representation. The sequence converges *geometrically* if the groups $\rho_i(\Gamma)$ converge with respect to the Hausdorff-topology on compact subsets to a discrete subgroup Γ_G of $PSL_2(\mathbb{C})$. The group Γ_G is called the *geometric limit.* Up to passing to a subsequence, one may always assume that an algebraically convergent sequence also converges geometrically. In general, $\rho(\Gamma)$ is then a proper subgroup of Γ_G. One says that (ρ_i) converges *strongly* if it converges algebraically and geometrically, and $\rho(\Gamma) = \Gamma_G$.

For simplicity, we restrict to the case that Γ is the fundamental group of a closed surface S. Then the Ahlfors-Bers map parameterizes the space $QF(S)$ of (conjugacy classes) of quasi-fuchsian representations by two copies of the Teichmuller space $\mathcal{T}(S)$. We consider sequences of representations ρ_i in $QF(S)$ which converge algebraically to $\rho : \Gamma \to PSL_2(\mathbb{C})$ and give conditions for strong convergence in terms of their Ahlfors-Bers parameterizations. If $\rho(\Gamma)$ does not contain parabolic elements and the discontinuity domain of the action of $\rho(\Gamma)$ on $\hat{\mathbb{C}}$ is not empty, then the convergence is always strong [AC96]. In particular, this holds for interior points of $QF(S)$.

If $\rho \in \partial QF(S)$ and $\rho(\Gamma)$ contains parabolic elements, then every parabolic subgroup of $\rho(\Gamma)$ is cyclic. We will be interested in those primitive elements $\delta \in \Gamma$ such that $\rho(\delta)$ is represented by a simple closed curve around a puncture of a boundary surface of the convex core of $\mathbb{H}^3/\rho(\Gamma)$. We denote by $\mathcal{D}_c = \mathcal{D}_c(\rho) \subset \Gamma$ a maximal collection of such elements δ whose images under ρ generate non-conjugate parabolic subgroups of $\rho(\Gamma)$.

Assume now that the sequence $(\rho_i) \subset QC(\rho_0)$ is parameterized under the Ahlfors-Bers map by surface $X_i = (X_i^1, X_i^2) \in \mathcal{T}(S) \times \mathcal{T}(S)$. For every $\delta \in \Gamma$ we define $l_{X_i}(\delta)$ to be the minimum of the hyperbolic lengths of the corresponding geodesics in X_i^1 and X_i^2. We prove the following criterion for strong convergence.

Theorem 1. *Let S be a closed surface and $(\rho_i) \subset QF(S)$ a sequence of quasi-fuchsian representations which converge algebraically to ρ. Assume that ρ_i is parameterized under the Ahlfors-Bers map by surfaces $X_i = (X_i^1, X_i^2) \in \mathcal{T}(S) \times \mathcal{T}(S)$. Then ρ_i converges strongly to ρ if and only if for every $\delta \in \mathcal{D}_c(\rho)$, the length $l_{X_i}(\delta)$ tends to zero.*

The Theorem contrasts examples of non-strong convergence, as constructed by Kerckhoff-Thurston [KT90], Bonahon-Otal [BO88] and Brock [Bro01].

References

[AC96] J. Anderson and R. Canary, *Cores of hyperbolic 3-manifolds and limits of Kleinian groups*, Amer. J. Math., 118(4):745-779, 1996

[BO88] F. Bonahon and J.-P. Otal, *Variétés hyperboliques à géodésiques arbitrairement courtes*, Bull. London Math. Soc., 20(3):255-261, 1988

[Bro01] J. Brock, *Iteration of mapping classes and limits of hyperbolic 3-manifolds*, Invent. Math., 143:523-570, 2001

[KT90] S. Kerckhoff and W. Thurston, *Noncontinuity of the action of the modular group at Bers' boundary of Teichmüller space*, Invent. Math., 100(1):25-47, 1990

An introduction to Perelman's work on Ricci flow

Bruce Kleiner

The lecture gave an overview of Perelman's preprints on Ricci flow, sketching some of the highlights of his argument for Thurston's Geometrization conjecture.

The Dehn filling space of a certain hyperbolic 3-orbifold

Sadayoshi Kojima

We construct the first example of a cusped hyperbolic 3-orbifold for which we see the true boundary of the space of hyperbolic Dehn fillings.

The virtually Haken conjecture, Heegaard splittings and Property (τ)

Marc Lackenby

The goal of my talk was to explain the interaction of the above seemingly unrelated topics. The virtually Haken conjecture asserts that any closed hyperbolic 3-manifold has a finite Haken cover. Property (τ) is a concept from geometric group theory that can be defined in terms of differential geometry, graph theory or representation theory. Lubotzky and Sarnak conjectured that hyperbolic 3-manifolds fail to have Property (τ). I have shown that this, together with a conjecture about Heegaard splittings, implies the virtually Haken conjecture. The conjecture about Heegaard splittings asserts that the Heegaard genus of the manifold's finite covering spaces grows sub-linearly in the degree of the covering if and only if the manifold is virtually fibred. I concluded my talk by outlining recent progress on this conjecture: the virtually fibred conclusion holds if the Heegaard genus grows more slowly than the fourth root of the degree.

The Orbifold Theorem

Joan Porti

(joint work with Michel Boileau and Bernhard Leeb)

The Orbifold Theorem says that every compact orientable irreducible and atoroidal 3-orbifold is geometric provided that its singular locus is non-empty. We sketch our proof, which differs from Thurston's one in several aspects. We reduce to small orbifolds, to simplify, and we give a different approach for collapses. Namely we study the geometric properties of thin parts of cone manifolds when cone angles are less than π, and we use simplicial volume when they approach to π. Cooper, Hodgson and Kerckhoff propose another approach closer to Thurston's.

Infinitely many hyperbolic 3-manifolds which contain no Reebless foliation

Rachel Roberts

(joint work with John Shareshian and Melanie Stein)

We investigate group actions on simply connected (second countable but not necessarily Hausdorff) 1-manifolds and describe an infinite family of closed hyperbolic 3-manifolds whose fundamental groups do not act nontrivially on such 1-manifolds. As corollary we conclude that these 3-manifolds contain no Reebless foliations. In fact, these arguments extend to actions on oriented $\mathbb{R}$-order trees and hence these 3-manifolds contain no transversely oriented essential laminations; in particular, they are nonHaken.

Taut and hyperbolic ideal triangulations

Joachim Hyam Rubinstein

(joint work with Ensil Kang)

Casson in 1995 described a program to try to directly find complete hyperbolic structures on the interiors of compact orientable irreducible atoroidal 3-manifolds, by solving the hyperbolic gluing equations for a suitable ideal triangulation. We start with Lackenby's taut triangulations and try to deform the taut structure into angle structures (sometimes called semihyperbolic structures). We first show that such taut triangulations admit no immersed normal tori (incompressible or not) using sweepouts in covering spaces. We then go on to prove there are no branched normal surfaces with formal Euler characteristic zero, if and only if a taut structure can be deformed to an angle structure. (Thanks to Cooper and Lackenby for a very helpful conversation at Oberwolfach on the latter result!).

Variations of McShane's identity for punctured surface groups

Makoto Sakuma

(joint work with Hirotaka Akiyoshi, Miyachi Hideki and Caroline Series)

G. McShane described a remarkable identity concerning the lengths of simple closed geodesics on a once-punctured torus with a complete hyperbolic structure of finite area. This identity was extended by B. Bowditch to an identity for quasifuchsian punctured torus groups. He also described a formula which applies to hyperbolic once-punctured torus bundles.

We gave a formula which expresses the "width" of the limit set of a geometrically finite punctured surface group in terms of the complex transformation lengths of closed geodesics. We also proposed a conjectural identity for hyperbolic cone manifolds which have 2-bridge knot complements as underlying spaces where upper and lower tunnels are cone axes.

Algebraic limits of geometrically finite hyperbolic manifolds are tame

Juan Souto

Let G be a finitely generated fundamental Kleinian group. and assume that there is a sequence of geometrically finite Kleinian groups which converge to G. We show that the quotient manifold $\mathbb{H}^3/G$ is homeomorphic to the interior of a compact 3-manifold with boundary. As a consequence we prove Ahlfors' conjecture for algebraic limits of geometrically finite Kleinian groups.

This is a joint work with Jeff Brock, Ken Bromberg and Richard Evans in the case that the discontinuity domain of G is not empty. The general case is a joint work with Jeff Brock.

A Bassackward Counterexample in Convergence Groups

Eric Swenson

We give an example of a Kleinian group G which is the amalgamation of two closed hyperbolic surface groups along a simple closed curve. The limit set ΛG is the closure of a "tree of circles" (adjacent circles meeting in pairs of points). We alter the action of G on its limit set such that G no longer acts as a convergence group, but the stabilizers of the circles remain unchanged, as does the action of a circle stabilize on said circle. This is done by first separating the circles and then gluing them together backwards.

We then show that in some sense, this is the only obstruction to bootstrapping. As a corollary we prove that G, acting by homeomorphism on S^n, acts as a convergence group on S^n provided there is a collection A of embedded S^{n-1}s satisfying:

i) A is null.
ii) Any two points of S^n are separated by a finite. collection of elements of A.
iii) For each $b \in A$, the stabilizer of b acts on b as a convergence group.

The algebraic and the geometric rank of graph manifolds

Richard Weidmann

For all orientable closed 3-manifolds M the Heegard genus $g(M)$ is at least at large as the rank of its fundamental group $r(M)$. There is a class of Seifert manifolds exhibited by Boileau and Zieschang and extended by Moriah and Schultens for which these two numbers do not coincide, i.e. for which $r(M) < g(M)$. We show that these examples are in fact part of a much larger class of manifolds with this property, all of which are graph manifolds, and that the difference can be arbitrarily large (joint work partly with J. Schultens, partly with M. Boileau).

Local rigidity of 3-dimensional cone-manifolds

Hartmut Weiss

Let C be a 3-dimensional cone-manifold of curvature $\kappa \in \{-1, 0, 1\}$ and cone-angles $\leq \pi$. Then the singular locus $\Sigma \subset C$ is a trivalent graph. The smooth part $M = C \setminus \Sigma$ carries a smooth Riemannian metric of constant sectional curvature κ. Let $\mathcal{E} \to M$ be the flat vector-bundle of infinitesimal isometries. In the flat case $\mathcal{E}_{trans} \subset \mathcal{E}$ is a parallel subbundle. I discuss the following results:

Theorem 1. *Let C be a cone-manifold of curvature $\kappa \in \{-1, 0, 1\}$ with cone-angles $\leq \pi$. Then the following holds:*

i) $H^1_{L^2}(M, \mathcal{E}) = 0$ *if* $\kappa = \pm 1$
ii) $H^1_{L^2}(M, \mathcal{E}_{trans}) \cong \{\omega \in \Omega^1(M, \mathcal{E}) | \nabla\omega = 0\}$ *if* $\kappa = 0$

The proof uses a Bochner formula for $\mathcal{E}$-valued 1-forms and a Hodge theorem for the de Rham complex on M with values in $\mathcal{E}$. It essentially consists of the study of the selfadjoint extensions of the corresponding Hodge-Laplace operator.
From Theorem 1 I deduce local rigidity in the hyperbolic and the spherical case via an analysis of the variety of representations of $\pi_1 M$ into $\mathrm{SL}(2, \mathbb{C})$, resp. $\mathrm{SU}(2) \times \mathrm{SU}(2)$:

Theorem 2. *Let C be a cone-manifold of curvature $\kappa = \pm 1$ with cone-angles $\leq \pi$. Then the family of cone-angles provides a local parametrization of the space of cone-manifold structures of curvature κ near the given structure.*

Volume collapsed three-manifolds with a lower curvature bound

Takao Yamaguchi
(joint work with Takashi Shioya)

In this talk, I have reported on the structure of complete three-manifolds which collapse with a lower sectional curvature bound in the sense of having small volume, where we assume no upper diameter bound. The main result is : such an orientable three-manifold is either homeomorphic to a graph manifold, or having small diameter with finite fundamental group. This result is related with an announcement in Perelman's paper "Ricci flow with surgery on three-manifolds", where he claims that if a three-manifold collapses under a "local" lower sectional curvature bound, then it is a graph manifold. This result also follows from our result without an extra assumption there, since our gluing argument is only local.

Edited by Hartmut Weiß

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