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Breadth in Contemporary Topology

2017 Georgia International
Topology Conference
May 22–June 2, 2017
University of Georgia, Athens, Georgia

David T. Gay
Weiwei Wu
Editors

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Preface

Since 1961 the University of Georgia has organized and hosted an annual week-long topology conference and a major international topology conference every eight years. The tradition started in 1961 with a memorable four-week conference, the proceedings of which, *The Topology of 3-Manifolds and Related Topics*, were published by Prentice Hall. The 2017 Georgia International Topology Conference, continuing this long tradition, was held at the University of Georgia in Athens, Georgia, from May 22 to June 2, 2017. The conference had 41 speakers, ranging from the leading figures to talented young mathematicians, who covered a wide spectrum of the topics in topology and attracted a total of over 190 participants.

The main goals of our conference are to give wide exposure to new and important results and to encourage interaction among graduate students and researchers in different stages of their careers. Toward this end, we encouraged speakers to aim their talks at a broad audience of topologists, and we also scheduled a series of expository lectures that introduced graduate students to several of the themes of the conference.

The papers in this volume were written by both speakers and participants of the conference and cover topics ranging from symplectic topology to classical knot theory to the topology of 3- and 4-dimensional manifolds to geometric group theory. Several papers focus on open problems, especially the paper of Margalit on mapping class groups of surfaces. Other papers present new and insightful proofs of classical results, such as Pardon's paper on groups which can and cannot act on 2-manifolds. Still other papers lay out rich and technical foundational material or survey material presented in more depth elsewhere. Taken as a whole, this volume captures the spirit of the conference, both in terms of public lectures and informal conversations, and presents a sampling of some of the great new ideas generated in topology over the preceding eight years.

The conference was organized by David Gay, Jean Gutt, Will Kazez, Gordana Matic, Juanita Pinzón-Caicedo, Adam Saltz, Michael Usher, and Weiwei Wu. The Scientific Advisory Committee, consisting of Ian Agol, Yakov Eliashberg, David Gabai, Dusa McDuff, Tomasz Mrowka, Peter Ozsvath, Peter Teichner, and Karen Vogtmann, provided great assistance selecting speakers. The logistical support of the conference was due to the hard work of Julie McEver, Connie Poore, Gail Suggs, Laura Ackerley, and Christy McDonald. Finally, the organizers are grateful to the generous support of the National Science Foundation (grant DMS-1719320) and to the University of Georgia.

D. G.
W. W.

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2017 GITC Problem Sessions

This is a list of problems asked during the two problem sessions held at the 2017 Georgia International Topology Conference. The name in the parenthesis belongs to the person that brought up the question during the session, not necessarily the individual who first formulated the question. We do not have a record of who posed some of the questions. The sessions were moderated by John Etnyre and Rob Kirby and the list is compiled from notes by Mike Usher, Jean Gutt and Jeremy Van Horn-Morris and slightly edited by David Gay and Gordana Matic. We thank the question authors that replied to our request for proofreading and clarification or comments. The questions are presented in the order in which they were brought up.

QUESTION 1. *(Gay) Does there exist a* $(g, 0)$*-trisection, for some* $g < 22$*, of a four-manifold that is not the connected sum of* $\mathbb{C}P^2, \overline{\mathbb{C}P}^2, S^\times S^2$*? Due to a classification result of Meier and Zupan, we know that the answer is no for* $g < 3$*. Recently Lambert-Cole and Meier found a* $(22, 0)$ *trisection of the* $K3$ *surface. Thus the interesting range is* $3 \leq g \leq 21$*.*

Dave Auckly prefaces the following question with this discussion: One may associate a 3-manifold invariant to any suitable quantum group. Associated to $U_q(\mathfrak{sl}_N)$ one has the invariants $Z_{Y^3}(k, N)$ where N is the rank and k is the level. Is it possible to encode these invariants in an easier way?

The so-called gauge-string duality from mathematical physics provides some hope that this may be possible. In particular it relates the quantum invariants of the 3-sphere to the Gromov-Witten invariants of the resolved conifold. The Gromov-Witten invariants are a set of rational numbers with one associated to each possible degree and genus. The Gromov-Witten invariants, in turn are related to the Donaldson-Thomas invariants which are a set of integers. Finally, the Donaldson-Thomas invariants may be described via the so-called BPS states. Given that there is only one example, it is too much to call this a conjecture, but:

QUESTION 2. *(Auckly) Wild Speculation: There is an invariant* $Z_{Y^3}(q, a)$ *with properties similar to the following:*

- *Evaluating at* $q = e^{2\pi i/(N+k)}$*,* $a = q^N$ *yields Witten-Reshetikhin-Turaev invariant of rank* N *and level* k*;*
- *It can be expressed as* $1 + M(q) \sum_d \sum_{n=0}^{\infty} D_{n,d} q^n a^d$ *where* $D_{n,d} \in \mathbb{Z}$*;*

- *With $q = e^{iu}$, as $u \to 0$ the invariant takes the form*

$$1 + \sum_d \sum_g N_{g,d} u^{2g-2} q^d$$
$$= \sum_{g=0}^{\infty} \sum_{k=1}^{\infty} \sum_d n_{g,d} k^{-1} (-1)^{g-1} \left((-q)^k - 2 + (-q)^{-k}\right)^{g-1}$$

where $n_{g,d} \in \mathbb{Z}$ and $n_{g,d} = 0$.

The $N_{g,d}$ correspond to the Gromov-Witten invariants and the $D_{n,d}$ correspond to the Donaldson-Thomas invariants. The $n_{g,d}$ are the BPS states.

Remark: Formulae of the above form relating these three types of invariants are known to hold in the context of Gromov-Witten theory. The heuristic connection between Chern-Simons theory and Gromov-Witten theory leads one to ask how far the similar structure will go on the Chern-Simons side. Auckly-Koshkin [AK] contains exposition about the work on these ideas in the case of S^3. For S^3 this speculation is essentially true with $n_{0,1} = 1$ and the rest of the BPS invariants equal to zero.

Rob Kirby drew particular attention to two old problems from his problem list:

QUESTION 3. *(Kirby, due to Fox, problem 1.33 in Kirby's problem list.) Is every slice knot a ribbon knot?*

QUESTION 4. *(Kirby, problem 4.97 in Kirby's problem list.) Let X be an almost complex smooth four-manifold. Then gauge theory can be used to show that X isn't a connected sum. Does every irreducible, smooth, closed, simply connected 4–manifold other than S^4 have an almost complex structure?*

QUESTION 5. *(Eliashberg) What do canonical symplectic constructions remember about the smooth topology of the manifold?*

Remarks: To a smooth manifold M, one can associate a canonical symplectic manifold, the cotangent bundle of M, $(T^\star M, d\lambda)$, and a contact manifold, the unit cotangent bundle, $(ST^\star M, \ker(\lambda|_{ST^\star M}))$. What does the contact topology of ST^*M know about the smooth topology of M?

Can we see nontrivial four-dimensional gauge-theoretic invariants via T^*M or ST^*M?

Take a four-manifold X, maybe a potential counterexample to the smooth Poincare conjecture in dimension 4. Remove a ball, bounded by a standard sphere to obtain X_0. The cotangent bundle of the ball is flexible, but the boundary of the ball gives a Legendrian submanifold which might be a nontrivial knot. From studying Legendrians on S^3 viewed inside ST_0^X, can one see exotic structures on X?

QUESTION 6. *(Eliashberg)*

Inverting the usual fillability relationship questions, what can be said about symplectic manifolds as boundaries of contact manifolds? The right condition is that the boundary be convex, so it has a dividing set dividing the boundary into two symplectic manifolds. We can abstractly consider pairs of Liouville/Weinstein domain with same contact type boundary. When is such a pair fillable by a tight contact manifold and what are the tight fillings?

Remark: Note that one can always get an overtwisted filling.

Question 7. *(Rasmussen)*
L-spaces are manifolds with simplest-possible Heegaard Floer homology. The L-space conjecture [BGW] states that for a prime oriented manifold M^3 the following are equivalent:
1. M is an L-space
2. $\pi_1(M)$ is not left-orderable
3. M has no co-oriented taut foliation.

Remark: First of all note that this conjecture is only interesting for rational homology spheres, and that for an L-space Y, $dim\widehat{HF}(Y) = |H_1(Y, \mathbb{Z})|$. The conjecture connects different structures arising in low-dimensional topology in a somewhat surprising way, and there is really no apparent reason why it should be true, but it has resisted much effort to disprove it. The only implication known so far is $1 \Rightarrow 3$. i.e. that L-space carries no co-oriented taut foliation. There has been much work by many authors on proving the conjecture for the case of graph manifolds.

A possible route for disproving the conjecture is: Take a three-manifold with torus boundary, which has more than one L-space filling. Then one knows exactly which fillings give L-spaces and should check them for a counterexample. The Snappea census takes many of these fillings and hasn't turned up any counterexamples, but the work so far hasn't gone through them systematically. In particular one could look at the boundary of the interval of slopes giving rise to an L-space.

Question 8. *Given an irreducible closed rational homology sphere with an incompressible torus, is there a taut foliation on it? It would be nice to use classical methods.*

Question 9. *(Lidman) If there exists a degree-one map $Y \to Z$ between rational homology spheres, is $\dim \widehat{HF}(Y) \geq \dim \widehat{HF}(Z)$? This is related to the L-space conjecture because non-left-orderability is appropriately preserved under degree one maps between prime three-manifolds. For example this would imply, without geometrization or gauge theory, that homotopy spheres are L-spaces and property P.*

For some partial results along these lines, see [HRW]. For similar results in the case of maps of higher degree, see [LT] and [LM]. It is open if non-zero degree maps more generally preserve the property of being an L-space.

Question 10. *(Mann) Take a closed surface (other than S^2) and form a 3-manifold $\Sigma \times S^1$. Is the space of foliations transverse to S^1 connected? This is a good question in both $C^{0,1}$ and C^∞ categories.*

Remark: The only known case seems to be $C^{0,1}$ on $T^2 \times S^1$, but maybe there are high genus counterexamples.

Question 11. *(Coskunuzer) By using Heegard splittings, or Heegard-Floer theory in general, can we determine a given manifold admits a hyperbolic structure? In other words, can we detect hyperbolic 3-manifolds by using these tools? For a related question, see Hossein Namazi's thesis [Nam].*

Especially after the proof of Virtual Fibering Conjecture, we know that every closed hyperbolic 3-manifold has a finite cover which fibers over the circle. In particular, these manifolds are mapping tori for pseudo-Anosov maps on closed surfaces *of genus¿1. With this new input, is it possible to use Heegaard-Floer techniques or Heegaard splittings in general to detect hyperbolic 3-manifolds?*

Question 12. *(Affieri) How do the subgroups of the concordance group generated by the standard kinds of examples like L-space knots, algebraic knots, torus knots, intersect with the other kinds of examples like alternating (or quasi-alternating) knots. Is the subgroup generated by quasi-alternating knots modulo alternating knots infinitely-generated?*

Question 13. *(Coskunuzer) Rephrasing a very-well known old question in contact topology: Is there any hyperbolic 3-manifold with no tight contact structure? We know the existence of hyperbolic 3-manifolds without taut foliations. In these manifolds, Tolga Etgu constructed tight contact structures [E].*

Again, with the help of the Virtual Fibering Theorem, is it possible to show every hyperbolic 3-manifold admits a tight contact structure? If not, is it possible to construct a counterexample?

Remark: John Etnyre mentioned that this problem was also discussed in the 2001 Georgia Topology Conference Problem Session.

Question 14. *(Casals) Can we build a Liouville structure on a smooth four-dimensional three-handle, or more generally on a $2n$-dimensional $(n+1)$-handle? This Liouville structure should have a concave and a convex end, and endow the smooth cobordism given by the three-handle attachment with the structure of an oriented Liouville cobordism, from the initial contact manifold to the resulting surgered manifold.*

Remark: McDuff gave an example of a Liouville four-manifold whose topology requires three-handles [McD], so one could try isolating the three-handle with a Morse function.

Question 15. *Is the Torelli group finitely presented?*

Remark: Johnson proved that it is finitely generated for $g \geq 3$ and McCullough and Miller proved it is not finitely generated for g=2. It remains open whether the group is finitely presented for $g \geq 3$.

Question 16. *(Gay) Is there a three-component framed link in S^3, with surgery giving S^3, which is not handleslide equivalent to a split link?*

Remark: An affirmative answer to the question about existence of a $(3,0)$-trisection of a four-manifold that is not the connected sum of $\mathbb{C}P^2, \overline{\mathbb{C}P}^2, S^\times S^2$ (first question in this problem list), would give an affirmative answer to this question.

Question 17. *(This is a well known conjecture, brought up by Hutchings) Does every star-shaped region in $\mathbb{R}^{2n}$ have at least n Reeb orbits on its boundary. (This is known for $n = 2$.) More generally, what can be said about the number of periodic orbits.*

Question 18. *(Hutchings) What can we say about the weak version of Viterbo's conjecture asserting that for every compact convex domain $\Omega \subset R^{2n}$ with smooth boundary, there is a Reeb orbit γ on the boundary whose symplectic action $\mathcal{A}(\gamma)$ satisfies $\mathcal{A}(\gamma)^n \leq n vol(\Omega)$. (This is false for star-shaped domains.)*

QUESTION 19. *(Chaidez) Is there an analogue of the Atiyah-Floer conjecture for Kronheimer-Mrowka's instanton homology for webs $J^{\#}$ [KM]? Could this help establish nonvanishing? What would replace the Heegaard splittings in the usual Atiyah-Floer conjecture?*

QUESTION 20. *Does π_1 of every three-manifold other than S^3 have a nontrivial $SU(2)$-representation?*

Remark: By the Kronheimer-Mrowka proof of Property P this is true for surgeries on knots.

QUESTION 21. *(Hall, attributed to Agol)*

(i) *"Virtual four-coloring for surfaces": If G is a graph embedded in a surface Σ, is there a finite-cover of Σ in which the lifted graph is four-colorable? It can be shown that this holds for $\Sigma = T^2$.*
(ii) *Given a triangulated graph in an oriented surface Σ and a four-coloring, use this to construct a map to the oriented four-colored tetrahedral graph on S^2, thus assigning degree ± 1 to each triangle in Σ. The sum of the ± 1's around each vertex will be zero mod 3. If $\Sigma = S^2$ this is enough to reconstruct the original four-coloring, but that is not true for other Σ.*

    Conjecture: ± 1's can be assigned for a triangulated graph on any surface in such a way that the sum around any vertex is 0 mod 3, which would yield a 24-fold covering in which the graph is four-colorable (since $24 = |S_4|$). If this is true, it would imply (i).

QUESTION 22. *(Casals) Is there a way of characterizing three-manifolds with arboreal singularities [Na] such that $H_*(X; \mathbb{Z}_3) \neq 0$? These are singular complexes whose singularities are allowed to look like (trivalent vertex) times $\mathbb{R}^2$ or (cone over tetrahedron) times $\mathbb{R}$. The Legendrian surfaces coming from planar graphs [CM, TZ] have Lagrangian fillings with these types of singularities, and the number of $\mathbb{Z}_3$-augmentations coincides with the number of 4-colorings of the planar graph. In particular, if one can build fillings which have a non-vanishing $\mathbb{Z}_3$-homology class, this would imply the existence of a $\mathbb{Z}_3$ -augmentation and thus the four color theorem.*

QUESTION 23. *(Usher) Are $S^1 \times S^1$ and the Chekanov torus the only monotone Lagrangian tori in $\mathbb{R}^4$ up to Hamiltonian isotopy and scaling? In $\mathbb{C}P^2$ Vianna gives infinitely many examples, and Auroux gives infinitely many on $\mathbb{R}^6$*

QUESTION 24. *General question: understand the structure of the three-dimensional homology cobordism group $\Theta^3_{\mathbb{Z}}$ (three-dimensional integral homology three-spheres modulo homology cobordism, with connected sum as group operation).*

(i) *Is there any torsion?*
(ii) *Perhaps easier: does Rohlin invariant one imply infinite order (Manolescu proved it implies order greater than two which disproved the triangulation conjecture for high dimensional manifolds). If the answer is yes then the obstruction to triangulating higher-dimensional manifolds lives in $H^5(-; \mathbb{Z})$.*
(iii) *Does $\Theta^3_{\mathbb{Z}}$ contain $\mathbb{Z} \oplus \mathbb{Z}$, or perhaps even $\mathbb{Z}^\infty$, summands. It's known that it has a $\mathbb{Z}$ summand by Froyshov.*

QUESTION 25. *(Casals) Find an explicit contact open book for T^{2n+1} $(n \geq 2)$ whose page has the homotopy type of an n-dimensional complex. By using S. Donaldon's asymptotically holomorphic techniques, E. Giroux proves ([Gi]) that such an open book exists. The monodromy must be a compactly supported symplectomorphism of a Weinstein domain which cannot be written as the product of Dehn twists, of which we have not very many concrete examples. In general, it is an interesting question to find a compactly supported symplectomorphism of a Weinstein domain which is not symplectically isotopic to a Dehn twist, a fibered Dehn twist or a product of them.*

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