Université de Montréal

Faculté des arts et des sciences
Département de mathématiques
et de statistique

SMS 2013: Director's report.

The 52nd *Séminaire de Mathématiques Supérieures* took place in Montréal in the period June 24- July 5, 2013. It was the largest summer school in recent years, with 90 participants, and one of the most inter-disciplinary with lectures reflecting recent trends in parts of physics as well as mathematics. For the first time all lectures have been video-recorded.

The organizers, **Sergei Gukov, Mikhail Khovanov and Johannes Walcher** have done a tremendous job at all levels: scientific organization, student selection as well as insuring a stimulating environment during the school.

I thank all three of them for their hard work as well as **Ms. Sakina Benhima** from the CRM who assisted them and me with the administrative matters required in running this activity.

As in past years, this edition of the *SMS* was only possible with the co-operation of our main partners the **CRM**, **Fields Institute**, **PIMS** and **MSRI** as well as with support from the **ISM**, the **University of Montreal**, support from the **Canadian Mathematical Society** as well as, exceptionally, with the generous support of the **Simons foundation**. We also acknowledge the contribution of the Geometry-Topology CRM Laboratory (**CIRGET**). I thank all these institutions for their contributions and I also thank the board of directors of the SMS for their work and support.

In the following you will find a very detailed scientific, organizational and budgetary report. I thank again the organizers for taking the time to prepare such a thorough document.

Sincerely Yours,

O. Cornea

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August 27, 2013

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Séminaire de Mathématiques Supérieures 2013

Physics and Mathematics of Link Homology

June 24–July 5, 2013

— Scientific Report —

Dated: July 28, 2013

Contents

1 Organizers

* Sergei Gukov (Caltech Institute of Technology)
* Mikhail Khovanov (Columbia University)
* Johannes Walcher (McGill University)

2 Speakers

* Mina Aganagic (University of California at Berkeley)
* Dror Bar-Natan (University of Toronto)
* Hiroyuki Fuji (University of Tokyo)
* Sergei Gukov (California Institute of Technology)
* Joel Kamnitzer (University of Toronto)
* Anton Kapustin (California Institute of Technology)
* Mikhail Khovanov (Columbia University)
* Aaron Lauda (University of Southern California)
* Ciprian Manolescu (University of California at Los Angeles)
* Marcos Marino (Université de Genève)
* Alexei A. Oblomkov (University of Massachusetts Amherst)
* Ramadevi Pichai (Indian Institute of Technology Bombay)
* Jake Rasmussen (University of Cambridge)
* Lev Rozansky (University of North Carolina at Chapel Hill)
* Marko Stošić (Instituto Superior Técnico, Lisbon)
* Piotr Sulkowski (University of Warsaw)
* Johannes Walcher (McGill University, Montreal)
* Ben Webster (Northeastern University, Boston)

3 Number of Participants

* 90

4 Summary

Throughout recent history, the theory of knot invariants has been a fascinating melting pot of ideas and cultures, blending mathematics and physics, geometry, topology and algebra, gauge theory and quantum gravity. Participants of this year's Séminaire de Mathématiques Supérieures can confirm that the explosion we are witnessing most likely is just the beginning of a larger and much more uniform story.

One of the pervasive themes is "aiming for higher dimensions" — The original construction of the Jones polynomial invariant of knots and links (one-dimensional objects non-trivially embedded in three-space) in 1984 was firmly rooted in two-dimensional mathematical physics, but did not make all symmetries manifest. An intrinsically three-dimensional interpretation was given by Witten in 1988, representing the Jones polynomial as a physicist's path-integral over the space of connections with Chern-Simons action. Following the categorification paradigm, Khovanov in 1998 lifted the Jones polynomial to a homological invariant of link cobordisms living in four dimensions. Around the same time, developments initiated by Gopakumar and Vafa began to expose relations to higher-dimensional geometric invariants of interest in superstring theory. Splitting M-theory's eleven dimensions in various ways makes room for a large number of vantage points to help explain the origin of lower-dimensional phenomena.

This two week long programme on "Physics and mathematics of link homology" brought together leading researchers in mathematics and mathematical physics, in order to provide an opportunity to educate a new generation of scientists in this growing field. The challenges were remarkable.

Theories of link homology are studied from a large variety of mathematical approaches and backgrounds — topologists will find the axiomatic framework of topological quantum field theory most accessible. Algebraic geometers could be interested in derived categories of coherent sheaves on quiver varieties and on convolution varieties of affine Grassmannians, or the enumerative geometry of (relative) Donaldson-Thomas invariants of Calabi-Yau threefolds. Symplectic geometers might study Fukaya-Floer categories associated with Heegard splittings or with Lagrangians on quiver varieties. Researchers with a background in representation theory will focus on the lifting of quantum groups and their representation theory to higher categories. As refreshing as this diversity may be, it represented a barrier for newcomers to enter the field. So one of the goals of the SMS was to address the sorely felt need for a pedagogical introduction aimed at intermediate to advanced graduate students interested in the mathematics of knot homology.

And while the physics perspective promises to ultimately help clarify the relations between all these approaches, initially it only seems to complicate matters – In fact, one of the main attractions of homological knot invariants for mathematical physics is precisely that it mixes so many different parts of topological quantum theory. Not only do knot homologies provide a bridge between topological field theories of cohomological and Chern-Simons type,

the relation with the enumerative geometry of Calabi-Yau threefolds is one of the incarnations of the celebrated large-N (or gauge/gravity) duality that has come to dominate formal theoretical physics in the last 15 years. Providing an access point into the relevant parts of theoretical physics was a declared aim of the school as well. The organizers made a particular effort to encourage interactions and fruitful exchanges between the communities in order to facilitate the development of the unified picture.

Clearly, these are a lot of different topics to cover in a two-week summer school, aiming at a coherent and unified overview of the subject! With necessary gaps, the enthusiastic response and feedback from junior as well as senior participants alike is testimony to the fact that the programme amply succeeded in balancing the various interests. The 15 main lecturers were given the leisure of 3 (first week) or 2 (second week) times 75 minutes to explain the background that they felt most necessary or useful for their particular subject, sketch their main results and end with explaining those challenges that they view as most promising. Three topical seminar style lectures rounded out the programme. All the while, the consistently streamlined schedule of the school allowed for the organization of a number of spontaneous discussion sessions between students from mathematics and physics backgrounds, as well as several social outings around Montreal.

There were countless cross-references between the various lectures. Indeed, the group of speakers is very well in tune regarding each other's lecture topic. This is due to a number of recent events with a similar topic, albeit at a rather higher level. In particular, a Simons Symposium on Knot Homologies and BPS States was held in April 2012, and an MSRI program on Knot homology was hosted in 2010. This arrangement of content contributed to a very coherent school, and conversely, the school was a very welcome opportunity for transmitting the results discussed at these events to the larger group containing the next generation of professional researchers.

To enhance the pedagogical value of the school, the organizers strived to capitalized on two effects: first of all, the interactions between mathematics and physics, which has been a spectacularly powerful force driving progress in the theory of knot invariants. Not only did students discuss with lecturers after the talks, during coffee breaks, and beyond, but also did the students organize several "math-physics clinics", in which students with different backgrounds explained some basic concepts from their respective field to each other. One can be very confident that these seeds and contact will grow during the coming years. The second notable feature were the many open questions that each lecturer highlighted towards the end of their lectures. And these are as many opportunities for the formation of the next generation! As participants prepared to leave Montréal laden with a wealth of impressions, new friendships, and as much additional knowledge as they could carry, the organizers realized once again that the ultimate success of the school will really only be measured, several years down the road, in its contribution to the launch of the participants' research careers!

As its immediate predecessors, this year's edition of the SMS was made possible by

financial support from a consortium of North American Mathematics Institutes, including the Centre de Recherches Mathématiques, the Fields Institute, the Mathematical Sciences Research Institute, the Pacific Institute for the Mathematical Sciences, the Institut des Sciences Mathématiques, the Canadian Mathematical Society, the Centre Interdisciplinaire de Recherche en Géométrie et Topologie. In addition, we received a generous contribution from the Simons Foundation for the attribution of Fellowships to 20 particularly promising students.

5 Detailed record of Activities

The first week began with a quick and down-to-earth introduction to Khovanov homology by **Dror Bar-Natan**. Without any of the modern complications, Bar-Natan first reviewed the Kauffman bracket of the Jones polynomials as Kauffman told it in 1987, then the Khovanov homology story as Khovanov told it in 1999, and finally his "local Khovanov homology" story as understood in 2003. The lectures ended with some recent new ideas about categorification of the Alexander polynomial, rooted in the concept of "meta-groups" and the construction of "meta-bicrossed-product". Bar-Natan's particular emphasis on computability was, as always, a highly appreciated feature.

The pièce de résistance of the first week were three sets of lectures on the physics of Chern-Simons theory, each of different character, and focused on different aspects: **Ramadevi** gave an inspired review of Chern-Simons theory, braid calculus and recent results on Racah coefficients. Her first lecture included a basic review of Chern-Simons theory as a physical theory of knots and links. In the second lecture, she showed explicit calculations of the polynomial invariants for a few simple knots within SU(2) Chern-Simons theory (i.e., the colored Jones polynomial) and also SU(N) Chern-Simons theory (colored HOMFLY-PT). In the third lecture, she discussed some of her recent work on homological invariants. **Mina Aganagic**'s lectures were centred around so-called refined Chern-Simons theory—the basic idea being to introduce the dependence on the homological deformation parameter directly into the modular transformation matrices of the two-dimensional conformal field theory. It turns out that this program can be pushed to the end for Seifert fibered knots and 3-manifolds. Aganagic emphasized why the additional symmetry is so crucial for computability: It means that the relevant physical quantity in the M-theory picture reduces to an index computation, and does not require a (in general, messy) identification of the exact space of ground states. **Marcos Mariño** explained in detail the why and how of the "reformulation" of the colored HOMFLY and Kauffman invariants. The basic point is that the simplest basis in which to present the colored invariants is not the most naive one, indexed by irreducible representations of the symmetric group. Instead, one should perform a sequence of rather non-trivial transformations, as suggested by the relation with the topological string. In this interpretation, the expansion coefficients of the resulting expressions are the (yet to be rigorously defined) relative Gopakumar-Vafa invariants of a corresponding D-brane setup. Some of the associated integrality and polynomiality conjectures have recently been proven. The

challenge with which Mari´ no ended his lectures is the extension of the reformation to the homological invariants.

As one of the first mathematicians to take up to the challenges of large-N duality, **Alexei Oblomkov** reviewed his conjectures (with Rasmussen and Shende) relating Khovanov-Rozansky homology and Hilbert schemes, as well as the representation theory of the rational Cherednik algebra. In more detail, the conjectures concern the link of a planar singularity and the cohomology of some moduli spaces of sheaves on the corresponding planar curve. In the case of the quasi-homogeneous singularity $x^p = y^q$, it is also expected that the homology of the link, which is a toric link, carries an action of the Cherednik algebra (this representing joint work with Gorsky, Rasmussen and Shende). Oblomkov gave a detailed introduction of all the objects involved in the conjectures and discussed recent progress in proving these conjecture.

One of the recent landmarks in the theory of knot homology is **Ben Webster**'s categorification of arbitrary Reshetikhin-Turaev invariants. In his beautifully illustrated lectures at the school, Webster explained how to generalize Khovanov-Lauda-Rouquier algebras to categorify tensor products, and how to then apply these generalizations to construct categorifications of quantum knot invariants. The first two lectures were building up the subject, starting from fundamental representation of $su(2)$. In the third talk, Webster sketched the program that will relate these invariants to A-branes on quiver varieties.

A particular highlight of the first week were two lectures, by **Piotr Sulkowski** and **Hiroyuki Fuji**, on the recently developed relation between colored homological invariants and the super-A-polynomial via the volume conjecture. The constructions fit beautifully into the general physics framework of mirror symmetry, quantum curves, and topological recursion. The lack of a representation theoretic foundation of the deformed A-polynomial stands as one of the important open problems.

Bridging the first to the second week, **Johannes Walcher** started his lectures with an overview of the physics ideas underlying the interest in knot homology. He emphasized the role of large-N transition as the most important part of the duality web. As an illustration of the physics methods and language, and a preparation for Khovanov-Rozansky homology, Walcher then reviewed the role of matrix factorizations as boundary conditions in Landau-Ginzburg models. In his second lecture at the beginning of the second week, he explained the relation between the knot homology of the unknot for minuscule representations, the cohomology of Hermitian symmetric spaces, and Jacobi rings. He ended his lectures with the Landau-Ginzburg motivation underlying the differentials on knot homology. The challenge was to complete the construction of the universal differentials relating knot homologies for unitary and orthogonal/symplectic groups.

The start of the second week proper were **Aaron Lauda**'s lectures on the use of Howe duality for categorification of quantum knot invariants. This story begins with Cautis-Kamnitzer-Licata's simple new approach to understanding these invariants using basic representation theory and the quantum Weyl group action. The basic point of Howe duality, or

more precisely a version of it for exterior algebras called skew-Howe duality, is to pair the action of the braid group to the action of the quantum Weyl group. Even the graphical (or skein theoretic) description of the knot invariants can be recovered in an elementary way from this data. Even though it is restricted to a certain type of algebras and representations, the advantage of the Howe duality approach is that it suggests a 'categorification' where knot homology theories arise in an elementary way from higher representation theory and the structure of categorified quantum groups.

Pace picked up further with **Mikhail Khovanov**'s lectures, who gave an introduction to categorification of quantum groups, starting with the notion of Grothendieck groups of algebras and categories. He explained possible framework when the direct sum of Grothendieck groups of a family of algebras admits the structure of a bialgebra or a twisted bialgebra via maps induced by induction and restriction functors. From the model case of group algebras of symmetric groups he moved on to a more refined setup of KLR algebras, explaining how Serre relations on the categorified level emerge from the diagrammatics of these algebras. He concluded by explaining an approach to categorify these groups at a prime root of unity, by equipping KLR algebras with certain p-differentials and working in the hopfological framework.

One of the basic blends of math and physics ideas underlying knot homologies is the relation between higher categories and higher topological quantum field theories. **Anton Kapustin**, who is one of the pioneers of the subject, gave two lectures on a class of 3-dimensional topological field theories known as abelian Chern-Simons theory, in which the 2-category of boundary conditions can be described completely explicitly. The theory, which turns out to be surprisingly restrictive, also has applications in condensed matter physics such as the quantum Hall effect.

Lev Rozansky, who was one of the senior participants of the school, was asked to give a one-hour seminar to share his expertise with the students. He chose to talk about the construction of colored Khovanov homology using the Jones-Wenzl projector. The idea is to cable link components and present the Jones-Wenzl projector as a limit of a directed system of twist braids. One advantage is that the twist braid representation makes colored Khovanov homology computable with the help of programs computing the non-colored theory.

The most detailed overview over the physics of knot homology was offered by **Sergei Gukov**. He explained in a stimulating lecture the diversity of relevant physical theories, involving topological quantum field theories in 2, 3, 4, and even 5 and 6 dimensions, string theories, M-theory, and dualities between all of the above. The main message was that these are really just different vantage points, from each of which particular structures become best visible. In his second lecture, Gukov explained the origin and uses of the vortex equations for the purposes of explicitly constructing knot homology.

As mentioned above, one of the most intriguing structural properties of knot homologies is the existence of differentials that relate various theories, both in rank space (where they correspond to finite-N corrections in the physics language), as well as in color space. The

excitement is due in large measure to the fact that the differentials lack an obvious counterpart before categorification, even though they are usually accompanied by new structural properties of the polynomial invariants as well. **Marko Stošić** presented a comprehensive overview of the presently known structure of differentials on theories of knot homologies. The motivations stem from physics/geometry insights that include BPS state counting and Landau-Ginzburg theories, but are also related to representation theory of superalgebras and Cherednik algebras. The main features are the "colored" differentials that relate homological invariants of knots colored by different representations. Stošić finished his lectures with a discussion of the relationship between differentials and the recursion relations of colored knot invariants encoded in the super-A-polynomial of Fuji-Gukov-Sulkowski.

Even though the theory of differentials in that full glory remains conjectural, there is a firm ground f or hope. As explained in **Jacob Rasmussen**'s lectures, one can indeed explain some of the differentials on Khovanov-Rozansky theory categorifying HOMFLY-PT by constructing appropriate spectral sequences converging to the sl(N) theories, thereby generalizing certain early observations of Lee and Gornik on knot Floer homology and Khovanov homology, respectively. Rasmussen finished his two lectures with a sketch of the uses of Cherednik algebras for further progress in this very promising area, which is fully understood at least for torus knots.

Joel Kamnitzer described his joint work with Cautis for constructing knot homology theories using the affine Grassmannian and the geometric Satake correspondence, which works well for all minuscule representations. He also gave an aperçu of the relations to other approaches to knot homology, including those of Khovanov, Mackaay, Webster and Witten. Thereby, the quantization of associated hyperkahler manifolds emerged as a very promising theme of the future.

Last not least, **Ciprian Manolescu** reviewed knot Floer homology and its relation with Heegard Floer homology. Knot Floer homology takes its origin in Seiberg-Witten theory. Manolescu reviewed the original definition given by Ozsvath-Szabo, and Rasmussen around 2003, which was based on symplectic geometry. In the meantime, at least five different combinatorial descriptions have become available. Manolescu explained the one based on grid diagrams (joint work with Ozsvath and Sarkara from 2006) and the one based on a cube of resolutions, which is reminiscent of HOMPLY-PT homology (work of Ozsvath and Szabo from 2007). One of the nice features of the symplectic approach to knot homology is the clear relation with a corresponding theory of invariants of three-mnanifolds (Heegard Floer homology). This is almost completely missing in the other approaches, and so the program of the school ended with the challenge wether the general three-manifold invariants of Reshetikhin-Turaev-Witten type could similarly be categorified.

6 Organization and Administration

We received over 120 applications from around the world. We sent out 101 invitations, offering partial support (accomodation in dormitories) to all non-local invitees. In correspondence with responsible people, we selected 23 participants for funding through MSRI. Based on excellence recommendation from their advisors, we also selected 20 students for support through Simons Fellowships. Of those invited, 28 attended with SMS support, 21 with MSRI support, 19 with Simons Fellowships, and 3 with a CMS Scholarship. 19 (mostly locals) did not receive any support from us. A number of participants received additional support from their home institutions toward travel expenses.

Around 90% of the support for participants went to graduate students. In addition, we also offered support to several high-profile senior participants with limited own funds. This decision was based in part on the pedagogical and scientific value that these participants contributed through topical seminars, interacions with students, and leading of discussion sessions.

Of the 90 participants, 13 (14%) were female. Canadian participants included 3 from the University of Toronto, 1 each from the Fields and Perimeter Institute, 7 from UQAM, 3 from McGill and 1 from Sherbrooke. The students from Toronto were awarded a CMS scholarship, valued 700$ each.

We offered full support (travel, accomodation and per diem meals) to speakers, although some instead chose to use their own funds for travel. All lectures were recorded and are available online via the SMS website.

The overall administration, arrangement of accomodation, refreshments, folders, and reimbursements, were all handled superbly by the SMS Staff.

7 Outline of Expenditures

- SPEAKERS: Housing at the Terrace Royal hotel near the Université de Montréal, reimbursement of travel expenses and per diem meals.
- SMS FUNDED PARTICIPANTS: 2 weeks at the Université de Montréal dormitories, nonrefundable, plus support for travel expenses depending on the distance to Montréal from the participant's location of study.
- MSRI FUNDED PARTICIPANTS: 21 participants. MSRI support covered housing, meals and travel expenses.
- SIMONS FELLOWSHIPS: 19, valued $1000 each.
- CMS FELLOWSHIPS: 3, valued $700 each.
- SENIOR PARTICIPANTS/SESSION LEADERS: partial support of accomodation in hotel or dormitories, and travel expenses
- SOCIAL EVENTS: daily breakfast and coffee breaks, one wine-and-cheese reception (covered by registration fee), two speakers' dinners at local restaurants.
- MISCELLANEOUS: Poster, video recording, photographs, photocopies

8 List of Participants

* Zodinmawia, IIT Bombay (Simons Fellow)
* Abel, Maabel, Virginia (MSRI)
* Appel, Andrea, Northeastern (Simons Fellow)
* Artamonov, Semen, ITEP (Simons Fellow)
* Bade, Nathaniel, Northeastern (MSRI)
* Baik, Hyungryul, Cornell (Simons Fellow)
* Bashkirov, Denis, Perimeter (Pdf) (no support)
* Belin Alexandre, McGill (no support)
* Berg-Brisebois, Karl-Alexander, UQAM (no support)
* Bosc, Jean-Franois, UQAM (no support)
* Brown, Michael, Nebraska (MSRI)
* Bryden, John, Bin Fahd (Prof) (SMS)
* Burgos Soto, Hernando, George Brown (Pdf) (no support)
* Celoria, Daniele, Florence (Simons Fellow)
* Chien, Edward, Rutgers (SMS)
* Chung, Hee Joong, Caltech (Simons Fellow)
* Collin, Olivier, UQAM (no support)

* Colon, Nelson, Iowa (SMS)
* Cooper, Benjamin, MPI Bonn (Pdf) (no support)
* Dancso, Zsuzsanna, Fields (Pdf) (no support)
* Dawra, Nakul, Caltech (MSRI)
* Egilmez, Ilknur, USC (MSRI)
* Elliot, Ross, Caltech (MSRI)
* Ellis, Alexander, Columbia (SMS)
* Fay, Eric, Rutgers (no support)
* Fuji, Hiroyuki, Tokyo (Prof) (SMS)
* Gainullin, Fjodor, Imperial (Simons Fellow)
* Ginory Alejandro, Rutgers (no support)
* Gomes, Chris, Chicago (MSRI)
* Grant, Jonathan, Durham (Simons Fellow)
* Gu, Liling, Caltech (MSRI)
* Halacheva, Iva, Toronto (CMS)
* Heyman, Andrea, Columbia (SMS)
* Hogancamp Matt, Virginia (SMS)
* Ito, Noboru, Waseda (Prof) (no support)
* Jimenez, Ana Cristina, Iowa (MSRI)
* Jones, Dan, Durham (Simons Fellow)
* Karimi, Homajun, UQAM (no support)
* Kauffman, Louis H, Chicago (Prof) (SMS)
* Khardani, ali, UQAM (no support)
* Konishi, Masahide, Nagoya (Simons Fellow)
* Krcatovich, David, Michigan (Simons Fellow)
* Kutluay, Deniz, Indiana (MSRI)
* Lai, Alan, Caltech(Pdf) (no support)
* Lambert-Cole, Peter, Louisiana (MSRI)
* Lazarus Tynan, Rutgers (no support)
* Le, Ian, Northwestern (SMS)
* Leverson, Caitlin, Duke (MSRI)
* Lin, Francesco, MIT (MSRI)
* Manfredi Enrico, Universita di Bologna (SMS)
* Mangual, John, UCSC (SMS)
* Morgan, Stephen, Toronto (CMS)
* Mossessian, George, Davis (MSRI)
* Nawata, Satoshi, NIKHEF (Pdf) (SMS)
* Pan, Yu, Duke (SMS)

* Perry, Alex, Harvard (MSRI)
* Putrov, Pavel, Caltech (Pdf) (SMS)
* Putyra, Krzysztof, Columbia (Simons Fellow)
* Queffelec, Hoel, Jussieu (Simons Fellow)
* Ravelomanana, Huygens Christian, UQAM (no support)
* Rose, David, USC (SMS)
* Rozansky, Lev, UNC SEN
* Saberi, Ingmar, Caltech (SMS)
* Saltz, Adam, Boston (MSRI)
* Samperton, Eric, Davis (Simons Fellow)
* Samuelson, Peter, Toronto (CMS)
* Schultz, Douglas, Rutgers (MSRI)
* Scott, Maxim, UQAM (no support)
* Seed, Cotton, Princeton (no support)
* Selmani, Sam, McGill (no support)
* Sne, Mamadou, Sherbrooke (SMS)
* Seo, Jihye, McGill (no support)
* Seonhwa, Kim, Seoul (MSRI)
* Setter, Kevin, Caltech (SMS)
* Shakirov Shamil, Berkeley (SMS)
* Shelly, Tom, Amherst (SMS)
* Starostka, Maciej, Polish Acad Sc. (SMS)
* Su Kung-Yi, Caltech (SMS)
* Sulkowski, Piotr, Warsaw (Prof) (SMS)
* Thorngren, Ryan, Caltech (SMS)
* Truong, Linh, Princeton (Simons Fellow)
* Tsumura, Yu, Purdue (MSRI)
* Wang, Zhao, Texas A&M (SMS)
* Wedrich, Paul, Cambridge (Simons Fellow)
* Wilson, Tobias, Umass (SMS)
* Yoo, Philsang, Northwestern (Simons Fellow)
* You, Qi, Columbia (MSRI)
* Young, Matthew, Stonybrook (Simons Fellow)
* Zenkevich, Yegor, ITEP (Simons Fellow)
* Zhou, Qiao, (MSRI)

9 Feedback from Participants

Following the event, we collected feedback from the participants via an online questinnaire on the CRM website. Here are some results.

Question: *Which of the following statements to you most agree with?*	
The lectures were so difficult that I could not benefit at all	0
The lectures were very difficult, but I could still benefit	28
The lectures were easy to follow, and I learned a lot	23
The lectures were too easy, and I was bored	1

Question: *The schedule was*	
too light	1
about right	43
too tight	6

Comments (Selection)

- "The intention of the program is great. Bringing physicists and mathematicians to look at one particular subject of topology from different angles."
- "It's great to talk to physicists as a mathematician. This is really a rare opportunity for a math new graduate like me. "
- "De nombreux moments de discussion ont permis d'échanger avec un grand nombre de doctorants, post-doctorants et conférenciers. Je repars avec de nombreuses idées, et de nouveaux contacts !"
- "The physics lectures were far from introductory, unfortunately."
- "the main asset of this conference was meeting people. I had never meet Lou Kauffman before! Or heard Dror Bar-Natan speak. I also met Marcos Marino and Sergei Gukov. Ramadevi was excellent pedagogically. In general, I found the algebraists too... algebraic. We grad students organized our own math-physics discussion session, trying to reconcile the two disciplines. It will be a long time. Not all faculty were approachable. I couldn't really talk to Kapustin or Aganagic much. That's the way the ball bounces."
- "As the workshop was advertised as being for graduate students from multiple disciplines within both physics and mathematics, some more introductory talks would have been helpful; alternatively, the discussions would have been more useful had they been held on the second or third day, instead of the third to last day. "
- "The scientific programming was of very high quality, and I think valuable for participants of all levels. "

* "Outstanding. It was a nice blend of physicists and mathematicians. The mathematicians were not just confined to low-dimensional topologists, but also algebraic geometers and representation theorists. They gave a nice broad overview of the subject."
* "These lectures spawned new questions for me to explore. I've spent the weekend scouring the arXiv for papers by Johanes Walcher and Sergei Gukov. I have the happy problem of having yet more things to learn."
* "Talks were scheduled appropriately so that related talks were close to each other (in time)"
* "The scientific programming was excellent. Many of the speakers were well-known experts in the field, and many of them gave very useful, well-planned talks. There was also a good variety of levels of the talks. Overall they provided an excellent introduction to the field, a broad overview of the theory as a whole, and a good survey of several very interesting recent results and conjectures."
* "I learned several things at this summer school that will immediately impact my work in a positive way. The summer school also opened several new avenues of possible long-term research that may create interesting new connections between my work and the topics discussed during the lectures and conversations afterwards."
* "It was extraordinarily helpful to have a thematic program dedicated to exploring a wide variety of perspectives on and developments related to knot homologies, and aimed at graduate students or beginning researchers rather than experts in the field. I strongly feel that summer schools such as the SMS are essential for young mathematicians trying to get up to speed. I learned a lot, and I am confident that the other attendees did as well."

Centre de recherches mathématiques
Université de Montréal

École d'été SMS 2013 : Physique et Mathématiques de l'Homology des Entrelacs
Du 24 juin au 5 juillet 2013

SMS 2013 Summer School: Physics and Mathematics of Link Homology
June 24 - July 5, 2013

HORAIRE / *PROGRAM*

Le lundi 24 juin 2013 / *Monday, June 24, 2013*

08:00 - 09:00 Inscription et café croissants (Hall d'entrée Aisenstadt) / *Registration and Coffee & Croissants (Hall d'entrée Aisenstadt)*

09:00 - 10:15 **Dror Bar-Natan** (University of Toronto)
"A quick introduction to Khovanov homology-I"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Ramadevi Pichai** (Indian Institute of Technology)
"Chern-Simons theory and knot invariants-I"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Alexei A. Oblomkov** (Massachusetts Institute of Technology)
"Topology of planar curves, knot homology and representation theory of Cherednik algebras-I"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:30 **Mina Aganagic** (University of California)
"Knots and string dualities-I"

Le mardi 25 juin 2013 / *Tuesday, June 25, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Marcos Marino** (Université de Genève)
"Integrality properties of link invariants from topological-strings-I"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Dror Bar-Natan** (University of Toronto)
"A quick introduction to Khovanov homology-II"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Alexei A. Oblomkov** (Massachusetts Institute of Technology)
"Topology of planar curves, knot homology and representation theory of Cherednik algebras-II"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:30 **Mina Aganagic** (University of California)
"Knots and string dualities-II"

16:30 Cocktail de bienvenue (6245) / *Welcoming reception (6245)*

Le mercredi 26 juin 2013 / *Wednesday, June 26, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:15 - 10:15 **Piotr Sulkowski** (University of Warsaw)
"TBA"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Dror Bar-Natan** (University of Toronto)
"Meta-groups, Meta-bicrossed-products, and the Alexander polynomial"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Ramadevi Pichai** (Indian Institute of Technology)
"Chern-Simons theory and knot invariants-II"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:30 **Ben Webster** (Northeastern University)
"Knot homology, KLR algebras and quiver Varietys-I"

Le jeudi 27 juin 2013 / *Thursday, June 27, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Marcos Marino** (Université de Genève)
"Integrality properties of link invariants from topological strings-II"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Ben Webster** (Northeastern University)
"Knot homology, KLR algebras and quiver Varietys-III"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Alexei A. Oblomkov** (Massachusetts Institute of Technology)
"Topology of planar curves, knot homology and representation theory of Cherednik algebras-III"

14:45 - 15:15 Pause-café / *Coffee break*

15:15 - 16:30 **Ramadevi Pichai** (Indian Institute of Technology)
"Chern-Simons theory and knot invariants-III"

Le vendredi 28 juin 2013 / *Friday, June 28, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Ben Webster** (Northeastern University)
"Knot homology, KLR algebras and quiver Varietys-II"

10:15 - 10:45 Pause-café / *Coffee break*

10:45 - 12:00 **Marcos Marino** (Université de Genève)
"Integrality properties of link invariants from topological strings-III"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Johannes Walcher** (McGill University)
"Matrix factorizations and topological strings for knots-I"

14:45 - 15:15 Pause-café / *Coffee break*

15:15 - 16:15 **Hiroyuki Fuji** (University of Tokyo)
"TBA"

Le lundi 1 juillet 2013 / *Monday, July 1, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Johannes Walcher** (McGill University)
"Matrix factorizations and topological strings for knots-II"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Aaron Lauda** (University of Southern California)
"Knot invariants and their categorifications via Howe duality-I"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Mikhail Khovanov** (Columbia University)
"Categorification of the HOMFLYPT polynomial and its specializations-I"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:30 **Anton Kapustin** (California Institute of Technology)
"Abelian Chern-Simons theory as an extended topological field theory-I"

Le mardi 2 juillet 2013 / *Tuesday, July 2, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Aaron Lauda** (University of Southern California)
"Knot invariants and their categorifications via Howe duality-II"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Mikhail Khovanov** (Columbia University)
"Categorification of the HOMFLYPT polynomial and its specializations-II"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Anton Kapustin** (California Institute of Technology)
"Abelian Chern-Simons theory as an extended topological field theory-II"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:15 **Lev Rozansky** (University of North Carolina at Chapel Hill)
"TBA"

Le mercredi 3 juillet 2013 / *Wednesday, July 3, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Sergei Gukov** (Harvard University)
"Overview of physics of knot homologies-I"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Marko Stosic** (Instituto Superior Técnico)
"Colored HOMFLY homology of knots and links-I"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Jake Rasmussen** (University of Cambridge)
"Differentials on knot homologies- I"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:30 **Joel Kamnitzer** (University of Toronto)
"Knot homology via the affine Grassmannian-I"

Le jeudi 4 juillet 2013 / *Thursday, July 4, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Ciprian Manolescu** (UCLA)
"An introduction to knot Floer homology"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Sergei Gukov** (Harvard University)
"Overview of physics of knot homologies-II"

12:00 - 13:30 Pause-déjeuner / *Lunch break*

13:30 - 14:45 **Marko Stosic** (Instituto Superior Técnico)
"Colored HOMFLY homology of knots and links-II"

14:45 - 15:15 Pause-café / *Coffee break*
(Salle / *Room* 1221)

15:15 - 16:30 **Jake Rasmussen** (University of Cambridge)
"Differentials on knot homologies- II"

Le vendredi 5 juillet 2013 / *Friday, July 5, 2013*

08:30 - 09:00 Café croissants (1221) / *Coffee & Croissants (1221)*

09:00 - 10:15 **Joel Kamnitzer** (University of Toronto)
"Knot homology via the affine Grassmannian-II"

10:15 - 10:45 Pause-café / *Coffee break*
(Salle / *Room* 1221)

10:45 - 12:00 **Ciprian Manolescu** (UCLA)
"From knot Floer homology to invariants of 3- and 4-manifolds"

Appendix 2: Budget

You will find below a summary of expenditures and income. The pages that follow contain a detailed budget.

EXPENDITURES

Speakers – travel and local expenses:	28685.19$
Student participants – student residences and travel support:	52,117.12$
Other expenditures – meals, advertisements, staff pay, proceedings distribution (estimated)	14,996.65$
TOTAL EXPENDITURES (estimated):	95798.96$
INCOME – grants and registration fees:	95,985.00$

For the tables that follow, the expenditures that are only estimated at this time (due to delays with various transactions, reimbursements etc) are in blue.

Revenue

CRM	$	20,000.00
FIELDS	$	10,000.00
PIMS	$	10,000.00
ISM	$	7,500.00
CMS	$	2,000.00
CIRGET	$	5,000.00
SIMONS	$	19,865.00
MSRI	$	20,000.00
REGISTRATION FEES		1,620.00$
Total revenue	**$**	**95,985.00**

Summary of Expenditures.

Speakers, housing and travel	
Housing	11,603.69$
Travel	17,081.50$
Total expenditures speakers	**28,685.19$**
Student Participants housing and travel	
Housing	33,240.00$
Travel	18,877.12$
Total student expenditures	**52,117.12$**
Other Expenditures.	
Poster	**1,770.62$**
Video recording and photos	**3,000.00$**
Hospitality fees.	
Pauses café	2,634.82$
Réception	1,174.68$
Épicerie	438.47$
Frais de représentation	1,751.66$
Total hospitality	**5,999.63$**
Paper etc	**99.40$**
Technical Assistants and staff	
70 heures à 16,11 $	**1,127.00$**
Other expenditures - total	**11,996.65$**
Proceedings volume - distribution	
	3,000.00$
Total expenditures	**95,798.96$**

Detail of expenditures for each participant.

Conférenciers		Hôtel	Remboursement		Total Conférenciers
Mina Aganagic	Berkeley	**259.42**	*1,700.00$*		
Dror Bar-Natan	Toronto	**648.55**	625.01$		
Sergei Gukov	Caltech	**778.26**	1,085.00$		
Joel Kamnitzer	Toronto	**621.18**	762.54$		
Anton Kapustin	Caltech	**389.13**	1,424.00$		
Mikhail Khovanov	Columbia	**956.76**	405.00$		
Aaron Lauda	Southern California	**648.55**	902.00$		
Ciprian Manolescu	Ucla	**1059.1**	225.00$		
Marcos Mariño	Geneva	**518.84**	2,939.00$		
Alexei Oblomkov	Amherst	**1605.31**	*1,500.00$*		
Ramadevi Pichai	Bombay	**827.05**	2,165.00$		
Jake Rasmussen	Cambridge	**648.55**	769.95$		
Marko Stošić	Lisbon	**778.26**	1,486.00$		
Johannes Walcher	McGill				
Ben Webster	Northeastern	**1475.6**	1,093.00$		
Piotr Sulkowski		**389.13$**			
		11,603.69$	17,081.50$		**28,685.19$**
Participants	**Institution**	**University Residence**	**Travel**	**Funding**	**Total participants**
, Zodinmawia	IIT Bombay		600.00$	SIMONS	
Abel, Maabel	Virginia			MSRI	
Appel, Andrea	Northeastern		600.00$	SIMONS	
Artamonov, Semen	ITEP		600.00$	SIMONS	
Bade, Nathaniel	Northeastern			MSRI	
Baik, Hyungryul	Cornell		600.00$	SIMONS	
Bashkirov, Denis	Perimeter (Pdf)				
Belin Alexandre					
Bosc, Jean-François	UQAM				
Brown, Michael	Nebraska			MSRI	
Bryden, John	Bin Fahd (Prof)		1,000.00$	SMS	
Burgos Soto, Hernando	George Brown (Pdf)		*250.00$*		
Celoria, Daniele	Florence		600.00$	SIMONS	
Chien, Edward	Rutgers			SMS	
Chung, Hee Joong	Caltech		600.00$	SIMONS	
Colon, Nelson	Iowa			SMS	
Cooper, Benjamin	MPI Bonn (Pdf)			SMS	
Dancso, Zsuzsanna	Fields (Pdf)				
Dawra, Nakul	Caltech			MSRI	
Egilmez, Ilknur	USC			MSRI	
Elliot, Ross	Caltech			MSRI	
Ellis, Alexander	Columbia			SMS	
Fay, Eric	Rutgers				
Fuji, Hiroyuki	Tokyo (Prof)		500.00$	SMS	
Gainullin, Fjodor	Imperial		600.00$	SIMONS	
Ginory Alejandro	Rutgers				
Gomes, Chris	Chicago			MSRI	
Grant, Jonathan	Durham		600.00$	SIMONS	
Gu, Liling	Caltech			MSRI	
Halacheva, Iva	Toronto		300.00$	CMS	
Heyman, Andrea	Columbia			SMS	
Hogancamp Matt	Virginia			SMS	
Ito, Noboru	Waseda (Prof)				
Jimenez, Ana Cristina	Iowa			MSRI	
Jones, Dan	Durham		600.00$	SIMONS	
Kauffman, Louis H	Chicago (Prof)		1,000.00$	SMS	
khardani, ali	UQAM				
Konishi, Masahide	Nagoya		600.00$	SIMONS	
Krcatovich, David	Michigan		1,000.00$	SIMONS	
Kutluay, Deniz	Indiana			MSRI	
Lai, Alan	Caltech(Pdf)			SMS	
Lambert-Cole, Peter	Louisiana			MSRI	
Lazarus Tynan	Rutgers				
Le, Ian	Northwestern			SMS	
Leverson, Caitlin	Duke			MSRI	
Lin, Francesco	MIT			MSRI	
Manfredi Enrico	Universita di Bologna			SMS	
Mangual, John	UCSC			SMS	
Morgan, Stephen	Toronto		240.00$	CMS	
Mossessian, George	Davis			MSRI	
Nawata, Satoshi	Nikhef (Pdf)		700.00$	SMS	
Pan, Yu	Duke		*250.00$*	SMS	
Perry, Alex	Harvard			MSRI	
Putrov, Pavel	Caltech (Pdf)		700.00$	SMS	
Putyra, Krzysztof	Columbia			SIMONS	
Queffelec, Hoel	Jussieu		600.00$	SIMONS	
Ravelomanana, Huygens Christian	UQAM				
Rose, David	USC			**SMS**	
Rozansky, Lev	UNC			SMS	
Saberi, Ingmar	Caltech			SMS	
Saltz, Adam	Boston			MSRI	
Samperton, Eric	Davis		600.00$	SIMONS	
Samuelson, Peter	Toronto (Pdf)		700.00$	CMS	
Schultz, Douglas	Rutgers			MSRI	
Selmani, Sam	McGill				
Sène, Mamadou	Sherbrooke			SMS	
Seonhwa, Kim	Seoul			MSRI	
Setter, Kevin	Caltech			SMS	
Shakirov Shamil	Berkeley		637.12$	SMS	
Shelly, Tom	Amherst			SMS	
Starostka, Maciej	Polish Acad Sc.		*250.00$*	SMS	
Su Kung-Yi	Caltech			SMS	
Sulkowski, Piotr	Warsaw (Prof)		500.00$	SMS	
Thorngren, Ryan	Caltech			SMS	
Truong, Linh	Princeton		1,000.00$	SIMONS	
Tsumura, Yu	Purdue			MSRI	
Wang, Zhao	Texas A&M		*250.00$*	SMS	
Wedrich, Paul	Cambridge		600.00$	SIMONS	
Wilson, Tobias	Umass			SMS	
Yoo, Philsang	Northwestern		600.00$	SIMONS	
You, Qi	Columbia			MSRI	
Young, Matthew	Stonybrook		600.00$	SIMONS	
Zenkevich, Yegor	ITEP		600.00$	SIMONS	
Zhou, Qiao	Berkeley			MSRI	
Berg-Brisebois Karl-Alexander	UQAM				
Karimi Homajun			*250.00$*		
Scott Maxim	UQAM				
Seed Cotton	Princeton				
Seo Jihye					
Olivier Collin	UQAM				
		33,240.00$	18,877.12$		**52,117.12$**
Grand total					**80,802.31$**