

Final Report
JUNIOR TRIMESTER PROGRAM
SYMPLECTIC GEOMETRY AND REPRESENTATION THEORY

Gustavo Jasso and Julian Külshammer

Group name:

Mirror symmetry, Fukaya categories and Auslander-Reiten theory

Group members:

Luís Diogo, Gustavo Jasso, Julian Külshammer, Sangwook Lee, Cheuk Yu Mak, Michael McBreen, Hyung-Seok Shin.

Research interests:

A_∞ -structures; Auslander–Reiten theory; Fukaya categories; bocses; quasi-hereditary algebras; Koszul duality; (homological) mirror symmetry; symplectic Khovanov homology; symplectic topology.

Scientific activities

The group acknowledges the excellent working conditions provided by the Hausdorff Research Institute for Mathematics (HIM). We are particularly grateful for the funding provided to organise the workshop below, an activity beneficial to all the members of our group and to the additional participants who travelled to Bonn for this event.

Workshop: A_∞ -structures in geometry and representation theory ([go to homepage](#))

The aim of the workshop was to bring together young researchers interested in the applications of A_∞ -structures to (symplectic or algebraic) geometry and representation theory. The workshop was very successful, with 63 registered participants and 16 talks. Recordings of most talks are available online at [the program's online schedule](#).

Speakers:

Anna Barbieri, Raf Bocklandt, Agnieszka Bodzenta, Roger Casals, Luís Diogo, Daniela Egas Santander, Ailsa Keating, Sangwook Lee, Cheuk Yu Mak, Michael McBreen, Daniel Pomerleano, Alice Rizardo, Helge Ruddat, Dmytro Shklyarov, Nicolò Sibilla, Tashi Walde.

Trimester seminar ([go to schedule](#))

The Junior Trimester Program included a regular seminar. Group member Julian Külshammer contributed the talk 'From A_∞ -algebras to bocses via Koszul duality'.

Research output

Below we list the research output of our group, including published articles, preprints, and preprints in preparation on which (at least partial) work was done by the members of our group during their stay at the HIM.

- **Luís Diogo** acknowledges fruitful discussions with Daniel Pomerleano and Helge Rudat (both workshop speakers). He also acknowledges discussions with the symplectic geometry group in Bochum, where he gave a talk while visiting the HIM.
- **Luís Diogo** worked on an ongoing project with Mohammed Abouzaid, about monotone Lagrangians on cotangent bundles of spheres. They found generators for the compact monotone Fukaya category of such cotangent bundles. The Yoneda embedding reduces the problem to a classification of modules over a polynomial algebra in one variable, that is to Jordan form.

- **Luís Diogo** worked on an ongoing project with Dmitry Tonkonog, Renato Vianna and Weiwei Wu. In this project they lift monotone Lagrangians from Donaldson-type hypersurfaces in closed symplectic manifolds. They find a formula for the superpotential of a Biran-lift of a monotone Lagrangian. This has applications to the classification of monotone Lagrangians on closed monotone symplectic manifolds, and yields a new proof of a version of the quantum Lefschetz theorem in Gromov–Witten theory.
- **Gustavo Jasso** and **Julian Külshammer** continued work on their article [JK19] and on the forthcoming preprints [BJK, JK]. These works introduce and develop the representation theory of higher Nakayama algebras, a new class of finite-dimensional algebras generalising the class of Nakayama algebras from the point of view of higher Auslander–Reiten theory.
- **Julian Külshammer** worked on an ongoing project generalising joint work with Steffen Koenig and Sergiy Ovsienko on using A_∞ -structures to construct exact Borel subalgebras of quasi-hereditary algebras. He especially acknowledges helpful discussions with Sam Gunningham (participant of the JTP) and Theo Raedschelders (postdoc at HCM at the time) through which he got ideas for an alternative proof which admits an easier generalisation.
- **Sangwook Lee** and **Hyung-Seok Shin** worked on the preprint [CLS18] which is joint work with Cheol-Hyun Cho. In this work they compare Calabi–Yau structures on categories mirror to each other using closed mirror symmetry relating a quantum cohomology and a Jacobian ring. The remarkable fact is that they need to modify the ring isomorphism between them by Floer theoretic point class.
- **Sangwook Lee** also worked on the preprint in preparation ‘Noncommutative homological mirror symmetry of elliptic curves’. In the paper ‘Noncommutative homological mirror functor’ by Cho-Hong-Lau, Hansol Hong and Siu-Cheong Lau (arXiv:1512.07128), they gave a functor from the Fukaya category of 2-torus to the category of matrix factorizations of a potential in a Sklyanin algebra which is noncommutative. By comparing the functor via Orlov’s LG/CY correspondence functor and homological mirror symmetry of Polishchuk–Zaslow, it is proved that the noncommutative functors are indeed equivalences.
- **Cheuk Yu Mak** and Helge Ruddat (workshop speaker) worked on their preprint [MR19], in which they use tropical curves and toric degeneration techniques to construct closed embedded Lagrangian rational homology spheres in several Calabi–Yau three-folds. Among other things, they apply their construction to the tropical curves obtained from the 2875 lines on the quintic Calabi–Yau three-fold.

References

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- [MR19] C. Y. Mak and H. Ruddat, *Tropically constructed lagrangians in mirror quintic threefolds*, arXiv:1904.11780 (2019).

Quantum geometric and algebraic representation theory

Final Report

Quantum Geometric and Algebraic Representation Theory was one of three constituent groups of the junior Trimester program on *Symplectic Geometry and Representation Theory* during fall 2017.

The group members were: Alexander Caviedes Castro, Peter Crooks, Sam Gunningham, Iva Halacheva, Benjamin Harris, David Jordan, Cris Negron, Maarten van Puijssen, Travis Schedler, José Simental Rodríguez, Tobias Weich, Yaping Yang, Gufang Zhao. In addition, a number of graduate students were working directly with the group members during the trimester, including Daniel Kaplan, Anna Mrktchyan, Tim Weelink, and Michael Wong. The group leaders were Sam Gunningham and Travis Schedler.

The group brought together researchers from various different areas of representation theory (including analytic, algebraic, combinatorial, and geometric flavours) each with a common interest in symplectic and Poisson geometry.

1 Visitors

We invited various visitors over the course of the trimester program to discuss and collaborate with the program members. In some cases, the visitors gave talks in one of the seminar series.

The visitors associated with our group included: Gwyn Bellamy, Michel Van den Bergh, Yannick Bonthonneau, Julia Budde, Jordan Ganey, Wahei Hara, Yoshiki Oshima, Guido Pezzini, Brent Pym, Pavel Safronov, Changjian Su, Wai-Kit Yeung.

2 Workshop

The group organized a workshop from 16th to 18th October. There were 53 registered participants, including many graduate students and junior researchers who had travelled to Bonn to attend. Talks were given by: Gwyn Bellamy, Ben Davison, Tina Kanstrup, Allen Knutson, Martina Lanini, Penghui Li, Michael McBreen, Yoshiki Oshima, Olivier Schiffmann, Jan Schröer, Peng Shan, Wolfgang Soergel, Špela Špenko, Michel Van den Bergh, and Yaping Yang.

Many of the talks were recorded by the HIM and are available online. There was also a live stream of the talks displayed in another room, allowing for a greater number of participants.

3 Internal Seminar Series

Along with the Trimester seminar organized with the other groups, our group held a regular internal seminar series where members of the group gave 20 minute talks introducing their research topics to the other program participants. A number of the group members felt that these talks did a good job building links between the various research areas in the group and stimulating discussion.

4 Research Output

Below we give an overview of the progress made by the researchers in our group that was facilitated by the HIM trimester program.

- Peter Crooks and Iva Halacheva studied instances of resolutions of singularities in the context of closures of highest weight orbits (in progress). Since the trimester, they have also extended our collaboration to study a new framework for Hessenberg varieties and completely integrable systems.
- Peter Crooks and Maarten van Pruijssen used spherical geometry to solve the non-emptiness problem for a large class of hyperkähler quotients. Their work has resulted in the preprint [CvP19].
- Sam Gunningham and David Jordan continued their project on quantum D -modules. The background work done during the trimester program formed the basis for two papers (both currently still in progress): the first on quantum Springer theory (joint also with Monica Vazirani), and the second on skein modules (joint also with Pavel Safronov, who was one of the visitors during the program).
- Sam Gunningham worked on revisions to the articles [Gun18, Gun17], and had a number of useful conversations with David Jordan on these papers during the program. He also started preparing an article on twisted quantum Hamiltonian reduction and cuspidal D -modules, which is still in preparation.
- Iva Halacheva worked with Martina Balagovic (a member of one of the other groups of the trimester program) and Catharina Stroppel (University of Bonn, and program organizer) on the affine VW supercategory, related to the representation theory of the periplectic Lie superalgebra. In their preprint [BDEA⁺18] (joint also with Zajj Daugherty, Inna Entova-Aizenbud, Johanna Hennig, Mee Seong Im, Gail Letzter, and Vera Serganova) they prove two main results: a basis theorem for the morphism spaces of the supercategory, and an explicit description of the centre of its endomorphism algebras.

- Benjamin Harris and Tobias Weich worked together on a follow up project from their paper on wave front sets of reductive Lie group representations [HW17], making some good progress.
- Daniel Kaplan continued work on his (since published) article [Kap18], profiting particularly from discussions with José Simental Rodríguez and Julian Külshammer.
- Cris Negron and Travis Schedler finished a project on Hochschild cohomology of complex linear orbifold quotients (\mathbb{C}^n/G), resulting in a preprint [NS⁺18]. They studied the algebraic structure and learned how to extend this to Gerstenhaber structures (in progress) and connected it to the Frobenius structure on orbifold cohomology and a version defined by Fantechi and Goettsche, as well as to Ruan’s cohomological hyperkaehler resolution conjecture.
- Maarten van Pruijsen collaborated with Guido Pezzini, who visited the HIM during the trimester program and gave a lecture in one of the seminars. Their project concerns branching rules of reductive groups in a multiplicity free setting and its implications for orthogonal polynomials (in progress).
- José Simental Rodríguez worked with Emily Norton (MPIM Bonn) on a conjecture of Berkesch Zamaere-Griffeth-Sam that gives an explicit standard (aka BGG) resolution of a simple unitary module in category \mathcal{O} for the rational Cherednik algebra of type A. This resulted in a preprint [BNS18].
- José Simental Rodríguez made progress on computations of induction, coinduction and restriction functors for Harish-Chandra bimodules for rational Cherednik algebras that, in particular, show that induction and coinduction don’t coincide. This will be part of the paper “Harish-Chandra bimodules for type A rational Cherednik algebras” in preparation.
- Travis Schedler worked with Gwyn Bellamy (program visitor and workshop speaker) on their program concerning symplectic resolutions. Their interactions during the trimester program contributed to two papers [BS19, BS16]. (The second preprint was already posted when the HIM program began, but during the program it was realized the need to make several corrections. It will soon be split into a couple of papers and submitted to journals.)
- Travis Schedler also acknowledges some influential discussions during the trimester program with Yanki Lekili (workshop speaker), Benjamin Gammage (HIM visitor and graduate student workshop participant), Daniel Kaplan (PhD student in the group), and David Jordan. These discussions eventually contributed to the articles: [KS19, ST18]. He also had very productive discussions with Brent Pym, that have led to current work in progress with Maatviichuk and Pym, probably to be posted in 2019.

- Yannick Bonthonneau visited Tobias Weich twice for a week during which time they were finalizing their work on Ruelle Resonance for manifolds with hyperbolic cusps [BW17].
- Tobias Weich also worked with his student Julia Budde, who visited during the trimester program. Budde is also working on wavefront sets of Lie group representations and profited from discussing with Benjamin Harris.
- Michael Wong continued work on his (successful) PhD thesis on Hochschild cohomology of matrix factorizations appearing as noncommutative mirrors of Riemann surfaces, benefiting particularly from conversations with visitors Raf Bocklandt and Yanki Lekili; he received an ERC fellowship with Ed Segal as a result of his work.
- Yaping Yang and Gufang Zhao worked on their project on double loop Grassmannians via fusions, which is still in progress, joint with Ivan Mirkovic. They had conversations with Olivier Schiffmann on the relations of cohomological Hall algebras and Yangians and with Allen Knutson about a conjecture of Kamnitzer and Knutson. They proved a simplified version of this conjecture in our joint paper with Ivan Mirkovic [MYZ18]. They also had some conversations with Jose Simental about his project on Geiss-Leclerc-Schröer quiver varieties, which we found inspiring. They initiated a project studying cohomological Hall algebras and their representations of the generalized preprojective algebras, on which they made progress afterwards.
- Changjian Su visited Gufang Zhao for a few days during the program. Their discussions were integrated into the preprint [SZZ19].

5 Other comments

- The group members particularly appreciated the opportunity to work on collaborative projects with other group members, trimester participants, invited visitors, and from the wider mathematical community in Bonn. As well as continuing existing projects, several new collaborations and connections were formed over the course of the semester (for example, Peter Crooks and Maarten van Pruijssen). The excellent working conditions and funding for visitors afforded by the trimester program greatly facilitated such collaborations.
- In addition to formal collaborations, the group members cited innumerable informal research discussions over the course of the trimester program. The friendly social environment at Poppelsdorfer Allee 82 and 45, and the daily tea and cake breaks contributed to a vibrant and energetic working atmosphere.
- Many of the group members found the lecture series on Coulomb branches to have been particularly useful, in particular the talks of Michael McBreen and Peng Shan.

Other lecture series, workshop, and seminar talks that the group found particularly useful during the course of the program include those of Gwyn Bellamy, Thomas Gobet, Eugene Gorsky, Allen Knutson, Yoshiki Oshima, Jan Schröer, Wolfgang Soergel, Catharina Stroppel, and Michel Van den Bergh.

- The group would also like to show their appreciation for the excellent staff at the HIM. Their capable handling of the administrative tasks, contributed significantly to the research productivity of the group. The daily tea and cake breaks were also particularly appreciated!

References

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Final report for the Junior Hausdorff Trimester Program “Symplectic Geometry and Representation Theory”, 02.Oct.2017–21.Dec.2017

Key information

Group: Braids, webs, affine Grassmannian, and ‘higher’ representation theory.

Research areas: Geometry, representation theory and topology, more specifically geometry of Grassmanians, Lagrangian submanifolds, braid and knot theory, link homology, TQFT, tensor categories, categorification, 2-representation theory, modular representation theory.

Members: Martina Balagovic, Michael Ehrig, Agnès Gadbled, Jonathan Grant, Peter McNamara, Peng Shan, Anne-Laure Thiel, Daniel Tubbenhauer, Emmanuel Wagner, Paul Wedrich, Arik Wilbert, Oded Yacobi.

Group leaders: Anne-Laure Thiel anne-laure.thiel@unicaen.fr and Daniel Tubbenhauer daniel.tubbenhauer@math.uzh.ch.

Our research group, consisting of the members named above, participated in the Junior Hausdorff Trimester Program “Symplectic Geometry and Representation Theory” in the fall 2017. We were based in the main building of the HIM which made interactions within our group very easy. We also enjoyed the discussions with the other two groups, the Institute providing a vibrant and exciting atmosphere. On the whole the synergy of the three groups was really amazing and was made possible by the choice of the scientific theme of the trimester made by the HIM. This theme was indeed on the edge of recent mathematical developments and allowed to bring together people from diverse scientific communities.

More specifically the main goal of our research group was to get a better understanding of the interplay between symplectic geometry and representation theory and their applications to link homologies and categorification. At the cornerstone of these two fields of mathematics lies Khovanov’s famous link homology, which turns up, in one way or another, in a lot of aspects of modern geometric or algebraic representation theory.

In the inspiring atmosphere instilled by the HIM, this main aim of ours turned out to lead to very fruitful collaborations with various (quite diverse) ideas coming together. Our group and its guests have studied the following topics (among others): geometric Satake correspondence, symplectic duality, Coulomb branches of certain quiver gauge theories, quantum representation theoretical aspects as e.g. webs and link homologies, categorified quantum groups and their 2-representations, categorical representations of braid groups, super algebras and their representations, just to name a few.

We would like to thank the HIM for the opportunity to participate in this Junior Hausdorff Trimester Program. This unique chance to interact with mathematicians from many different research areas was much appreciated.

Winter school and workshop

We had two very intense weeks around the end of November with a winter school and a follow-up workshop, both entitled “Categorification, representation theory and symplectic geometry”.

- The winter school had five main speakers, Eugene Gorsky, Yankı Lekili, Andrew Mathas, Volodymyr Mazorchuk, Catharina Stroppel, from all around the world. Most talks were recorded by the HIM and are available online. With about 80 participants, mostly students and postdocs, the winter school was a very

successful and lively activity. The participants were given the opportunity to present their research during a poster session. This was a great success with around 20 posters displayed. We also offered the authors of posters to give a short presentation, which most of them happily did.

- The follow-up workshop, with about 70 participants, enabled to strengthen and deepen the ideas broached during the winter school through several talks by international experts in the field such as Joseph Grant, Sira Gratz, Marco Mackaay, Vanessa Miemietz, James Pascaleff, Krzysztof Putyra, Gwyn Bellamy, Konstanze Rietsch, Louis-Hadrien Robert, Nicolò Sibilla and Joshua Sussan. Most talks were recorded by the HIM (and are available online) and we also had organised a live streaming throughout the course of the workshop which was screened in the secondary seminar room of the Institute.

Visitors and international interaction

During the program our group had plenty of visitors who came for a week or longer and contributed to the trimester program through collaborations, discussions, giving seminars and guest lecture series.

- Giving a small lecture series: Chris Elliott, Thomas Gobet, Owen Gwilliam, Pedro Vaz.
- Giving lectures during the winter school: Andrew Mathas, Volodymyr Mazorchuk.
- Others: Gwyn Bellamy, Daniele Faenzi, Marco Mackaay, Vanessa Miemietz, Anna Mkrtychyan, Louis-Hadrien Robert, Nicolò Sibilla, Wai-kit Yeung.

(This list does not include all people participating in the winter school or the workshop for only one week.)

Seminars

We ran four types of seminars during the trimester program, which we organized together with the other two groups.

- Small lecture series which consisted in talks by international experts; we had four of these with a total of 12 talks. For all the series, lecture notes or videos can be found on the HIM website of the program.
- The Trimester seminar which consisted in talks given by guests or participants. There were 8 seminars in total, all of which are again available online.
- An informal seminar, held every Monday, given by the participants of our and the other groups to strengthen interactions.
- Various reading seminars, held every Monday, e.g. on aspects of Coulomb and Higgs branches. The speakers were the participants of the various groups.

Follow-up events

There were several events organized in the spirit of our very successful winter school and workshop, which would not have taken place without our

- Nils Carqueville, Anton Mellit and **Paul Wedrich** organised a workshop in January 2019 that followed up on the topics of the program: <http://www.categorification.net/esi19>.
- *Daniele Faenzi*, **Agnès Gadbled**, **Anne-Laure Thiel** and **Emmanuel Wagner** discussed braid group operations on exceptional sequences via mutations. The ideas brewed then led us to organize a follow-up workshop in Dijon in September 2018: <https://extresses.sciencesconf.org/>.
- **Daniel Tubbenhauer**, motivated by the huge success of the program, organized a conference in September 2018 during which quite a few participants or guests of the Junior Trimester program participated: <http://www.dtubbenhauer.com/conference2018.html>.

Hard research outcome

The following is the list of the research outcome of members of our group: new collaborations, projects, follow-ups, work in progress, (pre)publications. All of the below was carried out or initiated during the program (papers, of course, take some time to be completed). This list does not include the various very useful informal discussions which we had during the program. Participants of our group are in bold, our guests in italic.

- **Martina Balagovic**, Iva Halacheva, Emily Norton and Catharina Stroppel discussed the affine VW supercategory, which is used in describing the representation theory of the periplectic Lie superalgebra $p(n)$, and proved a basis theorem for it. [B+18]
- Jean-François Barraud, **Agnès Gadbled**, Roman Golovko and Hông Vân Lê constructed a Novikov version of the fundamental group which is the first step of a project to develop a Novikov–Floer fundamental group in symplectic geometry. [BGGL17]
- **Michael Ehrig** and **Daniel Tubbenhauer** developed a generalization of cellular algebras which might turn out to be useful in representation theory in the near future. [ET17]
- **Michael Ehrig** and **Daniel Tubbenhauer** studied, in a follow-up to their paper on relative cellular algebras, certain properties of certain path algebras. [ET18]
- **Agnès Gadbled**, **Anne-Laure Thiel** and **Emmanuel Wagner** explored the symplectic aspects of a categorical action of the braid group of the cylinder in a paper very near completion.
- *Thomas Gobet* and **Anne-Laure Thiel** constructed and studied some generalizations of the category of Soergel bimodules, in the case of Coxeter group of type A_2 in [GT18a] and in the case of cyclic groups in [GT18b].
- *Eugene Gorsky* and **Paul Wedrich** continued their collaboration on categorical invariants of annular links in the context of Hilbert schemes that led to the preprint [GT19].
- Joel Kamnitzer, Peter Tingley, Ben Webster, Alex Weekes and **Oded Yacobi** studied categorified tensor products via a version of category \mathcal{O} associated to affine Grassmannians. [KWWY18]
- *Marco Mackaay*, *Volodymyr Mazorchuk*, *Vanessa Miemietz* and **Daniel Tubbenhauer** used the quantum Satake equivalence to study 2-representations of Soergel bimodules. [MMMT18]
- *Marco Mackaay*, *Volodymyr Mazorchuk*, *Vanessa Miemietz*, **Daniel Tubbenhauer** and *Xiaoting Zhang* started a project to classify all 2-simples of Soergel bimodules, and the paper is expected to appear on arXiv in the Summer 2019.
- **Peter McNamara** proved the monoidality of Kato’s reflection functors in the theory of KLR algebras. [McN1]
- **Peter McNamara** found the first examples of non-perverse parity sheaves on the Schubert variety for $p > 2$ in an infinite family of examples. [McN2]
- Loïc Poulain d’Andecy, **Anne-Laure Thiel** and **Emmanuel Wagner** studied the Birman–Murakami–Wenzl algebras in [PdATW17]. They made explicit new bases on this tower of algebras, which are constructed inductively in the same spirit as for the Hecke algebras. They also classified transverse Markov traces on the BMW algebras.
- Hoel Queffelec and **Paul Wedrich** authored two papers on extremal weight projectors [QW18a] and the categorification of skein algebras of surfaces using Khovanov homology [QW18b].
- *Louis-Hadrien Robert* and **Emmanuel Wagner** completed their joint project on symmetric link homologies which appeared just after the end of the semester as a preprint. [RW18]

- *Louis-Hadrien Robert* and **Emmanuel Wagner** started their project on a combinatorial and algebraic categorification of the Alexander polynomial which appeared one year later as the preprint. [RW19]
- Neil Saunders and **Arik Wilbert** studied the geometry and topology of exotic Springer fibers for orbits corresponding to pairs of one-row partitions. [SW18]
- Marko Stosic and **Paul Wedrich** released a preprint that proves the conjectured “Knots-Quivers” correspondence of Kucharski–Reineke–Stošić–Sułkowski for 2-bridge links. [SW17] This was presented and discussed at the programme’s workshop and has led to an interpretation in terms of symplectic field theory that will lead to follow-up publications.

on behalf of our group,
A.-L. Thiel and D. Tubbenhauer
 June 12, 2019
 anne-laure.thiel@unicaen.fr
 daniel.tubbenhauer@math.uzh.ch

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