



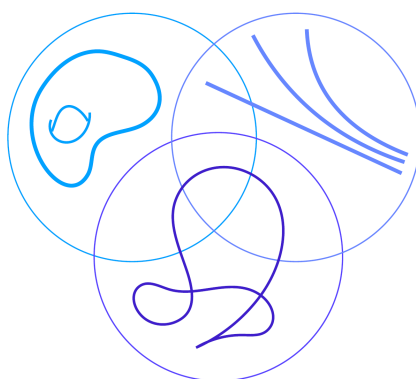
Annual Report 2022

(1 January 2022 - 31 December 2022, "Year 3")

Copenhagen Centre for Geometry and Topology
DNRF151

Department of Mathematical Sciences
University of Copenhagen

Established 1 April, 2020



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GEOTOP: CENTRE HIGHLIGHTS 2022



The year 2022 put the *Copenhagen Centre for Geometry and Topology* in the spotlight on the international scene. The centre hosted its Gordon conference in July, as a hybrid event, as part of an international effort to save the International Congress of Mathematicians (ICM) 2022, originally planned to be held in Saint Petersburg that summer. GeoTop was well-represented in this quadrennial's most prestigious mathematics conference worldwide, with 1 plenary speaker and 2 invited sectional speakers among its PIs (pictured above)!

By the end of the year, the centre counted 11 permanent members, 2 senior visiting members, 4 associated members, 11 postdocs, and 15 PhD students.

RESEARCH & ACTIVITIES

Highlights in the research progress include a proof of a conjecture about stable cohomology of congruence subgroups by **Randal-Williams**, a classification of modular functors by **Woike** and coauthor, and new classification results for collapsed translating singularities of low entropy by **NM Møller** and coauthors. **Grodal's** article *Endotrivial modules for finite groups via homotopy theory* was accepted for publication (to appear in 2023) in the prestigious Journal of the American Mathematical Society.

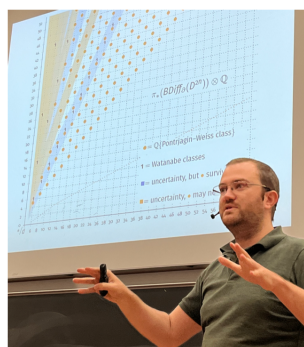
The centre hosted 2 masterclasses and 4 conferences. In addition to our Gordon conference, this included the Young Topologists Meeting (picture below), which attracted more than 150 master's and PhD students and junior postdocs from around the world for an intense week covering a wide range of aspects of the subject.



RECOGNITION

In addition to the three ICM talks by **Colding**, **Randal-Williams** and **Wahl**, centre PIs **Galatius** and **Randal-Williams** jointly received the Clay Research Award for their profound contributions to the understanding of high-dimensional manifolds and their diffeomorphism groups. Also, **Clausen** received the Hartmann Foundation's Diploma Prize for his work on developing and understanding the deep connection between geometry and number theory.

GEOTOP: CENTERHØJDEPUNKTER 2022



Året 2022 bragte *Copenhagen Centre for Geometry and Topology* helt ind i rampelyset på den internationale scene. Centret var vært for sin Gordon-konference i juli, som hybrid-event, som del af en international indsats for at redde Den Internationale Matematikerkongres (ICM) 2022, som efter den oprindelige plan skulle have været afholdt den sommer i Sankt Petersburg. GeoTop var velrepræsenteret ved denne mest prestigøse matematikkonference i verden afholdt hvert fjerde år, med 1 plenartaler og 2 inviterede sektionstalere blandt centrets PIs (fotografier ovenfor).

Ved årets afslutning talte centret 11 permanente medlemmer, 2 senior-gæstemedlemmer, 4 associerede medlemmer, 11 postdocs og 15 ph.d.-studerende.

FORSKNING & AKTIVITETER

Blandt årets højdepunkter i forskningen kan nævnes **Randal-Williams'** bevis for en formodning om stabil kohomologi af kongruensundergrupper, **Woike** og medforfatters klassifikation af modulære funktorer samt **NM Møller** og medforfatters klassifikationsresultater for kollapsede translaterende singulariteter med lav entropi. **Grodals** artikel *Endotrivial modules for finite groups via homotopy theory* blev accepteret i *Journal of the American Mathematical Society*.

Centret arrangerede 2 masterklasser og 4 konferencer. Foruden Gordon-konferencen afholdtes Young Topologists Meeting hvor mere end 150 kandidat- og ph.d.-studerende samt yngre postdocs fra hele verden i løbet af en uge præsenterede deres forskning i mange aspekter af topologi for hinanden.



PRISER OG ANERKENDELSER

Ud over de tre ICM-foredrag af **Colding**, **Randal-Williams** og **Wahl**, modtog to af centrets PIs **Galatius** og **Randal-Williams** sammen Clay Research Award for deres dybe bidrag til forståelsen af højdimensionale mangfoldigheder og deres diffeomorfigrupper, mens **Clausen** modtog Hartmann Fondens diplompris for sit arbejde med at udvikle og forstå den dybe forbindelse mellem geometri og talteori.

1 Organisation

The centre throughout 2022 ran as planned, with **Wahl** taking the strategic decisions in coordination with **Galatius** and **NM Møller**, and when relevant also with **Randal-Williams** and **Colding**. They were aided on all administrative matters and day-to-day running of the centre by the centre administrator **Tapdrup**. The supporting faculty **Adiprasito**, **Clausen**, **Grodal**, **Hesselholt** and **J Møller** have actively aided the supervision and training of the BSc, MSc, PhD students and postdocs at the centre. **Randal-Williams** visited the centre in July and October, and **Colding** in July and August.

2022 was essentially the first normal year for the centre, after COVID-19, with the centre running throughout the year at full speed, with only the January postdoc and PhD interviews being online.

1.1 Scientific staff

The scientific staff at the end of 2022 comprised 5 core faculty, 6 supporting faculty, 2 visiting senior faculty, 11 postdocs, and 15 PhD students, again well above the contractual 6 postdocs and 6 PhD students, enabled by substantial external funding. The number of associated members increased to 4, with Thomas **Nikolaus** (Münster) joining in; we have many overlaps of interests with Münster, a *Cluster of Excellence* of the DFG (German Research Foundation), and are planning to promote exchanges of junior members. We have slightly more PhD students and fewer postdocs than last year because the PhD students' application pool was very strong.

The two visiting faculty, Joachim **Kock** and Imma **Galvez-Carrillo** are supported by external funding (a Marie Curie fellowship and a grant supported by Next Generation EU respectively).

The centre hired 5 new postdocs (**Briggs**, **Burklund**, **Mramor**, **Steinebrunner**, and **Vorhaar**), with **Briggs** funded by a Marie Curie fellowship and **Burklund** partially funded by a (US) National Science Foundation fellowship. A total of 8 postdocs left in 2022. (**Avvakumov**, **Das** and **Iwasa**, **Zheng**, **Biswas** are now postdocs at the Universities of Toronto, Stockholm, Paris-Saclay, Houston-Downtown, and Paris-Saclay respectively, while **Land**, **Naef** and **Woike** are now tenure-track faculty at Ludwig-Maximilians-Universität München, Dublin University and University of Burgundy in Dijon.)

We hired 5 new PhD students (**Bai**, **Harr**, **Juran**, **Kjærsgaard**, and **Mezher**). Two additional external PhD students (**Delarue** at Paris Sorbonne, France, and **Haya Enriquez** at Louvain-la-Neuve, Belgium) have started this year, with co-advisors at the centre. Three PhD Fellows associated with the centre defended their PhD theses: **Leip**, **van der Meer** and **Tan**. (**Leip** and **van der Meer** now work in industry, while **Tan** is now a postdoc at the Max Planck Institute in Bonn.)

1.2 Visitors

The centre hosted many long-term guests this year (where long-term means staying for at least 3 weeks), at every level, from visiting students to retired professors. Each enriched the centre in their own way:

Senior visitors: Chris Davis, Francisco Martín, Bob Oliver, Andrew Tonks, and Christian Zickert.

Junior visitors Guillaume Laplante-Anfossi, Calista Bernard, and Peter Dillery.

Visiting students: Wilson Forero (PhD student), Dounia Darkaoui and Oscar Fontaine (École normale supérieure - students).

The visit of Martín led, for example, to a preprint with core member **NM Møller** about translating singularities, Zickert wrote a paper with postdoc **Kaufman** on polylogarithms, a topic Zickert introduced to all centre members at one of the GeoTop lunch meetings, and Darkaoui wrote a project supervised by **Wahl** about lens spaces, a kind of spaces much relevant to Part B of the research.

In addition to that, we had around 50 non-conference-related shorter-term visitors and more than 350 conference participants.

1.3 Administration

Continuing from last year, **Tapdrup** took care of practicalities such as running events and administration as centre administrator, and Natasha Roschier Rørdam Gulddal took care of budgeting, budget follow-up, and financial accounting.

1.4 GeoTop Activities

The centre continued to run a Geometry and a Topology seminar, normally meeting on a weekly basis in term time, and a GeoTop meeting every other week over lunch. Standard points on the agenda of the GeoTop meetings are short research presentations and presentations of upcoming courses and events. The meetings also covered other topics, such as the job market or, this year, popularisation.

The postdocs and PhD students organise additional seminars and reading groups. **Carmeli's** Homotopy theory question seminar stays a lively meeting ground every Friday, where questions proposed by the participants are discussed and sometimes even solved. A new arXiv seminar (called seminarXiv!) started at the end of the year, where participants presented papers that were posted recently on the international preprint archive arXiv.org.

Gordon conference: GeoTop hosted its Gordon Conference in July 2022, in connection with the ICM (International Congress of Mathematicians). The ICM is a very large event held every four years, bringing together researchers from all corners of mathematics and from all over the world. The ICM 2022 was scheduled to take place in St Petersburg, which became impossible. While the International Math Union moved the official event online, an international community of mathematicians organised hybrid events at different locations, attempting to salvage at least some of the spirit of the ICM. Our centre having one plenary speaker (**Colding**) and two invited sectional speakers (**Randal-Williams** and **Wahl**), offered to host a part of the event in particular targeted to the Geometry and Topology sections. The conference included 25 talks from the official ICM and a large number of shorter talks by junior and more senior researchers from around the world. The event was a great success, alternating between the official ICM part broadcasted to the world, and our local event, with much time for informal discussions.

Shortly after the ICM, we hosted another large conference, the Young Topologists Meeting (YTM). YTM is a yearly event hosted at different locations each summer, and for the 6th time in Copenhagen. It is fully organised by junior mathematicians (PhD students or young postdocs) supported by the centre administrator and attended by master students, PhD students and postdocs, mainly from Europe and the US. The event consisted of 3 lecture series by more senior mathematicians and 40 talks by participants, with additional events such as a math-games session and generally many opportunities to meet new people. This event is a great recruiting ground for us.

We also hosted a conference in June to celebrate the work of associated member Ryszard **Nest**, who recently retired, and one in October to celebrate the lifetime achievements of our emeritus professor Ib **Madsen**, who turned 80 in 2022. These were occasions to have a current state of the art of their lines of research. Both have had great influence locally, internationally, and still today at the centre.

Finally, we hosted two masterclasses at the centre this year: one on Mean Curvature Flow and Related Topics in March and one on Cluster Algebras and Representation Theory in November.

This year, we ran our first Summer Research Program for bachelor and master students. The program gives students the opportunity to join the centre for a small research project they can try their hands on or for guidance to learn mathematics at a research level. We had 5 students for our first run of the program, one through a collaboration with the centre of excellence DAWN and 4 internal students. The program ended with a common presentation of the projects at the end of the summer.

1.5 Recruitment and gender strategy

The centre and the Department of Mathematical Sciences had two calls for PhD fellowships and one for postdoc positions in 2022. We use the international platform MathJobs to increase visibility for

positions. The postdoc call had about 350 applicants in pure mathematics, including, similarly to previous years, more than 150 applicants in the research areas of the centre. **NM Møller** coordinated the postdoc call for the whole department. For PhD fellowships, we had calls for applications in April and in November. After the first shortlisting, the centre had 40 and 35 PhD applicants, respectively, in the spring and fall application calls this year.

Diversity is on our minds whenever we hire: this applies to both gender diversity and general diversity in the sense of not always going for the same type of “usual profiles”. We pay much attention to this, including when we choose whom to invite for interviews. **Wahl** is part of the department’s diversity committee and ran an activity at the 2022 Department Day to raise awareness of diversity issues when hiring PhD students and postdocs, where GeoTop is a major player in the Department. We know we still have to work on our gender diversity at the centre. This year, 1 out of 4 new postdocs are female, and 0 out of 5 PhD hires were female. However, one external female PhD student starting will periodically visit the centre. What gives some hope is that there were many female participants (and speakers!) at the Young Topologists Meeting.

1.6 Research integrity and data management

The three central principles of the Danish research integrity code of conduct are *honesty*, *transparency* and *accountability*. We are fully committed to these three principles and actively work to implement them in several ways.

Mathematics has a tradition of being relatively open in the research process, with researchers sharing their results long before they are in final published form. At GeoTop, we ask all centre members to put their preprints on the international preprint archive arXiv.org before submitting them to journals for publication; this promotes transparency. Likewise, preprints posted to the arXiv by staff members are presented at bimonthly centre meetings.

We encourage everyone to publish in high-standard international journals with thorough refereeing processes. Potential issues in mathematical publishing are mistakes (these do happen and need fixing when the author becomes aware of them), failing to give proper credit to people one has received ideas from, or worst, actual plagiarism. The ArXiv online platform automatically checks for text overlap with every article submitted to the platform and adds a comment to the paper’s page in case of significant overlap.

The University of Copenhagen also runs compulsory classes on “Responsible conduct in research” for PhD students and PhD supervisors.

We do not collect data and thus have no data management issues.

2 Research plan

We report here on the progress made on our research plan, under each of the three headings *Moduli*, *Geodesics* and *Singularities*, selecting the most illustrative results.

2.1 (A) Moduli

Core: Galatius, Randal-Williams, Wahl

Visiting: Kock, Zickert

Postdocs: Bianchi, Biswas, Burklund, Carmeli, Iwasa, Jansen, Land, Voorhaar

PhDs: Asgeirsson, Aumonier, Cordova, Harr, Hilman, Juran, Kjærsgaard, Leip, van der Meer, Mezher, Ramzi, Subramanian

The focus on this part of the research has again this year been on Goal A.1, the identification of the homotopy type of moduli spaces.

The centre leader **Wahl** and core member **Randal-Williams** both published invited manuscripts in the Proceedings of the ICM, Wahl about homological stability and Randal-Williams about diffeomorphisms

of discs. **Randal-Williams** and **Galatius** used finite cyclic groups to detect Pontryagin classes of Euclidean bundles, aided by a detailed study of the family signature theorem by **Randal-Williams**. In the direction of homological stability, **Randal-Williams** resolved a conjecture by F. Calegari about stable cohomology of congruence subgroups. With Vistrup and new centre PhD student **Harr**, centre leader **Wahl** gave a new perspective on the classical Harer stability theorem.

New centre postdoc **Kaufman**, centre visitor **Zickert**, and coauthors defined and studied a Lie coalgebra of polylogarithms and a Hopf algebra of multiple polylogarithms.

Maxime **Ramzi**, a PhD student at the centre and coauthors have submitted several papers establishing basic properties of important constructions, including multiplicativity in fibre sequences for Euler characteristics of finitely dominated spaces and naturality of the ∞ -Yoneda embedding. Centre postdoc **Carmeli** and coauthors studied generalizations of the classical Fourier transform to chromatic homotopy theory, and in another preprint, studied a refined notion of units and line bundles in stable homotopy theory. Centre postdoc **Iwasa** and a collaborator published a paper on moduli of vector bundles and submitted a paper about motivic spectra in a non- \mathbb{A}^1 -invariant setting.

Three PhD students associated with the centre defended their thesis: **Hilman**, who wrote a thesis about the structure of equivariant Hermitian K -theory, **Leip**, with a thesis computing the Hochschild homology of certain quotients of polynomial rings, and **van der Meer**, who wrote a thesis about representation categories of finite groups.

2.2 (B) Geodesics

Core: **Wahl**

Visiting: Galvez-Carrillo

Postdocs: Avvakumov, Bianchi, Briggs, Das, Kaufman, Naef, Schnider, Steinebrunner, Woike, Zheng

PhDs: Bai, Elis, Mehzer, Steinmeyer, Aamand

Most of the work was again this year centred around the first goal of that part of the proposal, with a particular emphasis on the study of the modular operad of surfaces, that is structures one can associate to surfaces that are compatible under gluing.

Steinebrunner and Barkan developed a new framework for spaces of operations (infinity properads) that is expected to be useful for this and other parts of the proposal. Müller and **Woike** showed that the Drinfeld center of any pivotal finite tensor category gives rise to a modular functor, a family of representations of the mapping class groups of surfaces compatible under gluing. Together with Brochier, **Woike** gave, in addition, a classification of modular functors in terms of factorization homology.

Naef, **Wahl** and Rivera extending the earlier result of **Naef**, showed that the string topology coproduct can be used to determine whether homotopic lens spaces are actually homeomorphic. **Elis**, to better understand the impact of these results, revived the study of the same coproduct on the based loop space, while **Briggs**, who joined the team this year, is considering such string-like structures through the lens of Hochschild cohomology.

2.3 (C) Singularities

Core: **Colding**, **NM Møller**

Visiting: Martín

Postdocs: Ma, Mramor

PhDs: Muhammad, Zhang

We have this year made progress on especially Goal C.1, classifying singularities in geometric flows, also devoting time to applications in neighbouring fields of geometry and partial differential equations.

Significant new progress was made on translating solitons for the mean curvature flow. Owing to the classification by **NM Møller** and past PhD student Chini, translating solitons are known to always have

convex hulls which are “generalized slabs” in space. This makes the notion of collapsedness of translating solitons very natural, and even allows for its definition outside of the class of convex surfaces. **NM Møller** jointly with Gama and centre visitor **Martín**, in new joint work, showed that certain integer-valued invariants are well-defined on such collapsed translating singularities. Geometrically speaking, these invariants count the number of “wings” coming out of the singularity and enter into the authors’ simple new formula for the entropy.

Building further on this idea, by combining it with a method from topology known as Morse theory, together with nodal set techniques from the advanced theory of partial differential equations, Gama, **Martín** and **NM Møller** were furthermore able to give new classification results for topologically simple collapsed translating singularities of low entropy, with even stronger conclusions in the case of graphs.

Sperked by the above-mentioned new work and techniques, **Ma**, together with Ooi and Pyo, managed to answer further uniqueness questions for translating graph singularities.

Applying related geometric analysis techniques to the nearby field of symplectic geometry, which is, for example, the geometry of phase space in classical mechanics, Chen and **Ma** proved compactness theorems for spaces of Hamiltonian stationary Lagrangians.

Zhang investigated the geometry and partial differential equations which govern quantum mechanics. Here, in a series of papers, together with Sigal and several other collaborators, **Zhang** proved new so-called Lieb–Robinson bounds. These entail limits on the maximum possible velocity of exchange of information in quantum many-body systems, reminiscent of the famous appearance of light cone geometry in the theory of relativity, so their work may even find applications in the design of quantum computers.

Colding published an invited manuscript in the Proceedings of the ICM entitled *Evolution of form and shape*.

3 Comments to the appendix

Appendix—A: Collaboration with industry and public organizations. Nothing to report.

Appendix—B: Conferences. The centre had a busy conference year in 2022, with more than 350 participants at centre conferences. Major events include the Geometry and Topology sectional workshop at the International Congress of Mathematicians (ICM) and the Young Topologists Meeting. In addition to other local events, GeoTop staff helped organise nine international conferences.

The centre received three invitations to the International Congress of Mathematicians 2022: **Colding** as a plenary speaker, **Randal-Williams** and **Wahl** as sectional speakers in the Topology section. This congress takes place every 4 years and is the most prestigious conference in Mathematics.

See Section 1.4 above for more details.

Appendix—C: Educational activities. The centre ran 10 PhD courses (2 were open international PhD courses), 10 graduate courses and 3 bachelor courses.

The new summer research experience for undergraduates, in collaboration with DNRF centre DAWN and CalTec, had five participants and proved very successful. Additionally, GeoTop members advised 10 master’s and 4 bachelor’s theses.

Appendix—D: External funding. In 2022 GeoTop, in addition to DRNF and departmental funding, received money from four ERC grants, the Independent Research Fund Denmark, the Carlsberg Foundation, and six Marie Skłodowska-Curie stipends. The extra funding totalled 9.8 million DKK in 2022.

Appendix—E: Awards. 2022: Søren Galatius and Oscar Randal-Williams received the Clay Research Prize (c. 205,000 DKK), and Dustin Clausen received the Hartmann’s Foundation Diploma Prize 2022 (150,000 DKK).

Appendix—F: Public outreach. GeoTop again participated in Copenhagen Culture night at the HC Ørsted Institute. This year broke all records with 2,315 visitors at the event. **NM Møller** also contributed

to the Bloom Festival for Science 2022.

Appendix—G: spin-off companies established. Nothing to report.

Appendix—H: Publications. 37 articles containing work carried out at the centre appeared in international journals this year, 3 appeared in conference proceedings and 3 PhD theses were produced. All are published with open access. Publication times for articles in mathematics can be very long; it can take up to 10 years from the first version of a preprint to final publication in a journal. On the other hand, it is customary in mathematics to publish open-access preprints in the depository arXiv.org from their first version. These can go through several revisions but are already cited while on the arXiv. The centre's 2022 preprints totalled 68, of which 47 are new preprints (the remaining 21 being revisions), and 5 have already been accepted for publication in 2023.

Appendix—I: Other societal activities. Nothing to report.

4 Signature

I hereby confirm the correctness of the information concerning annual accounts, including itemisations. Also, I confirm that the compiled annual reporting, including the appendices, is correct, i.e. it is free of material misstatement or omissions, and that the administration of the funds has been secure and sound, and in accordance with the conditions of the centre agreement.

Date
31/3 2022

Nathalie Wahl



Professor, centre Director