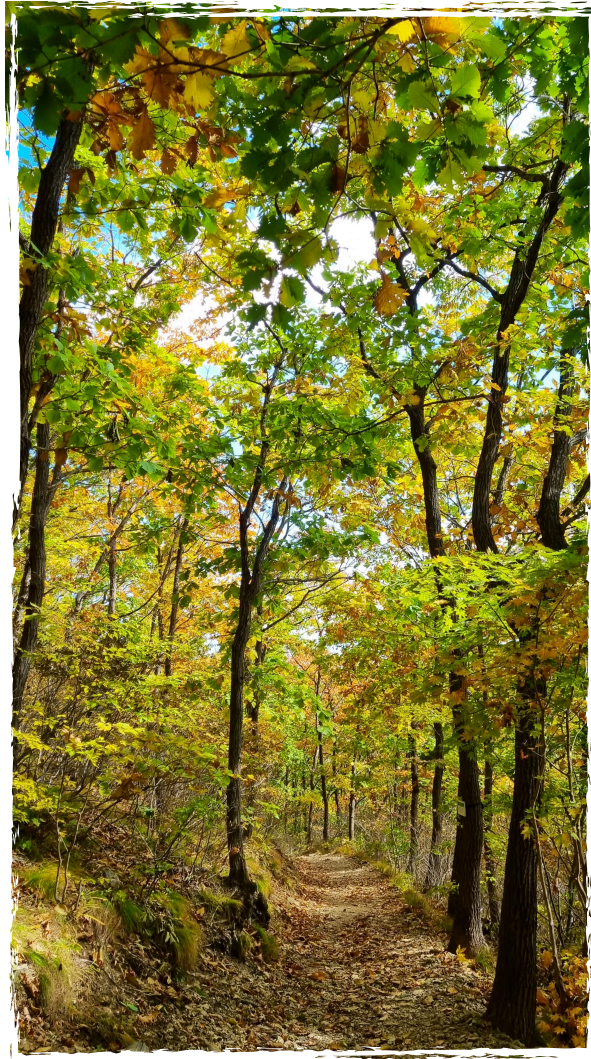


IBS Center for Geometry and Physics

CGP Walk

— *Beyond the horizon* —



The Third Issue
2022

ibS 기초과학연구원
Institute for Basic Science

IBS Center for Geometry and Physics

CGP Walk

— *Beyond the horizon* —

The Third Issue

2022

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Greetings : Director's Note

Year 2022 is the 10th Anniversary of IBS-CGP. I was happy to see the CGP alumni and members getting together, some as speakers and others as participants, to celebrate the occasion in the 10th year Anniversary Workshop held on October 4 – 6. It was a memorable moment.

As the Director of CGP, the past 10 years was some adventurous journey itself. At the time of founding of CGP, nobody was sure about CGP after 10 years just like nobody was sure about what IBS itself would look like. When I took the Directorship of CGP, I wanted to participate in this historical moment in Korean science history and by doing so I would like to contribute to the effort of taking Korean science one level up. But as soon as IBS and CGP opened, reality squeezed in. I felt both excitement and peril: becoming one of the 9 prestigious inaugural Directors for doing what I like most, but at the same time not being uncertain about my success in running CGP handle in the uncharted territory of the Korean science. In hindsight after 10 years, there is no doubt that both Korean government and I had made a correct move to the right direction.

It turns out that the hardest step has been the first step of taking the CGP Directorship. Once the Center started to roll many helping hands came in. First of all, the excellent administrative team and two Group Leaders greatly relieved my worry about on Director's administrative chores, and for other bigger administrative huddles I stuck to the basic principles. Continuous supports from Korean Mathematical Society, CGP Scientific Advisory Committee and helping hands from out of nowhere every time I need have become huge spiritual guidance to me. Most importantly, high quality post-doctoral members knocked the doors of CGP and gathered from all of the world. They have been the stem of CGP's research activities and generated remarkable research outcomes. I take this opportunity to thank Korean government, IBS headquarter, CGP members and all other helping hands for their generous support, encouragement and criticism through the years.

How about my self? I have been doing what I had been doing for decades as well as I have been trailblazing into an uncharted territory following my own curiosity keeping the motto **“Following your own curiosity is the best way to do the most creative research.”**

Year 2022 is ending. COVID-19 is still prevalent and I am writing this note under the COVID-19 influence wishing for the Covid-free 2023. I also dream about the next journey beyond the horizon more closely with our CGP members than before in the long-awaited new CGP building!



Background and Vision

The Center for Geometry and Physics (CGP) was founded in July 2012 as one of the first research centers of the Institute for Basic Science (IBS). The CGP originated in a government funded award, via IBS, to the research program of its director Yong-Geun Oh. This program aims to help establish and develop the emerging field of symplectic algebraic topology through a collaborative effort by experts in fields such as symplectic geometry, dynamical systems, algebraic geometry and mathematical physics. The Center is currently evolving into an international institution with a broader scope, focusing more generally on geometry and mathematical physics.

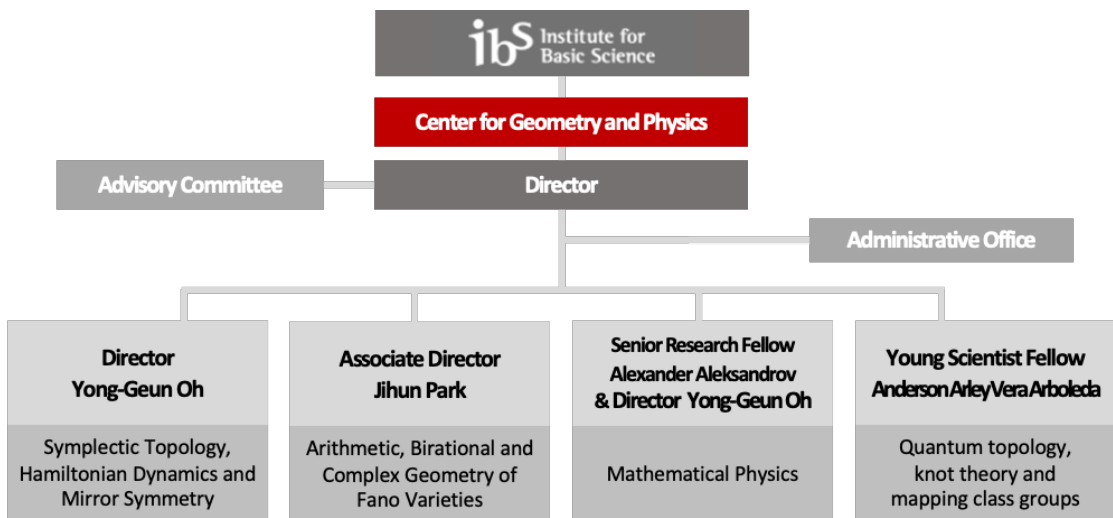
An ideal scientific research institute should be a place which fosters the disinterested pursuit of learning and the fundamental innovative thinking that advances the individual fields of inquiry of an intellectual community. The mission of the Center for Geometry and Physics (CGP) is to enable the research environment at the CGP to achieve this ideal. By now, the CGP has created such an atmosphere that ideas from mathematics and physics are naturally shared and interact. The CGP will ensure maintaining this unique research environment to serve the international community by

- Providing intellectual leadership and stewardship, guiding the development of relevant mathematics in fruitful directions by strengthening the interaction between geometry and physics,
- Playing the role of a physical nexus in Korea and beyond for the events which are the social glue of mathematical progress by hosting workshops, conferences, visitors, and so on, in order to lubricate the flow of ideas throughout the international community,
- Becoming as an incubator for young mathematicians, giving them the time and freedom to pursue ambitious and idiosyncratic research goals in a nurturant and enriching environment.

Organization

One arching research theme of the CGP is to promote interaction between symplectic geometry, algebraic geometry and mathematical physics in the study of symplectic topology and homological mirror symmetry and their applications to theoretical physics.

The CGP is organized into multi research groups, each of which comprises a senior scholar and several researchers whose areas of expertise and interest overlap synergistically.



YSF research group is initiated from December 16, 2022.

Research Groups

Symplectic Topology, Hamiltonian Dynamics and Mirror Symmetry

Team Leader: Yong-Geun Oh

The current status of symplectic topology resembles that of classical topology in the middle of the twentieth century. Over time, a systematic algebraic language was developed to describe problems in classical topology. Similarly, a language for symplectic topology is emerging, but has yet to be fully developed. The development of this language is much more challenging both algebraically and analytically than in the case of classical topology. The relevant homological algebra of A_∞ structures is harder to implement in the geometric situation due to the analytical complications present in the study of pseudo-holomorphic curves or "instantons" in physical terms. Homological mirror symmetry concerns a certain duality between categories of symplectic manifolds and complex algebraic varieties. The symplectic side of the story involves an A_∞ category, called the Fukaya category, which is the categorified version of Lagrangian Floer homology theory. In the meantime, recent developments in the area of dynamical systems have revealed that the symplectic aspect of area preserving dynamics in two dimensions has the potential to further understanding of these systems in deep and important ways.

Research members and their research themes:

- ✦ **Elijah Fender** (The interplay of dynamics and symplectic/contact geometry)
- ✦ **Volker Genz** (Explicit problems in representation theory)
- ✦ **Hongtaek Jung** (Symplectic structures of Hitchin components and Anosov representations)
- ✦ **Sungkyung Kang** (Heegaard Floer theory, knot theory)
- ✦ **Jongmyeong Kim** (Homological mirror symmetry)
- ✦ **Taesu Kim** (Homotopy theoretic aspects of symplectic geometry)
- ✦ **Norton Lee** (Supersymmetry, Integrable Systems, Quantum Field Theories, Mathematical Physics)
- ✦ **Sangjin Lee** (Lagrangian foliations, Symplectic mapping class group, Fukaya category)
- ✦ **Seul Bee Lee** (Ergodic theory of dynamical systems, Number Theory and Geometric Group Theory)
- ✦ **Yong-Geun Oh** (Symplectic topology, Hamiltonian dynamics and mirror symmetry)
- ✦ **Arthur Soulié** (Algebraic topology, homological algebra, representation theory, braid groups and mapping class groups)
- ✦ **Yat-Hin Suen** (Complex geometry, Symplectic geometry, SYZ mirror symmetry, Homological mirror symmetry)

Arithmetic, Birational and Complex Geometry of Fano Varieties

Team Leader: Jihun Park

Fano varieties are algebraic varieties whose anticanonical classes are ample. They are classical and fundamental varieties that play many significant roles in contemporary geometry. Verified or expected geometric and algebraic properties of Fano varieties have attracted attentions from many geometers and physicists. In spite of extensive studies on Fano varieties for more than one centuries, numerous features of Fano varieties are still shrouded in a veil of mist. Contemporary geometry however requires more comprehensive understanding of Fano varieties.

Research members and their research themes:

- ✦ **Shinyoung Kim** (Complex geometry)
- ✦ **Igor Krylov** (Birational geometry)
- ✦ **Jihun Park** (Birational geometry)
- ✦ **Haowu Wang** (Theory of modular forms and its applications)
- ✦ **Yuto Yamamoto** (Tropical geometry)

Mathematical Physics

Team Leader: Alexander Aleksandrov and Yong-Geun Oh

The mathematical relevance and deep interconnections between theoretical physics and mathematics are well-established. This subject is universally appreciated for its integrative role and for being one of the most fruitful sources of new ideas, theories and methods, and have numerous powerful applications to problems in mathematics, in particular, of geometry and topology. In recent decades, there have been various developments in supersymmetric quantum field theories and string/M-theory. In this premise, matrix models, integrable systems, Chern-Simons gauge theory, Landau-Ginzburg theory and mirror symmetry, and topological quantum field theories are the main themes of research pursued in this group.

Research members and their research themes:

- ✦ **Alexander Aleksandrov** (Mathematical physics, random matrix models, integrable systems, enumerative geometry)
- ✦ **Yifan Li** (Algebraic geometry, algebraic topology and mathematical physics)
- ✦ **Hisayoshi Muraki** (Noncommutative geometry, nongeometric backgrounds in supergravity, discretized geometry, matrix model)
- ✦ **Dmytro Voloshyn** (Mathematical physics, cluster algebras, Poisson geometry, quantum groups, integrable systems)

Quantum topology, knot theory and mapping class groups

Team Leader: Anderson Arley Vera Arboleda (Young Scientist Fellow)

Quantum topology lies in the intersection of algebra, topology and mathematical physics and it is a source of knot and 3-manifold invariants (quantum invariants) giving rise to the so-called Topological quantum field theories (TQFT). The construction of such TQFTs requires techniques from representation theory, combinatorics and topology. We mainly pursue two research directions:

- (a) topological “meaning” of quantum invariants, this leads to the study of classical invariants such as Milnor invariants as well as the study of the mapping class groups and their representation theory.
- (b) construction of new invariants for braids, knots and 3-manifolds, in particular, we point to a development of quantum invariants for knots in thickened surfaces.

The Young Scientist Fellowship research project is initiated from December 16, 2022.

Research members and their research themes:

- ✦ **Anderson Arley Vera Arboleda** (quantum topology, knot theory, mapping class groups)

CGP Advisory Committee

The CGP Advisory Committee consists of eight distinguished scholars from Korea and abroad. The committee meets once a year and provides advice and input on the operations of the Center.

The current members of the Advisory Committee are:

Alexander Givental

Professor at University of California, Berkeley

Jae-Hun Jung

Professor at Pohang University of Science and Technology (POSTECH)

Mikhail Kapranov

Professor at Kavli IPMU*, University of Tokyo

Ludmil Katzarkov

Professor at University of Miami & University of Vienna & Institute of Mathematics and Informatics

JongHae Keum

President at Korean Mathematical Society

Professor at Korea Institute for Advanced Study (KIAS)

Jongil Park

Professor at Seoul National University

Kyewon Koh Park

Emeritus Professor at Ajou University

Herman Verlinde

Professor at Princeton University

* Kavli Institute for the Physics and Mathematics of the Universe

Research Infrastructure



The Center for Geometry and Physics aims to provide a research environment in which new and original ideas are boldly proposed, tested and revised by means of scientific interactions and communication. By doing so, we hope that some of those ideas evolve into a mature form of truly new mathematics. Thus, the goal of the center is to become the birthplace of fundamentally new research areas in addition to carrying out those projects envisioned in its initial proposal.

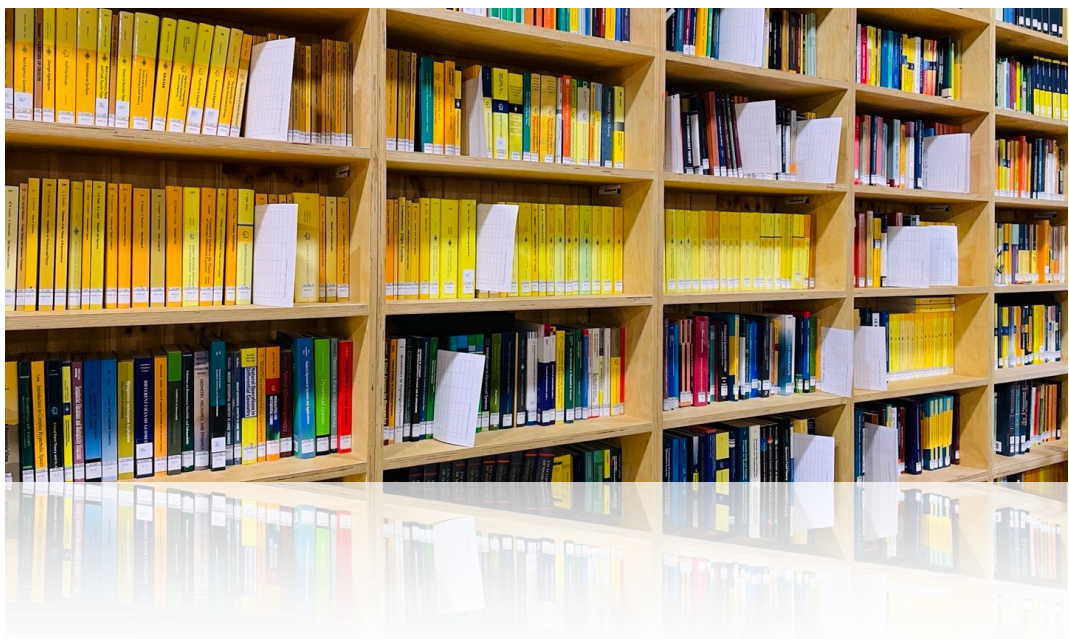
CGP Hall & Library

The CGP Hall is the central location of the Center's academic and social activities.



The hall serves as the venue for most of the seminars, talks and teatimes hosted by the Center. Members and visitors often gather here in small groups for discussions, exchange of ideas or simply for relaxing. It also has several offices for visitors and some members.

The CGP library collection of 4,553 books that the Center has established in topics related to the research areas of the Center greatly complements the rich archive sources available to its members and visitors. The entire CGP library collection is housed at the CGP Hall, and is open to POSTECH members as well so that students and researchers at the Department of Mathematics can take advantage of the collection.



Website, Video System, and Computing Facilities

The CGP website (<http://cgp.ibs.re.kr>) continues to provide schedules and information on events hosted not only by the Center but also by the Department of Mathematics and other mathematics centers at POSTECH at a glance. Also available on the website are the preprints of the members of the Center and the database for the entire collection of the CGP library which can be searched by title, author, ISBN, or year of publication.

In addition, video recordings of most talks, lectures, and conferences hosted by the CGP are uploaded and made available on the website with the consent of speakers. This feature allows anyone who is interested to access and benefit from the talks regardless of their physical location.

For the convenience of visitors and job applicants and the efficiency of the application process, the Center has implemented application features on its website. Those who are interested in visiting and conducting collaborative research with the members of the Center or who are interested in a research position at the Center can apply online at the website.

The CGP Hall, where most of the talks hosted by the Center are given, is equipped with a projector system including a Mac computer dedicated for the purpose of presentations and a Windows computer for general use.

The CGP operates a Linux-based high-performance computation server that can be used to run several CAS (computer algebra systems) such as Mathematica and Maple. The Center also provides web-publishing services for conferences and seminars as well as research-related materials and personal webpages.

CGP Guesthouse



The Center aims to facilitate the active creation of new research and the dissemination of recent progress at the boundary of what is known. CGP has created a comprehensive visitor programs to attract researchers from both Korea and abroad.

The Center operates a fully-furnished apartment-style guesthouse to better accommodate our visitors, especially those who are visiting with their family, and/or visiting for an extended period of time. The guesthouse is located near POSTECH campus, approximately 20 minutes walking away from the Center.



Scientific Activities



Statistics

- ◆ 2 conferences
- ◆ 61 talks and seminars
- ◆ 1 lecture series

CGP at a Glance



AWARD

Yong-Geun Oh, 2022 Samsung Ho-Am Prize in physics and mathematics



2022



2022



Event
1st CGP Townhall Meeting (July 25)

New Research Member
Dmytro Voloshyn

Event
IBS-CGP 10th Anniversary Conference (October 4 – 6)
2022 CGP Advisory Committee Meeting (October 7 – 8)

New Research Member
Seul Bee Lee
Arthur Soulié

JUL

SEP

NOV

AUG

OCT

DEC

New Research Member
Igor Krylov

New Research Member
Anderson Arley Vera Arboleda (Young Scientist Fellow)

New Research Team
Quantum topology, knot theory and mapping class groups
(Team leader: Anderson Arley Vera Arboleda)

Event
IBS-CGP and MATRIX workshop on Symplectic Topology (December 5 – 16)

Conferences

In an effort to take on a leading role in enriching the mathematical society, the Center works in collaboration with other institutes and organizations to hold conferences for a wider audience of mathematicians and scholars. The Center has organized or co-organized 3 conferences:

- **IBS Center for Geometry and Physics 10th Anniversary Conference;** October 4 – 6, 2022

- Organizers: Alexander Aleksandrov (IBS-CGP)
Yong-Geun Oh (IBS-CGP & POSTECH)
Jihun Park (IBS-CGP & POSTECH)
- Invited Speakers: Ivan Cheltsov (University of Edinburgh)
Cheol-Hyun Cho (Seoul National University)
Sung Rak Choi (Yonsei University)
Kento Fujita (Osaka University)
Ko Honda (University of California, Los Angeles)
Sungkyung Kang (IBS-CGP)
Eunjeong Lee (Chungbuk National University)
Kyoung-Seog Lee (University of Miami)
Todor Milanov (Kavli IPMU*)
Paul Norbury (University of Melbourne)
Yong-Geun Oh (IBS-CGP & POSTECH)
Philsang Yoo (Seoul National University)



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- **IBS-CGP and MATRIX workshop on Symplectic Topology;** December 5 – 16, 2022
 - Organizers: River Chiang (National Cheng Kung University)
Yong-Geun Oh (IBS-CGP & POSTECH)
Brett Parker (Australian National University)
 - Participants: Mark Gross (University of Cambridge)
Bernd Siebert (The University of Texas at Austin)
Mohammad Abouzaid (Columbia University)
Conan Nai Chung Leung (Chinese University of Hong Kong)
Grigory Mikhalkin (University of Geneva)
Kaoru Ono (Research Institute for Mathematical Sciences, Kyoto University)
Sara Tukachinsky (Tel Aviv University)
Yoosik Kim (Pusan National University)
Brett Parker (Australian National University)
Yong-Geun Oh (IBS-CGP & POSTECH)
Yat-Hin Suen (IBS-CGP)
Bai-Ling Wang (Australian National University)
Paul Norbury (University of Melbourne)
Jongmyeong Kim (IBS-CGP)
Taesu Kim (IBS-CGP)
Yuto Yamamoto (IBS-CGP)
Ian Le (Australian National University)
Hanwool Bae (Seoul National University)
Ke Zhu (Minnesota State University Mankato)

This two-week research program will gather leading experts and early career researchers for a research-intensive program on symplectic topology; with focus in the areas of tropical geometry, the Fukaya category, open Gromov–Witten invariants and singular symplectic geometry. The aim of this program is to encourage collaboration in an atmosphere where mathematicians at all career stages work side by side. There will be two introductory lecture series and some scheduled talks to encourage interaction, but the majority of time will be set aside for informal discussions, research, and collaboration.

Seminars

The CGP hosts various seminars given both by visiting scholars and the members of the Center.

Symplectic Monday Seminar (Mondays 16:00 – 18:00)*

The talks are focused on symplectic geometry and chaired by Director Yong-Geun Oh.

Algebraic Geometry Seminar (Tuesdays 16:00 – 18:00)*

The talks are focused on algebraic geometry and chaired by Associate Director Jihun Park.

Wednesday Noon Seminar (Wednesdays 12:00 – 13:00)

The Wednesday Noon Seminar runs weekly with lunch for talks by CGP members on various topics of their own research interest or current works. This is kind of semi-closed seminar open to CGP members and visitors only. (*Paused due to COVID-19*)

Director's Seminar (Bi-weekly Wednesdays 13:30 – 15:30)

The purpose of this seminar is to give updates on current developments and mathematical research highlights in general to CGP members and visitors, and to promote deeper interaction between the speaker and the audience. The seminar's general spirit reflects that of the famous Gelfand Seminar.

The Center for Geometry and Physics Seminar (Thursdays 16:00 – 18:00)

The Center for Geometry and Physics Seminar on every Thursday afternoon is the most important regular event of the CGP, and generally all members of the Center participate. The seminars are formatted to encourage robust and dynamic interactions among participants. The seminar is structured as a two-hour talk by a designated speaker with a thirty minute intermission with tea and snack. The first half is intended to be a colloquium-level talk suitable for a general mathematical audience, while the second half can be more specialized. Discussions may continue over dinner.

Mathematical Physics Seminar (Fridays 13:00 – 15:00)*

The talks are focused on mathematical physics chaired by Director Yong-Geun Oh and a research fellow, Alexander Aleksandrov.

IBS-CGP Post-doc Lecture Series

The Director encourages CGP post-doc members to give 3–4 one-hour lectures on their research area. The main purpose of the series is to train post-doc's lecture skills so the Director comments on the lecture series and give suggestions to improve.

* Depending on the invited speaker's location, the online seminar was held flexibly at 10:00 – 11:00 or 16:00 – 18:00.

List of All Talks

Symplectic duality for hypertoric varieties via Floer theory

Xiao Zheng (The Institute of Mathematical Sciences, CUHK*)
December 19, 2022

Some results and conjectures the rank of some knot homologies

Marco Marengon (Alfréd Rényi Institute for Mathematics)
December 15, 2022

Abelian/Nonabelian correspondence and derived categories

Dongwook Choa (Korea Institute for Advanced Study)
November 28, 2022

[IBS-CGP Post-doc Lecture Series]

The Bethe/Gauge correspondence I – III

Norton Lee (IBS-CGP)
November 22 – 25, 2022

Open r -spin theories with multiple boundary states

Ran Tessler (Weizmann Institute of Science)
November 18, 2022

Natural differentiable structures on statistical models and the Fisher metric

Hong Van Le (Institute of Mathematics of ASCR†)
November 17, 2022

Equivariant Homological Mirror Symmetry for $\mathbb{C}P^1$

Masahiro Futaki (Chiba University)
November 14, 2022

Morita invariance of Categorical Enumerative Invariants

Lino Jose Campos Amorim (Kansas State University)
November 7, 2022

Strings, knots and quivers

Piotr Sułkowski (University of Warsaw)
November 4, 2022

Symplectic blowing down in dimension six

Weiyi Zhang (University of Warwick)
October 31, 2022

Superintegrability: new and old meanings and techniques

Aleksandr Popolitov (Moscow Institute for Physics and Technology)
October 28, 2022

On birationally solid Fano 3-fold hypersurfaces

Takuzo Okada (Saga University)
October 25, 2022

Strong closing property of contact forms and action selecting functors

Kei Irie (RIMS‡, Kyoto University)
October 24, 2022

Perturbative connection formulas for Heun equations

Oleg Lisovyi (University of Tours)
October 21, 2022

A classification of 3+1D topological orders in bosonic systems

Xiao-Gang Wen (Massachusetts Institute of Technology)
October 18, 2022

Contact Hamiltonian Floer homology and Eliashberg-Polterovich's orderability

Jun Zhang (University of Science and Technology of China)
October 17, 2022

Integrable Systems and mirror symmetry in probability theory and combinatorics

Jian Zhou (Tsinghua University)
October 14, 2022

Fractional quantum Hall effect via the Grothendieck-Riemann-Roch formula

Dimitri Zvonkine (University of Versailles Saint-Quentin-en-Yvelines)
September 30, 2022

The spin Gromov-Witten/Hurwitz correspondence

Reinier Kramer (University of Alberta)
September 23, 2022

Groups of area preserving homeomorphisms and subleading asymptotics of link spectral invariants

Vincent Humilière (The Mathematics Institute of Jussieu)
September 19, 2022

Defect in gauge theory and quantum spin chains

Norton Lee (IBS-CGP)
September 16, 2022

Counting divisorial contractions with centre a CA_n -singularity

Erik Paemurru (University of Miami & ICMS§-Sofia)
July 26, 2022

* The Chinese University of Hong Kong

† The Academy of Sciences of the Czech Republic

‡ Research Institute for Mathematical Sciences

§ The International Center for Mathematical Sciences

Families of simple subgroups in the Cremona group arising from del Pezzo fibrations**Igor Krylov** (Korea Institute for Advanced Study)
July 19, 2022***Compactness results of Hamiltonian stationary Lagrangian submanifolds in symplectic manifold*****Man Shun Ma** (University of Copenhagen)
July 14, 2022***On toric Schubert varieties*****Eunjeong Lee** (Chungbuk National University)
July 5, 2022***Strong Suslin reciprocity, additive dilogarithms, and a family of algebraic curves*****Jinhyun Park** (Korea Advanced Institute of Science and Technology)
June 16, 2022***Gorenstein spherical Fano varieties*****Giuliano Gagliardi** (Leibniz University Hannover)
June 14, 2022***Double lines in the quintic del Pezzo fourfold*****Kiryong Chung** (Kyungpook National University)
May 31, 2022***Compactification of Popsicles with interior insertions*****Cheol-Hyun Cho** (Seoul National University)
May 23, 2022***Groups of area-preserving homeomorphisms, spectral estimators, and Sikorav's trick*****Lev Buhovsky** (Tel Aviv University)
May 19, 2022***Compact Moduli of K3 surfaces with a prescribed nonsymplectic cyclic action*****Changho Han** (University of Georgia)
May 17, 2022***Floer homology and right-veering monodromy*****Steven Sivek** (Imperial College London)
May 16, 2022***Mirror symmetry of Fano manifolds via toric degenerations*****Fumihiko Sanda** (Gakushuin University)
May 9, 2022***Topological entropy, barcodes and Floer theory*****Viktor Ginzburg** (University of California, Santa Cruz)
May 2, 2022***Quantum trace map for 3-manifolds and a 'length conjecture'*****Dongmin Gang** (Seoul National University)
April 29, 2022***A birational Torelli theorem for parabolic symplectic bundles*****Sumit Roy** (IBS-CGP)
April 26, 2022***Equivariant Lagrangian Floer cohomology over integers via semi-global Kuranishi structures*****Erkao Bao** (University of Minnesota)
April 25, 2022***Hall-Littlewood functions and Virasoro constraints*****Xiaobo Liu** (Peking University)
April 22, 2022***On construction of open descendant potentials in all genera II*****Alexander Aleksandrov** (IBS-CGP)
April 20, 2022***Fano manifolds with Lefschetz defect 3*****Cinzia Casagrande** (University of Turin)
April 19, 2022***Complex Lagrangian vector spaces and representations of the Heisenberg Lie algebra*****Hyunmoon Kim** (Seoul National University)
April 18, 2022***The B-model for singular spectral curves and its enumerative interpretation*****Gaëtan Borot** (Institute for Mathematics & Institute for Physics, Humboldt University of Berlin)
April 15, 2022***New developments in involutive Heegaard Floer homology*****Ian Zemke** (Princeton University)
April 14, 2022***On construction of open descendant potentials in all genera*****Alexander Aleksandrov** (IBS-CGP)
April 13, 2022***Mutations and flat families with toric fibers*****Nathan Ilten** (Simon Fraser University)
April 11, 2022***Klein TQFT and real Gromov-Witten invariants*****Penka Georgieva** (The Mathematics Institute of Jussieu)
April 8, 2022***Open Gromov-Witten invariants: their definition, obstruction and wall-crossing*****Yong-Geun Oh** (IBS-CGP & POSTECH)
April 6, 2022***Geometry of algebraic surfaces via their Cox rings*****Kyoung-Seog Lee** (University of Miami)
April 5, 2022

On Gromov-Yomdin type theorems and a categorical interpretation of holomorphicity

Jongmyeong Kim (IBS-CGP)
April 4, 2022

Moduli spaces of residueless meromorphic differentials and the KP hierarchy

Paolo Rossi (University of Padua)
April 1, 2022

Hofer's geometry and entropy

Matthias Meiwes (RWTH* Aachen University)
March 28, 2022

Mirror symmetry for a cusp polynomial Landau-Ginzburg orbifold

Alexey Basalaev (National Research University Higher School of Economics)
March 25, 2022

On K-stability of Fano varieties

Hamid Abban (Loughborough University)
March 22, 2022

Polyhedral Liouville domains

Marco Castronovo (Columbia University)
March 21, 2022

b-monotone Hurwitz numbers: Virasoro constraints, BKP hierarchy, and $O(N)$ -BGW integral

Guillaume Chapuy (IRIF†, University of Paris)
March 18, 2022

Enumerative Geometry of Del Pezzo Surfaces

Yu-Shen Lin (Boston University)
March 14, 2022

Cluster integrable systems and supersymmetric gauge theories

Andrei Marshakov (Center for Advanced Studies, Skoltech)
March 11, 2022

On K-stability of Fano weighted hypersurfaces

Taro Sano (Kobe University)
March 8, 2022

Gluing theories of contact instantons and of pseudoholomorphic curves in symplectic buildings

Yong-Geun Oh (IBS-CGP & POSTECH)
March 7, 2022

Complex cobordism and Hamiltonian fibrations

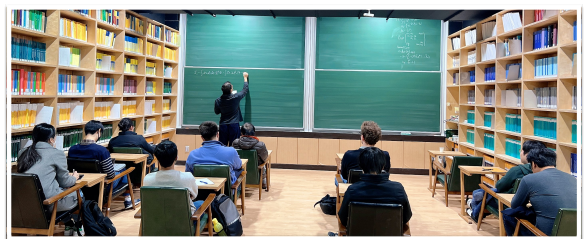
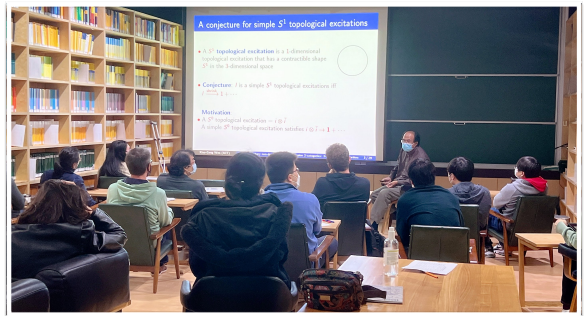
Mohammed Abouzaid (Columbia University)
February 29, 2022

Symmetries and Knot Floer homology

Abhishek Mallick (Max Planck Institute for Mathematics)
February 17, 2022

Seiberg-Witten Floer K-theory for knots

Hokuto Konno (The University of Tokyo)
January 13, 2022



* Rheinisch-Westfälische Technische Hochschule

† Institut de Recherche en Informatique Fondamentale

Visitor Programs and Visitors

CGP runs programs to support visiting scholars. The goal of the visitor programs at the center is to support dynamic researchers working in topics related to the core fields of interest. In particular, the center aims to facilitate the active creation of new research and the dissemination of recent progress at the boundary of what is known. More concretely, we believe that mixing interesting people working on interesting problems in one place has the potential to reveal commonalities, promote collaboration, and help those people advance in understanding.

The center can provide office space and housing for approved visitors. Limited funds are available to support for travel and local expenses for visiting scholars.



List of All Visitors

Eunjeong Lee (Chungbuk National University)
December 22, 2022 – February 28, 2023
July 22 – August 31, 2022

Kaiwen Sun (Korea Institute for Advanced Study)
October 30 – November 6, 2022

Takuzo Okada (Saga University)
October 23 – 26, 2022

Xiao-Gang Wen (Massachusetts Institute of Technology)
October 18, 2022

Mikhail Kapranov (Kavli IPMU*, University of Tokyo)
October 6 – 9, 2022

Sung Rak Choi (Yonsei University)
October 6, 2022

Jongil Park (Seoul National University)
October 5 – 9, 2022

Herman Verlinde (Princeton University)
October 5 – 8, 2022

Kyewon Koh Park (Kavli IPMU*)
October 4 – 7, 2022

Paul Norbury (University of Melbourne)
October 4 – 7, 2022

Ko Honda (University of California, Los Angeles)
October 4 – 7, 2022

Kento Fujita (Osaka University)
October 4 – 7, 2022

Todor Milanov (University of Melbourne)
October 4 – 7, 2022

JongHae Keum (Korean Mathematical Society & Korea
Institute for Advanced Study)
October 3 – 9, 2022

Cheol-Hyun Cho (Seoul National University)
October 3 – 7, 2022

Philsang Yoo (Seoul National University)
October 3 – 7, 2022

Kyoung-Seog Lee (University of Miami)
October 2 – 8, 2022

Ivan Cheltsov (University of Edinburgh)
October 2 – 4, 2022

Hanwool Bae (Seoul National University)
August 24 – 28, 2022
January 25 – 28, 2022

Erik Paemurru (University of Miami, ICMS[†]-Sofia)
July 21 – August 3, 2022

Dongsoo Lee (Seoul National University)
July 20 – 22, 2022

Kyeong-Dong Park (Gyeongsang National University)
July 14 – 16, 2022

Dongmin Gang (Seoul National University)
April 27 – 30, 2022

In-kyun Kim (Yonsei University)
February 7 – 11, 2022

Wonbo Jeong (Seoul National University)
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- 2nd BICMR&IBS-CGP Joint Symplectic Geometry Workshop (September 18 – 22, 2017 @ BICMR)
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Research Highlights

Yoosik Kim : A critical point analysis of Landau–Ginzburg potentials with bulk in Gelfand–Cetlin in systems

Yat-Hin Suen : Tropical Lagrangian multi-sections and smoothing of locally free sheaves over degenerate Calabi-Yau surfaces

Haowu Wang : Vertex algebras, BKM algebras and automorphic products

Joonyeong Won : Sasaki-Einstein 5-manifolds

A Critical point analysis of Landau Ginzburg potentials with bulk in Gelfand Cetlin systems

Yoosik Kim

Assistant Professor at Pusan National University
(CGP Research member from July 2016 to June 2017)

Arnold conjecture and Floer theory

The main driving force in the development of symplectic topology is the Arnold conjecture.

Conjecture 1.1 (Arnold). Let (M, ω) be a closed symplectic manifold. Let $\phi: M \rightarrow M$ be a Hamiltonian diffeomorphism. If the fixed points of ϕ are all non-degenerate, then the number of fixed points is at least the minimal number of critical points of a Morse function on M .

The conjecture can be generalized and formulated in terms of Lagrangian intersection by considering the anti-symplectic involution of $(x, y) \mapsto (y, x)$ in the product symplectic manifold $(M \times M, \omega \oplus -\omega)$.

Conjecture 1.2 (Arnold Givental). Let (M, ω) be a closed symplectic manifold and τ an anti-symplectic involution. Let L be the set of fixed points of τ . If L and $\phi(L)$ intersect transversally, the number of intersection points is at least the minimal number of critical points of a Morse function on M .

This conjecture implies that a certain Lagrangian submanifold L in symplectic topology enjoys a peculiar intersection property. Although the intersection pairing L and $\phi(L)$ in topology is trivial, the Lagrangian L and its Hamiltonian perturbation $\phi(L)$ always intersect for every Hamiltonian diffeomorphism, which leads to the following definition.

Definition 1.3. A Lagrangian submanifold L of a symplectic manifold (X, ω) is called *non-displaceable* if for every Hamiltonian diffeomorphism ϕ on X , the submanifold L and its Hamiltonian perturbation $\phi(L)$ always intersect, that is,

$$(1.1) \quad L \cap \phi(L) \neq \emptyset.$$

Then we can ask the following natural question.

Question 1.4. Find *non-displaceable* Lagrangian submanifolds of a symplectic manifold (X, ω) .

To attack the Arnold type conjecture, A. Floer invented infinite dimensional Morse theory, which is now-called *Floer theory*. In particular, he constructed Lagrangian Floer cohomology such that the non-vanishing of Floer cohomology of L (over a torsion free coefficient ring) yields the homological version of the Arnold conjecture.

Theorem 1.5 (Floer). *Suppose that a Lagrangian submanifold L satisfies $\omega(\beta) = 0$ for all $\beta \in \pi_2(X, L)$. Let ϕ be a Hamiltonian diffeomorphism on M . If L and $\phi(L)$ intersect transversally; then the number of intersections is greater than or equal to the sum of betti numbers of L . In particular, the Lagrangian submanifold L is non-displaceable.*

Lagrangian intersection Floer theory

After Floer's invention, Oh [Oh93] constructed Floer cohomology for monotone Lagrangian submanifolds. A foundational work of Fukaya–Oh–Ohta–Ono [FOOO09] defined Floer cohomology for compact Lagrangians in a general symplectic manifold. Moreover, the obstruction of Floer cohomology was analyzed and its deformation theory was developed therein. Also, they introduced a disk potential function of L , which is defined by counting holomorphic disks bounded by L and can be used to compute a differential for Floer cohomology.

The most well-studied examples include the toric fibers in toric manifolds. The monotone toric fiber, the toric fiber located at the barycenter of the moment polytope, of monotone toric manifolds was studied by Cho–Oh in [CO06]. In particular, they classified the holomorphic disks bounded by each toric fiber. In particular, for compact Fano toric manifolds, the classification result yields that the disk potential function agrees with the Givental–Hori–Vafa superpotential, which can compute the quantum cohomology ring as its Jacobian ring. For general compact toric manifolds, Fukaya–Oh–Ohta–Ono [FOOO10] constructed Lagrangian Floer theory on the de Rham model. To detect more non-displaceable Lagrangian toric fibers, they developed the Floer theory bulk-deformed by toric cycles to detect more Lagrangian toric fibers in [FOOO11].

A natural follow-up direction is to investigate algebraic varieties occurring at generic fibers of a toric degeneration since they can be understood via the central irreducible toric variety. A particular type of toric degenerations such that the central toric variety admits a small toric resolution and each variety of the flat family is Fano was firstly studied. Conciulea–Lakshmibai's toric degeneration of a partial flag variety is the prototype of such degenerations. In this circumstance, Nishinou–Nohara–Ueda [NNU10] constructed a Lagrangian torus fibration commuting with the toric moment map via a continuous extension of a densely defined symplectomorphism arising from the gradient Hamiltonian flow. Moreover, they computed the disk potential function of a Lagrangian torus.

Non-displaceable Lagrangian submanifolds in flag manifolds

By applying Thimm's method, Guillemin–Sternberg [GS83] constructed a completely integrable system on a flag manifold, which is called a Gelfand–Cetlin system. The image of Gelfand–Cetlin system is a polytope, called the Gelfand–Cetlin polytope Δ . The face structure was described through certain subgraphs of the ladder diagram Γ by An–Cho–J. Kim [ACK]. In the preceding paper [CKO20], Cho–K.–Oh devised “3D-TETRIS®” with various shapes of blocks on the corresponding graph in Γ , described an iterated bundle structure of the fiber over a point in the relative interior of a face, and discussed whether the fiber is Lagrangian or not. The continuum family of non-displaceable Lagrangian tori occurs over line segments connecting the center of the Gelfand–Cetlin polytope Δ and the center of a certain face f of Δ .

Theorem A. *For $n \geq 3$, a monotone complete flag manifold $\mathcal{F}\ell(n)$ carries a continuum family of non-displaceable Lagrangian Gelfand–Cetlin torus fibers. Moreover, the flag manifold carries monotone non-displaceable non-torus Lagrangian submanifolds diffeomorphic to*

$$\mathrm{SU}(m) \times T^{n(n-1)/2-m^2-1} \quad \text{for } m = 2, \dots, \left\lfloor \frac{n}{2} \right\rfloor$$

where $\mathrm{SU}(m)$ is a special unitary group.

To prove Theorem A, we employ Schubert cycles to deform Lagrangian Floer theory. A Schubert cycle is represented by a union of the inverse images of faces by the work of Kogan–Miller [KM05]. Using the toric degeneration and Nishinou–Nohara–Ueda's work, we compute the bulk-deformed disk potential function. Once each torus in the line segment is shown to be non-displaceable, the non-displaceability of the non-torus Lagrangian fiber at the limit follows. In this case, the parameter space for bulk-deformation is not large enough so that terms in the disk potential cannot be deformed. It contrasts to the toric case where all terms in the disk potential can be independently deformed. Getting the aid of the ladder diagram Γ , we successfully find a bulk-parameter making the bulk-deformed Floer cohomology non-vanishing.

In particular where $n = 3$, combining with Pabiniak's work [Pab15] on displaceable Lagrangian tori, the result leads to a complete classification of non-displaceable Gelfand–Cetlin fibers.

Theorem B. *Consider a monotone complete flag manifold $\mathcal{F}\ell(3)$. The Gelfand–Cetlin polytope Δ contains a line segment I connecting the barycenter of Δ and a vertex at which the Lagrangian 3-sphere is located. Then each Gelfand–Cetlin fiber at the line segment I is non-displaceable. In particular, the Lagrangian 3-sphere is non-displaceable. Moreover, every Lagrangian torus not located at the line segment I is displaceable.*

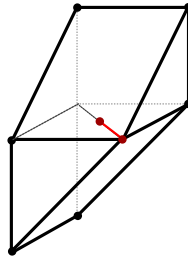


Figure 1. The positions of non-displaceable Gelfand–Cetlin Lagrangian fibers in $\mathcal{F}\ell(3)$.

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Tropical Lagrangian multi-sections and smoothing of locally free sheaves over degenerate Calabi-Yau surfaces

Yat-Hin Suen

Research member since August 2018

Mirror symmetry

In mathematics, there are two subjects that used to be developed separately, namely, *algebraic geometry* and *symplectic geometry*. Algebraic geometry studies the geometry of the zero set of polynomials and geometric objects on them like vector bundles, coherent sheaves. Symplectic geometry originated from the study of Hamiltonian mechanics and was abstracted by Arnold to its modern form. In '90s, when a group of string theorists were studying conformal field theory, they found out that some complicated problems in symplectic geometry can be solved dramatically simpler by passing to algebraic geometry [1]. They called this discovery *mirror symmetry*.

To understand mirror symmetry mathematically, Kontsevich proposed the *homological mirror symmetry (HMS) conjecture* [11] in 1994. He proposed that an algebraic variety \check{X} is (homologically) mirror to a symplectic manifold X if the derived category of \check{X} is equivalent to the derived Fukaya category of X . Mathematically, we write

$$D^{\pi}Fuk(X) \cong D^bCoh(\check{X}).$$

Objects in these categories are usually called *branes* because they are the boundary conditions that the end points of an open string attaches to. Basic objects in $D^{\pi}Fuk(X)$ are Lagrangian submanifolds in X while those in $D^bCoh(\check{X})$ are locally free sheaves on \check{X} . Despite the power of HMS, it doesn't tell us how to find mirror pairs. Two years after Kontsevich's proposal, Strominger-Yau-Zaslow provided an entirely geometric method to obtain mirror manifolds, which is now known as the *SYZ program* [14]. They conjectured the existence of a special Lagrangian torus fibration (possibly with singular fibers) on a Calabi-Yau manifold X . Then a mirror \check{X} of X can be obtained by taking the dual torus fibration. Furthermore, the equivalence in the HMS conjecture can be realized by a Fourier-Mukai-type transformation. The SYZ program is beautiful except that it needs to be "corrected". These corrections are called *instantons* in the physics literature.

The Gross-Siebert program

After SYZ program, Fukaya was the first to suggest the use of asymptotic analysis to understand what means by “SYZ with corrections” mathematically [6]. However, the analysis in Fukaya's proposal is so complicated that there were no progress until the recent breakthrough by Chan-Leung-Ma [2, 3, 4]. The work of Chan-Leung-Ma was heavily motivated, not just by Fukaya, but also the important work of Gross-Siebert [7, 8, 9]. The famous *Gross-Siebert program* uses toric degenerations to construct mirror manifolds. Roughly speaking, beginning with a smooth polarized Calabi-Yau manifold X , one finds a degeneration of X into a union of projective toric varieties X_0 . Since each irreducible component of X_0 is a projective toric variety, it has a corresponding polytope. By gluing these polytopes together according to how the irreducible components of X_0 intersect, one obtains a so-called *affine manifold with singularities* B equipped with a *polyhedral decomposition* \mathcal{P} . Here is where *tropical geometry* comes in. Tropical geometry is a field where mathematicians use combinatorics to study algebraic geometry. The combinatorial/tropical data (B, \mathcal{P}) actually encodes the algebraic information on how X is degenerated to X_0 or, conversely, how X_0 is smoothed. This algebraic information is called a *log structure*, which is laying in the heart of the Gross-Siebert program. To connect toric degenerations with mirror symmetry, Gross-Siebert told us to run the following procedures (Figure 1). By taking the discrete Legendre transform of (B, \mathcal{P}) , we obtain another affine manifold with singularities \check{B} and polyhedral decomposition $\check{\mathcal{P}}$. Then by reversing the construction, we get a space \check{X}_0 , which is also a union of projective toric varieties and carries a log structure. A fascinating result of the Gross-Siebert program is that there is a canonical smoothing \check{X} of \check{X}_0 that can be constructed order-by-order by using a combinatorial tool called *scattering diagrams*, which was introduced by Kontsevich-Soibelman [12] to construct the mirror of K3 surfaces. The resulting smoothing \check{X} will then be mirror to X .

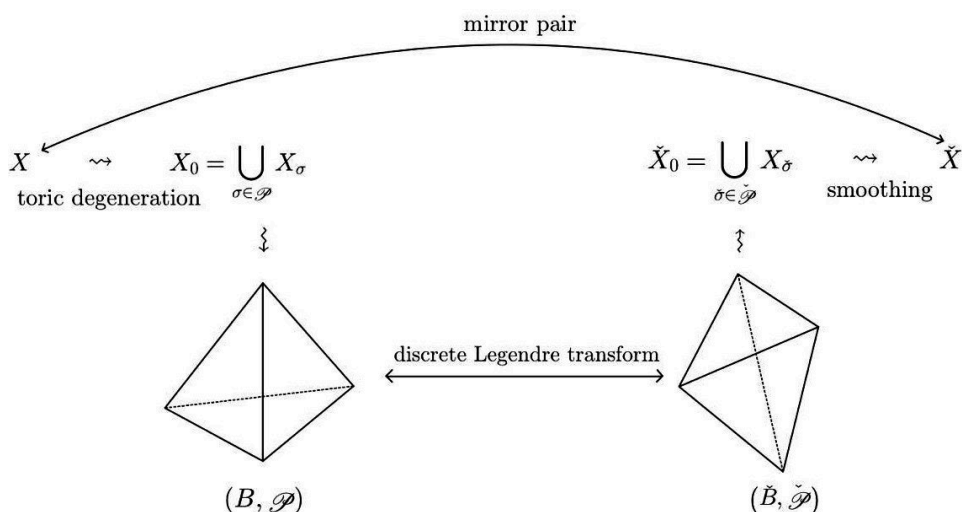


Figure 1. The Gross-Siebert program

Tropical Lagrangian multi-sections

In the Gross-Siebert program, they didn't tell us what is the tropical analog of branes. For instance, what should be the correct combinatorial objects on (B, \mathcal{P}) that correspond to locally free sheaves on \check{X}_0 or its smoothing \check{X} . In a joint work with Chan and Ma [5], we introduced the notion of *tropical Lagrangian multi-sections* over a general 2-dimensional affine manifold with singularities equipped with a polyhedral decomposition. This new concept is a combinatorial/tropical replacement of Lagrangian multi-sections in the SYZ proposal. Roughly speaking, a tropical Lagrangian multi-section \mathbb{L}^{trop} over (B, \mathcal{P}) is a branched covering map $\pi : L \rightarrow B$ for some topological space L that is equipped with a polyhedral decomposition \mathcal{P}' so that cells in \mathcal{P}' are mapped to cells in \mathcal{P} by π , and more importantly, a choice of multi-valued piecewise linear function φ on L . This notion was later generalized to any dimension by myself in [17]. We usually think of φ as a collection of local (continuous) potential functions of a Lagrangian multi-section. Due to the discrete nature of tropical Lagrangian multi-sections, we should not expect that a locally free sheaf can be uniquely determined. To resolve this problem, either we introduce some extra continuous data as in [10, 16, 17] or we need to fix a good local model around ramification points of $\pi : L \rightarrow B$. In our work, we choose the latter. The following local model was motivated by one of our works [15].

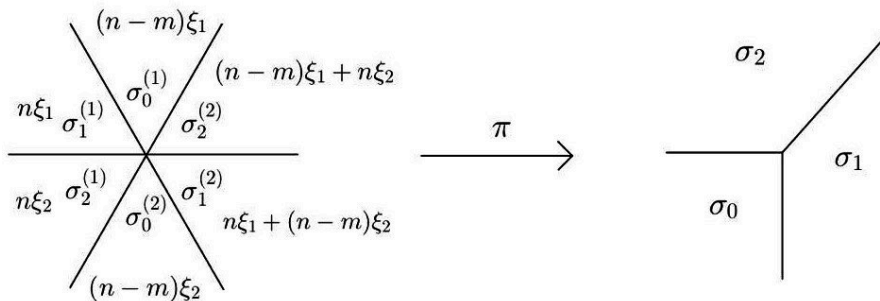


Figure 2. The local model of our tropical Lagrangian multi-section around ramification points.

With this local model in hand, we successfully constructed a locally free sheaf $\mathcal{E}_0(\mathbb{L}^{trop})$ over \check{X}_0 . The last job is to smooth the pair $(\check{X}_0, \mathcal{E}_0(\mathbb{L}^{trop}))$ as in the Gross-Siebert program. In the case that \check{X}_0 is a union of projective planes, we provided a decent combinatorial criterion for checking smoothability. When $m = n + 1$, the following are two examples, for which the corresponding pair $(\check{X}_0, \mathcal{E}_0(\mathbb{L}^{trop}))$ is smoothable.

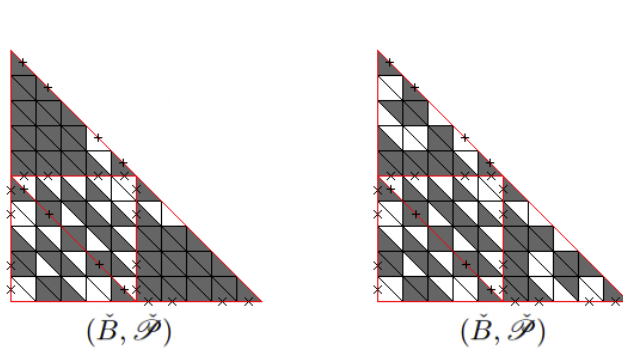


Figure 3. We use the dual picture $(\tilde{B}, \tilde{\mathcal{P}})$. We unfold a tetrahedron \tilde{B} into four big triangles and subdivide these triangles into smaller ones as shown above to get $\tilde{\mathcal{P}}$. Shaded cells correspond to branch vertices on (B, \mathcal{P}) . The crosses on the red lines are affine singularities. On the left (resp. right), we have 74 (resp. 58) branch points which determine a 2-fold branched covering map from a genus 36 (resp. 28) closed surface to B .

Our work is published in *Advances in Mathematics in June 2022*. However, that's not the end of the story. The mirror symmetry picture has not been completed yet. We still need to realize the tropical Lagrangian by an honest Lagrangian multi-section \mathbb{L} and prove that this multi-section is actually unobstructed in Seidel's program [13]. This will be an important future research work in realizing HMS of compact Calabi-Yau manifolds geometrically.

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Vertex algebras, BKM algebras and automorphic products

Haowu Wang

Research member since October 2021

Monstrous moonshine, proposed by McKay, Thompson, Conway and Norton in the 1970s, predicts that there exists a natural graded representation $V = \bigoplus_{n=0}^{\infty} V_n$ of the largest sporadic finite simple group, i.e. the monster group \mathbb{M} such that for each $g \in \mathbb{M}$ the graded trace

$$T_g(\tau) = \sum_{n=0}^{\infty} \text{Tr}(g | V_n) q^{n-1}, \quad q = e^{2\pi i \tau}, \quad \tau \in \mathbb{H} = \{\tau \in \mathbb{C} : \text{Im}(\tau) > 0\}$$

is a modular function on some genus zero subgroup of $\text{SL}_2(\mathbb{R})$. In 1988, Frenkel, Lepowsky and Meurman defined vertex operator algebras (VOA) and constructed the model V as a VOA of central charge 24 denoted $V^{\mathbb{H}}$ with $\text{Aut}(V^{\mathbb{H}}) = \mathbb{M}$ (named as the monster VOA). Borcherds then proved the moonshine conjecture for the model $V^{\mathbb{H}}$ in 1992 and won a Fields medal in 1998 due to this celebrated proof.

Borcherds introduced vertex algebras in 1986 and Borcherds–Kac–Moody (BKM) algebras in 1988, then he applied the no-ghost theorem of string theory to construct a BKM algebra (named as the monster Lie algebra) as the BRST cohomology of some vertex algebra related to $V^{\mathbb{H}}$, and finally he completed the proof by showing that $T_g(\tau_1) - T_g(\tau_2)$ equals the twist of the denominator of the monster Lie algebra by the action of $g \in \mathbb{M}$.

BKM superalgebras are infinite dimensional Lie superalgebras which generalize affine Kac–Moody algebras. They can be defined in terms of Chevalley–Serre generators and relations which are encoded in a generalized Cartan matrix. However, the restrictions on the generalized Cartan matrix are weaker. In particular, simple roots are allowed to have non-positive norm (i.e. can be imaginary roots). BKM superalgebras also have a character formula for highest-weight modules and a denominator identity.

We are mainly interested in BKM superalgebras whose denominators or super-denominators are automorphic forms. This is motivated by the fact that the denominators of affine Kac–Moody algebras have some modularity. More precisely, the denominator of an affine Lie algebra $\hat{\mathfrak{g}}$ can be viewed as a Jacobi form of lattice index, i.e. it is a holomorphic function on $(\tau, \mathfrak{z}) \in \mathbb{H} \times \mathfrak{h}$ which is $\text{SL}_2(\mathbb{Z})$ -modular on τ and quasi-periodic on \mathfrak{z} , where \mathfrak{h} is the Cartan subalgebra of \mathfrak{g} . Note that Jacobi forms were introduced by Eichler and Zagier in 1985.

The automorphic form arising from the denominator of a BKM superalgebra should have an infinite product expansion. In 1995 and 1998 Borcherds developed a theory of theta lift to construct meromorphic modular forms on orthogonal groups $\text{O}(n, 2)$ which have infinite product expansions. This type of modular forms is called Borcherds products. They are defined on the symmetric domain of type IV and their divisor is a linear combination of hyperplanes. The weight of holomorphic Borcherds product is bounded from below when $n \geq 3$. The possible minimal weight $n/2 - 1$ is called the *singular* weight, because any modular form of such a weight lies in the kernel of some Laplace operator. We are particularly interested in *reflective* Borcherds products, that is holomorphic Borcherds products which vanish only on hyperplanes orthogonal to roots. We

conjecture that holomorphic Borcherds products of singular weight are always reflective and there are only finitely many holomorphic Borcherds products of singular weight.

Borcherds suggested to classify BKM superalgebras whose denominators or superdenominators are holomorphic Borcherds products of singular weight and conjectured that these algebras could be constructed as BRST cohomologies of some vertex algebras. The roots and root multiplicities of such BKM superalgebras are encoded in the Fourier expansion of a modular form for the Weil representation of $SL_2(\mathbb{Z})$ (i.e. the input of the denominator as a Borcherds product). This input is usually related to the characters of the vertex algebra.

Borcherds constructed the fake monster algebra as the BRST cohomology of the Leech lattice VOA in 1990 and proved that its denominator is a reflective Borcherds product of singular weight on $O(26,2)$ in 1995. In 1992 Borcherds considered the action of the Conway group Co_0 (i.e. the orthogonal group of the Leech lattice) on the fake monster algebra. He proved that the twist Φ_g of the denominator of the fake monster algebra by $g \in Co_0$ is the untwisted denominator of some BKM superalgebra. He further conjectured that every Φ_g is identical to a holomorphic Borcherds product of singular weight.

Based on some previous work of Scheithauer, Dittmann and I [1] construct the twisted denominators Φ_g at the standard 1-dimensional cusps for eight Co_0 -conjugacy classes $[g]$ and show that they are reflective Borcherds products of singular weight on some lattices of type $2U \oplus L_g$, where U is the unique unimodular lattice of signature $(1,1)$ and L_g are some even positive definite lattices. We further prove that the leading Fourier–Jacobi coefficient of Φ_g at the standard cusp determined by $2U$ coincides with the denominator of some affine Kac–Moody algebra $\hat{\mathfrak{g}}$ as Jacobi forms. The cycle shapes of the 8 conjugacy classes and the associated Lie algebras with levels are formulated in Table 1. The lattice L_g is given by the maximal even sublattice of the normalized coweight lattice of \mathfrak{g} . We finally prove that each Borcherds product Φ_g equals the additive theta lift of the denominator of $\hat{\mathfrak{g}}$.

As a corollary, we give a proof of the theta block conjecture proposed by Gritsenko–Poor–Yuen in 2015, which characterizes Siegel paramodular forms of genus two which are simultaneously Borcherds products and Gritsenko lifts.

Table 1. cycle shapes of Co_0 -conjugacy classes and semi-simple Lie algebras

cycle shape of g	semi-simple Lie algebra \mathfrak{g}
$1^{-1}5^5$	$A_{4,5}$
$1^{-2}2^35^210^1$	$A_{1,2} + B_{3,5}$
$1^{-2}2^34^18^2$	$A_{1,2} + C_{3,4}$
$1^{-2}2^23^24^112^1$	$B_{2,3} + G_{2,4}$
$1^{-3}3^9$	$3A_{2,3}$
$1^{-4}2^64^4$	$3A_{1,2} + A_{3,4}$
$1^{-4}2^53^46^1$	$2A_{1,2} + A_{2,3} + B_{2,3}$
$1^{-8}2^{16}$	$8A_{1,2}$

In this year's joint work with Williams [2], we provide a complete proof of Borcherds' conjecture that the twist denominator of the fake monster algebra for arbitrary $g \in \text{Co}_0$ defines a holomorphic Borcherds product of singular weight on the lattice $U(N_g) \oplus U \oplus \Lambda^g$ and the input can be viewed as the characters of some orbifold VOA related to Λ_g , where N_g is the level of g , Λ^g is the fixed-point sublattice of the Leech lattice and Λ_g is the corresponding coinvariant lattice $(\Lambda^g)^\perp$. We also obtain some classification of holomorphic Borcherds products of singular weight. For example, we prove that the denominator of the fake monster algebra is the unique holomorphic Borcherds product of singular weight on maximal lattices, and show that there are exactly 12 holomorphic Borcherds products of singular weight on full orthogonal groups of lattices of prime level and all of them arise from twisted denominators of the fake monster algebra.

In the near future, I hope to classify the affine Kac–Moody algebras whose denominators appear as the leading Fourier–Jacobi coefficients of reflective Borcherds products of singular weight at standard 1-dimensional cusps, and identify the corresponding two-dimensional conformal or superconformal field theories. More generally, I would like to systematically study the connection of affine Kac–Moody algebras, vertex algebras and BKM algebras at the modular form level.

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URL arXiv:2207.14518

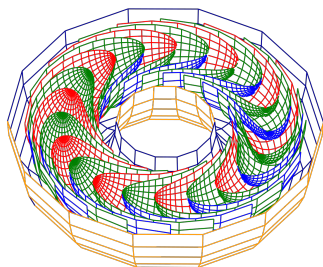
Sasaki-Einstein 5-manifolds

Joonyeong Won

*Assistant Professor at Ewha Womans University
(CGP Research member from April 2016 to May 2019)*

Sasaki-Einstein Geometry

The theory on Kähler-Einstein metrics and K-stability of Fano varieties and the theory on valuative criterions for K-stability have developed dramatically for the last ten years. This progress yields to extend to solve the old problem of the existence of Sasaki-Einstein metric on Riemannian manifolds.



A Riemannian manifold (M, g) is Sasaki-Einstein if it is both Sasakian and Einstein. Sasakian geometry is the odd-dimensional analogue of Kähler geometry that is a milestone to study complex geometry. Kähler geometry is a package of complex, symplectic and Riemannian geometry, likewise, Sasakian geometry is the interplay with CR, contact and Riemannian geometry.

A Riemannian manifold (M, g) is Sasakian if and only if its conical metric $\bar{g} = r^2g + dr^2$ is a Kähler metric on the cone $C(M) \times \mathbb{R}^+$. And $C(M) \times \mathbb{R}^+$ has odd dimension $2n + 1$, where n is the complex dimension of the Kähler cone.

A metric g is called Einstein if it satisfies the condition $\text{Ric}_g = \lambda g$ for some constant, which is called Einstein condition. A Sasakian manifold can be Einstein only for $\lambda = 2(n - 1)$ so that the metric g has positive Ricci curvature. Furthermore, a Sasakian metric g is Einstein with $\text{Ric}_g = 2(n - 1)g$ if and only if the conical metric \bar{g} is Ricci-flat.

Sasakian manifold (M, g) as the cousin of Kähler geometry has linked geometric structures with the Kähler of its cone. The canonical vector field $r\partial_r$ defines the Reeb vector field ζ on M through the integrable complex structure that is defined by $\zeta = J(r\partial_r)$, where J is the integrable complex structure of the Kähler cone. The restriction of ζ to isometrical embedding to $C(M)$ of the Sasakian manifold M ,

$$M = \{r = 1\} = M \times \{a\} \hookrightarrow C(M)$$

is unit length Killing vector field. Sasakian manifolds can be classified into three types according to the Reeb foliations that is orbits defined by one dimensional foliation of M given by the Reeb vector fields. If all orbits of the Reeb vector field ζ are compact, then ζ integrates to a locally free isometric circle action on (M, g) . If this action is free, then the Sasakian manifold M is said to be regular, otherwise it is said to be quasi-regular. On the other hand, if the Reeb vector field ζ has a non-compact orbit the Sasakian manifold is said to be irregular. If M is Sasaki-Einstein, then its space of leaves of the Reeb foliation becomes a Kähler-Einstein orbifold. Thus the classification of real $(2n - 1)$ -dimensional quasiregular Sasaki-Einstein manifolds is closely involved with the exploration of complex $(n - 1)$ -dimensional Kähler-Einstein Fano orbifolds.

On five dimension

We now focus on 5-dimensional Sasaki-Einstein manifold since five is the lowest non-trivial dimension. Many closed simply connected Sasaki-Einstein 5-manifolds have been studied based on the method introduced by Kobayashi and developed by Boyer, Galicki, and Kollar. A quasi-regular Sasakian structure on a manifold M can be written as the unit circle subbundle of a holomorphic Seifert \mathbb{C}^* -bundle over a complex algebraic orbifold (S, Δ) , where $\Delta = \sum (1 - \frac{1}{m_i})D_i$, m_i 's are positive integers, and D_i 's are distinct irreducible divisors. A simply connected Sasakian manifold M is Einstein if and only if $(-K_S + \Delta)$ is ample, the first Chern class of $c_1(M/S)$ is a rational multiple of $(-K_S + \Delta)$, and there is an orbifold Kähler-Einstein metric on the orbifold (S, Δ) . Thus 5-dimensional Sasaki-Einstein geometry is much related to Kähler-Einstein geometry of complex surfaces. From this trigger and its own sake, Kähler-Einstein geometry has been studied for weighted hyper surface which is one of the simplest Fano surface. Collaboration with researcher in a group, I classified Kähler-Einstein metrics on lower index weighted Fano hypersurface or codimension 2 complete intersections as follows.

- In-kyun Kim; **Joonyeong Won**, *Unstable singular del Pezzo hypersurfaces with lower index*, Comm. Algebra (2021) 49:6, 2679–2688
- In-kyun Kim; **Joonyeong Won**, *Delta-invariants of complete intersection log del Pezzo surfaces*, Proc. Roy. Soc. Edinburgh Sect. A., to appear
- In-kyun Kim; Nivedita Viswanathan; **Joonyeong Won**, *K-stability of log del Pezzo surface with index 2*, Internat. J. Math., to appear
- In-kyun Kim; Nivedita Viswanathan; **Joonyeong Won**, *On singular del Pezzo hypersurfaces with index 3*, Springer Proceedings in Mathematics and Statistics, to appear

And my collaborations aim to full classification of Kähler-Einstein geometry of weighted del Pezzo hypersurfaces.

Closed simply connected 5-manifolds are completely classified by Barden and Smale.

For a positive integer m , up to diffeomorphisms, there is a unique closed simply connected spin 5-manifold M_m with $H_2(M_m, \mathbb{Z}) = \mathbb{Z}/m\mathbb{Z} \oplus \mathbb{Z}/m\mathbb{Z}$. Furthermore, a closed simply connected spin 5-manifold M is of the form

$$M = k M_\infty \# M_{m_1} \# \dots \# M_{m_r},$$

where $k M_\infty$ is the k -fold connected sum of $S^2 \times S^3$ for a non-negative integer k and m_i is a positive integer greater than 1 with m_i dividing m_{i+1} .

Closed simply connected 5-manifolds are divided into three types for a convenience that are torsion free, rational homology sphere and mixed type by their rank and torsions. For torsion free type, all of the types are Sasaki-Einstein by many paper of Boyer, Galicki, Kollar, and Nakamaye. So Sasaki-Einstein problem shifted to second simple type, rational homology sphere and we have the following classification due to Kollar.

A simply connected rational homology 5-sphere admits a (quasiregular) Sasaki-Einstein metric if and only if it is one of the following:

- (1) the 5-sphere;
- (2) M_r , where r is a positive integer with $r \geq 2$ not divisible by 30;
- (3) $2M_5$;
- (4) $2M_4$;
- (5) $2M_3, 3M_3, 4M_3$;
- (6) nM_2 , where $n \geq 2$.

By α -invariant method, Boyer, Galicki, Kollar proved the existence of Sasaki-Einstein metric on the cases of (1) to (5) and they conjectured that number (6), that is, nM_2 is all Sasaki-Einstein for $n \geq 2$ which was open in 15 years.

In 2021, collaborating with Jihun Park who is an Associate Director of IBS-CGP, I completed the classification of simply connected Sasaki-Einstein rational homology 5-spheres by developing the estimation method of the delta invariant to show that the number (6) is Sasaki-Einstein.

- Jihun Park; **Joonyeong Won**, *Simply connected Sasaki-Einstein rational homology 5-spheres*, Duke Math. J. (2021) 170 (6), 1085–1112

Now 5-dimensional Sasaki-Einstein geometry problem remains for mixed types however it is wide open and many candidates are expected to be not Sasaki-Einstein. For a positive side, myself with collaboration has a partial answer of the type that $2M_\infty \# nM_2$ is Sasaki-Einstein.

- Dasol Jeong; In-Kyun Kim; Jihun Park; **Joonyeong Won**, *New Sasaki-Einstein 5-manifolds*, submitted

The followings are remaining candidates for Sasaki-Einstein 5-manifolds.

- $kM_\infty \# 2M_3$, where $k \geq 2$
- $kM_\infty \# 3M_3$, where $k \geq 2$
- $kM_\infty \# nM_2$, where $k \geq 3, n \geq 2$
- $kM_\infty \# M_m$, where $k \geq 9$ and $2 \leq m \leq 11$

I am trying to show that the following remarkable conjecture.

Conjecture 2.1. *For each integer $k \leq 8$ and $n \geq 2$, the Smale 5-manifold $kM_\infty \# nM_2$ admits a Sasaki-Einstein metric.*

Delta invariant method

Let X be a quasi-smooth hypersurface in a weighted projective space $\mathbb{P}(\mathbf{w}) = \mathbb{P}(a_0, a_1, \dots, a_n)$ defined by a quasi-homogeneous polynomial. The link of X is defined by the intersection $L_X = S_{\mathbf{w}}^{2n+1} \cap \widehat{X}$.

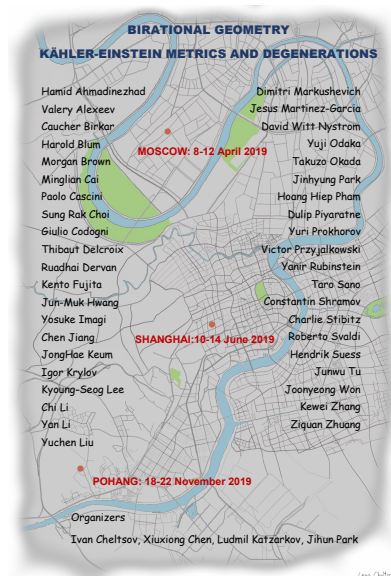
Then we have the following diagram.

$$\begin{array}{ccc}
 L_X & \hookrightarrow & S_{\mathbf{w}}^{2n+1} \\
 \downarrow & & \downarrow \\
 X & \hookrightarrow & \mathbb{P}(\mathbf{w})
 \end{array}$$

L_X is Sasaki-Einstein if and only if X is Kähler-Einstein so that we found a specific weighted hypersurface X such that $L_X = nM_2$. Then proved such X is Kähler-Einstein equivalently K-stable by delta invariant method. The delta invariant measures singularity of divisor that consists bases of pluri anti canonical system asymptotically. And it turns out that it detects K-stability exactly that

“Let (X, Δ) be a log \mathbb{Q} -Fano variety. Then (X, Δ) is K-stable if and only if $\delta(X, \Delta) > 1$ ”.

Indeed what my collaboration proved is that the delta invariant of X with $L_X = nM_2$ is large enough to show K-stability of X .



Interviews

Sung Rak Choi

Youngho Yoon

Volker Genz

Hisayoshi Muraki

Sung Rak Choi*Associate Professor at Yonsei University**(CGP Research member from July 2013 to February 2016)*

How is your life / work after CGP?

I have worked in IBS-CGP for about two and a half years until February 2016 as a Research fellow and IBS fellow. This was the most prolific time of my research and IBS-CGP provided me with the perfect research environment. In March 2016, I moved to Yonsei University to start a new position as an assistant professor in the mathematics department. Since then my life has drastically changed. Teaching courses every semester and advising students are (still) always big challenges for me. Although it takes time and effort, I take it also as a good opportunity to teach myself.

What made you decide to be a mathematician?

By chance, I had to move a lot in my childhood between Korea and Japan. I had to transfer four times in elementary school, once in middle school and twice in high school. In the new schools where I transferred to, getting to know new people and making new friends was always fun. However, it was often a difficult task for me to catch up with the classes because the curriculums were totally different from those of the previous schools. However, mathematics and science were taught universally in every school and I always enjoyed these subjects. So, naturally, I became interested in pursuing mathematician or physicist as a career. There was no particular incident that made me decide to become a mathematician (I decided not to become a physicist because I could not get into the physics department).

What is your current math-related interest?
Please tell us about your research.

Currently, I am mainly interested in establishing a variation of the minimal model program (MMP). Classical MMP is a birational modification on an algebraic variety which simplifies the variety in the canonical way without distorting the essential geometry. MMP has several variations and what I am interested in can be considered as anti-MMP. Supposedly, the resulting model of the anti-MMP on a variety with pseudoeffective anticanonical divisor is a weak Fano variety or Fano variety having singularities that are not too bad. In running such MMP, two issues need to be taken care of. Since the anti-MMP worsens the singularities of the given variety, we want to predict from the given variety that the resulting variety is not too singular.

To be precise, we require the resulting variety to be lc or klt. The technique handling this issue was first developed when I was in IBS-CGP. Another difficult issue to be taken care of is whether such MMP can be even initiated and can be run smoothly. The problems surrounding this issue are the main interest to me recently. The classical MMP are more or less complete for the general cases and we want to apply the same steps to the anti-MMP. Many steps fail to hold for our case and new theories need to be developed. Besides the problems related to the minimal model program, I am also interested in the applications of the Okounkov bodies to the litaka conjecture, and positivity of divisors.

What are you interested in recently?
Please share something about you.

Due to the Covid19 pandemic for the last two years, my leisure or hobby activities were very restricted. I plan to ride bicycles more often and do more exercises. I am also interested in how to live longer and healthy. 😊😌

We would like to hear about your dream or future plans.
Do you have a role model or a philosophy of life? :)

For now, I will focus on doing mathematics whether it is of the form of research, teaching courses, advising students, writing/translating math books, etc. I just hope that my life style can serve as an example of a form of life that young students may pursue. I like to watch sports games (especially soccer) and I often try to learn from the successful players, their professional attitudes to the careers. Maintaining the best condition physically and psychologically seems to be important not only to the sports players but also to mathematicians. The inspirations that I get from sports help me overcome the difficult moments and push myself to the limit.

Is there anything you want to tell younger mathematicians?

Nothing to say... You are younger than I and forever will be.



Youngho Yoon

*Assistant Professor at Chungbuk National University
(CGP Research member from July 2013 to July 2016)*



How is your life / work after CGP?

After CGP, I have worked at several places; Korea Institute for Advanced Study (KIAS), Seoul National University (SNU), Sungkyunkwan University (SKKU), and Chungnam National University (CNU). Now I am working at Chungbuk National University (CBNU) as a tenure track position from this semester. CBNU is located at Chungju city so I can only see my family on weekends. However, this separation makes me to focus on my work and to love my kids and wife more.

What made you decide to be a mathematician?

Mathematics is a fascinating subject in many ways. For me, the main reason I got into mathematics is because it gives me the best ways to find answers to my questions. Since childhood, I have always been interested in two questions. 'what' and 'why'. These two questions made me fall in love with science. At first, it was thought that physics could provide answers to these questions. At that time, I was not aware of the existence of mathematicians, so it must have been a natural thinking. While studying mathematics to become a physicist, I discovered that the subject I really wanted was mathematics. For a child who is curious about the outside world, the window, the only passage to the world, is very precious. The reason I started doing mathematics is because mathematics is like a window which I can see the world through.

What is your current math-related interest?
Please tell us about your research.

I have been studying singularity theory related to Miller fiber. A few years ago, I found that Hodge ideals recover spectrum of isolated singularities. Hodge Ideal is an algebraic (or analytic) invariant encoding information of singularities. On the other hand, spectrum is an invariant that encodes geometric aspects of singularities. It is quite natural to ask how the two invariants are related. The previous results show the answer in the case of isolated singularities. It raises the question of extension to more general cases. Currently I am on my way to get an answer to that question. Hyperplane arrangements has the simplest non-isolated singularity. The singularities defined by homogeneous polynomials are more general cases. These are my main targets now.

What are you interested in recently?
Please share something about you.

I do not look for my own hobbies because my five-year old son's hobby is mine too. After CGP, I had a son. My son loves the things that I loved when I was a child, and I rediscovered my old hobbies. Of course, his hobbies keep changing, but his new ones are my childhood's favorites and they are still attractive to me. These days, my son likes Pokémon. He collects seals and figures, and loves to watch animations and play games. Although the characters have changed, I enjoyed a lot of things related to the main characters of popular anime when I was a child. At the beginning I bought seals for him, but now I often find myself enjoying watching anime and playing games together. Maybe my son will find a new hobby sooner or later, however, as always it would be my old favorite that I've been forgetting for a while.



We would like to hear about your dream or future plans.
Do you have a role model or a philosophy of life? :)

When I was young, there were many things I wanted to do. I've tried many things and some of them are still in progress, like math research. As the experiences of success and failure have accumulated, there is one more thing I want to do. It is to share my experience. Until recently, I have thought that everything I did was done by myself or with a few friends of mine. But now I know that there were my parents and teachers who were with me invisibly from afar. They were always by my side while fulfilling their old dreams. Role models for me were people who had special abilities. To be precise, the image I heard from people was my role model. Now, my true role models are those who are right next to me and share their experiences. Now I have children and students. My old plan will continue in the future, but it will be my new work to share my experiences I have gained from it.

Is there anything you want to tell younger mathematicians?

I think that the most important thing for a person who wants to do math is to enjoy math. I am not a famous mathematician, but this is also emphasized by a famous mathematician; June Huh. In his interview, he said 'if you get overwhelmed by stress, math will not be enjoyable'. Of course, he meant 'don't push yourself too hard', but the fundamental reason not to do that is because mathematician needs to enjoy math. This is what I wanted to say to people studying mathematics, especially in Korea.

with June Huh



Volker Genz*Research member since October 2021*

How is your life in CGP / Pohang / Korea?

Life in Korea, especially when associated with a research institute, feels very comfortable: The cities seem built to have all amenities from supermarkets to bars stacked nearby the residential places, infrastructure, like transportation, is very well developed and affordable, people are friendly, helpful and there virtually seems to be no crime. I am very happy to be at CGP for its inviting and friendly atmosphere among researchers, directors and administration.



What made you decide to be a mathematician?

For plenty of people math is compelling being the language of the natural sciences. For me math is a wonderful game about arranging logical statements in an aesthetically pleasant way. Are you bored with the state of the game? Just invent a new playground by arranging logical statements in yet a novel way. I like to compare solutions to mathematical problems to a wormhole within the universe of logical structures, e.g. a formula relating something previously not (easily) computable to something from which we already know how to compute it.

Personally, what attracted me to math is the sense of power one encounters, when such a wormhole, pardon solution, emerges in one mind manifesting itself in the conscious, i.e. you “feel” that you “understood” the relations between the logical statements involved, even if you cannot give a concise presentation of them, yet.

Besides numbers, shapes, motions and other things, mathematicians study symmetries. I am building bridges between two very different type of symmetry theories: symmetries of linear

spaces one the hand and mirror symmetry, which originated from physics, on the other hand. Both types of symmetries meet in the realm of cluster algebras, a certain class of algebras, which come equipped with a special set of generators featuring a rich combinatorial structure. Utilizing this combinatorial structure I am, for example, interested in giving a formula and describing the intrinsic meaning of certain operators originating from the theory of linear symmetries within the framework of mirror symmetry of cluster varieties.

What is your current math-related interest?
Please tell us about your research.

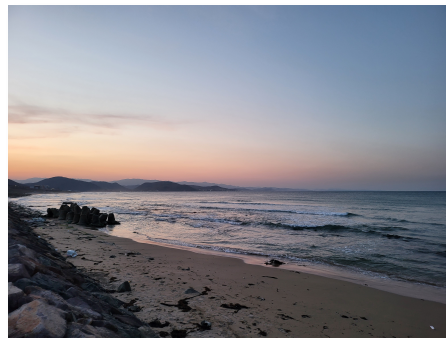
What are you interested in recently?
Please share something about you.

I enjoy dancing and sports. Afterall, what feels better when getting stuck within a thought in a logical puzzle than changing the perspective, start moving the body and sensing the physical side of things. Since moving to

Pohang I enjoy living close to the ocean offering nice waves to ride on. Unfortunately, in the cold time of the year only.... brrrrrr...🥶

We would like to hear about your dream or future plans.
Do you have a role model or a philosophy of life? :)

From my point of view life is about communication. Consequently, this plays a huge role in mathematics as well. I wish for an open world, in which everyone can freely move and actually meet physically to indulge in discussing, learning, exploring and teaching whatever gives joy. In my case, to a large extend this involves mathematics.



Hisayoshi Muraki*Research member since November 2021*

How is your life in CGP / Pohang / Korea?

I've been quite pleased about my life in Korea. Having spent one year in CGP as of the end of October 2022, in total, my stay in Korea unexpectedly gets extended to 5-year long (2 years in Seoul and 3 years in Pohang), which may show how comfortable I find it. Meanwhile I could have known many local researchers as well as foreign researchers from a vast variety of backgrounds both scientifically and culturally. Through communications with them, I could have learnt a lot of things of not only academic related but also personal related, from daily tips to a lesson of life, and I could have shared valuable time and experiences with them.



What made you decide to be a mathematical physicist?

I got interested in physics when I was a middle school student. At that time, I was more interested in engineering concerning with motorsports, like formula 1 car racing, and I was mad on building plastic models and radio-controlled models of racing cars and sports cars. I wondered if physics, especially thermodynamics and aero dynamics, had something to do with designing those engines and shapes, respectively, leading me to get an interest in physics. As time went by, through learning various branches of physics in undergraduate course, my interest in physics moved from applied aspects to rather basics aspects, and went into a group of theoretical elementary particle physics and cosmology during my PhD course in Tohoku University. Guided by my PhD advisor and stimulated by my colleagues, I have come across a track pursuing mathematical physics.

What is your current physics-related interest?
Please tell us about your research.

My research interest has been around gravity. Gravity might be the first force we experience in life, even infants are aware of it, and might have the longest history of study by great physicists, for instance, Galilei, Kepler, Newton, and especially Einstein. Among 4 forces of currently observed elementary forces in nature, the other 3 forces, i.e., electromagnetic force, weak force and strong force, are formulated as gauge theory and (at least conceptually) well understood in the framework of quantum mechanics. This is not the case for gravity and despite the best efforts by generations of physicists the formulation of gravity quantum mechanically has been one of the longstanding challenges of modern theoretical physics.

What are you interested in recently?
Please share something about you.



My favorite hobbies are playing the piano and flute, going for hikes, going cycling, strolling around town, going into restaurants randomly and trying some foods there. Pohang is a good location; I can enjoy both mountain and sea in a short trip, and its size is adequate for catching up on any changes like opening/closing diners and shops. Along the river Hyeongsan there is a nice cycle lane colored by flowers from season to season. It is my part of everyday life on weekends to ride my bicycle along the river to Yeongildae beach and on my way back home drop by diners for having a lunch and by grocery stores to buy daily necessities.



We would like to hear about your dream or future plans.
Do you have a role model or a philosophy of life? :)



Though I don't have any proverbs to tell others, my philosophy of life shall be something "do what I can do only now". While I was a PhD student I could not have imagined if I would be in Korea as a postdoc, that was also the case when I was in Seoul if I would be in Pohang. Nobody knows where I will be in 3 years, 5 years, 10 years, but wherever I go, I would like to enjoy my life and make it as richly experienced as possible.



Photos





April 28, 2022

Director Yong-Geun Oh introduces his research in a video shooting for 2022 Samsung Ho-Am Laureates at the CGP Hall. He was awarded in physics and mathematics. (Congratulations!)



The Samsung Ho-Am Prize presentation ceremony was held on May 31, 2022.

The ceremony video is on YouTube titled "2022 Samsung Ho-Am Prize Award Ceremony" and Director Oh's part starts at 17:20.





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CGP Walk

3rd Issue | 2022

- ✦ Publisher Yong-Geun Oh, IBS Center for Geometry and Physics
- ✦ Editor-in-chief Jihun Park
- ✦ Editors CGP Administration Team
- ✦ Published December 2022



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