April 2018–March 2019

Kavli IPMU

ANNUAL REPORT 2018

THE UNIVERSITY OF TOKYO

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

UTIAS 東京大学国際高等研究所 THE UNIVERSITY OF TOKYO INSTITUTES FOR ADVANCED STUDY

wpi World Premier International Research Center Initiative

KAVLI IPMU

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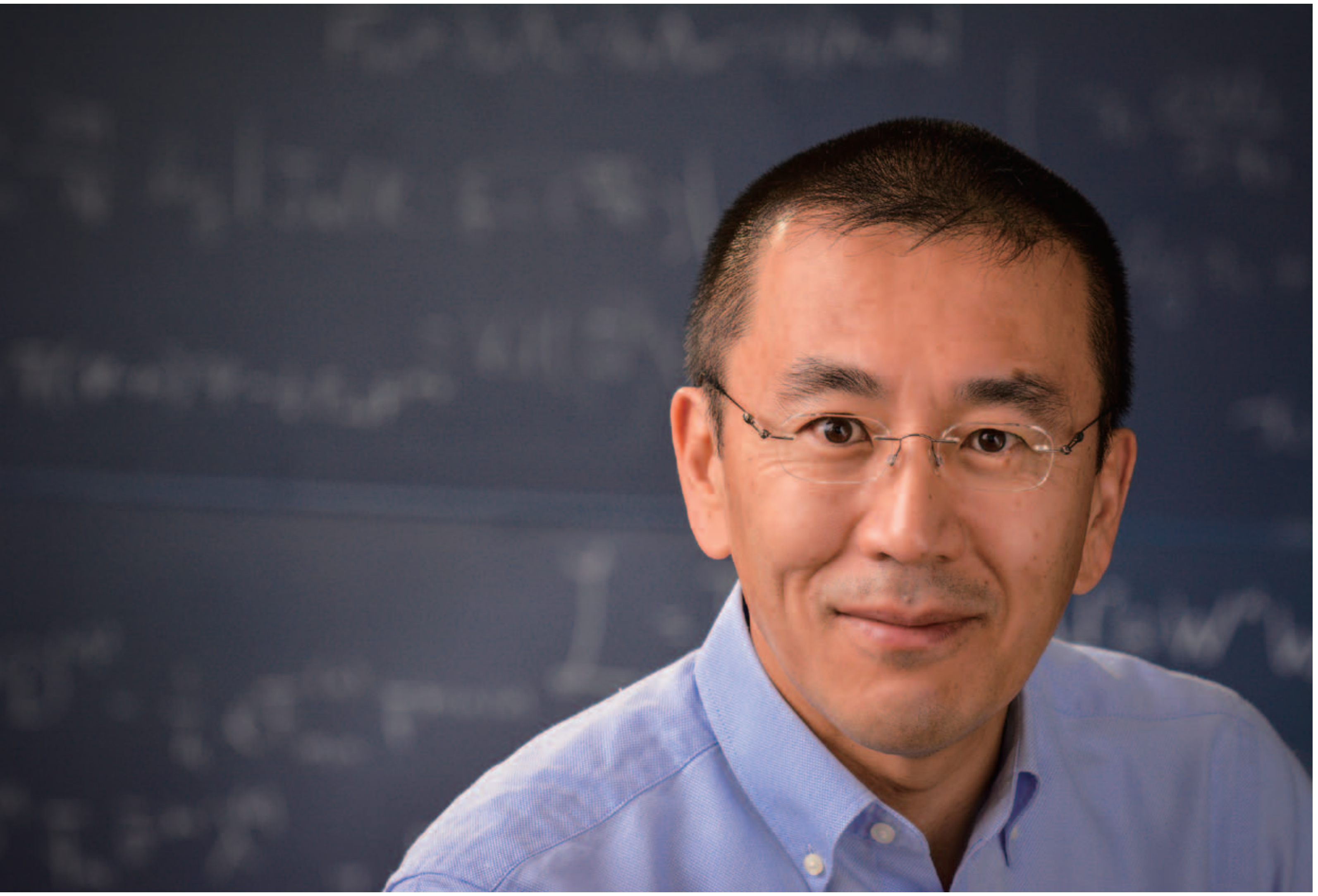
On the cover:
Photo at the all-hands meeting of Kavli IPMU members on October 15, 2018

FOREWORD



Hirosi Oguri
Director

I am delighted to present our 2018 annual report to you.

I became the second director of this institute a year ago, on 15 October 2018. Hitoshi Murayama, my predecessor, did an excellent job in creating the institute and bringing it up to the forefront of basic science research. My mission is to turn this successful start-up into a sustainable organization, keeping and exceeding our high level of research activities.

In my inaugural address last fall, I laid out a couple of initiatives that I wanted to implement immediately.

One was to conduct long strategic planning exercises. The institute was established in 2007, and we have had many scientific achievements since then. Some of the projects we started twelve years ago have run their course, and new opportunities are emerging. As we move into a sustainable mode of operation, we should carefully choose our research directions, identifying the most effective way to use our resources, taking calculated risks, and aim to become the best at what we do. The choices we make should be guided by the institute mission, which is to solve the most fundamental questions about the Universe.

Within a week after I became the director, I assembled a committee to start strategic planning for our next ten years. The committee worked diligently, meeting every month, interviewing experts and leaders of various research areas, discussing with our faculty members, and organizing conferences to learn new opportunities. A tentative report was submitted in June, and was reviewed by our external advisory committee. The final report was submitted to me in August. It will guide our priorities in hiring and allocating our resources in the coming years.

During my inaugural address, I also affirmed my commitment to provide an inclusive and supportive environment to the diverse group of people at the institute. This year, we rolled out several new administrative procedures to improve diversity in our scientific staff, visitors, and participants of our conferences. We have also established our code of conduct, reviewed and revised our harassment training materials, and diversified our leadership. We are also preparing bias training to improve our hiring practices. The weekly women's lunch, initiated by Professor Yukari Ito this year, provides network opportunities for female members of our community.

Over the past year, we have had several exciting developments in our research. The Hyper Suprime-Cam team at the Subaru Telescope produced their first set of 40 scientific papers. Among them was a three-dimensional dark matter map with unprecedented width and depth, determination of the lumpiness of matter in the universe, and constraints on primordial black holes. Our Belle II team successfully delivered silicon vertex detectors to the collider facility at KEK. Their B-physics experiment is in full operation, and they are busily analyzing data. In Kamioka, following the successful completion of our R&D effort at Evaluating Gadolinium's Action on Detector Systems (EGADS), Super-Kamiokande is being prepared for gadolinium loading. This will make neutrons visible, allow positive identification of anti-neutrino interactions, and greatly reduce physics backgrounds. We are expecting the first detection of diffuse supernova neutrinos from the universe before 2022.

We also heard two exciting announcements about our future projects. ISAS, the science branch of JAXA, has approved the launch of the LiteBIRD satellite in eight years from now to perform an all-sky CMB polarization survey and to test cosmic inflation, in particular its single-field large-variation slow-role models. MEXT announced that they are requesting 1.8 billion yen in the fiscal year 2020 budget to begin construction of Hyper-Kamiokande in Kamioka. It will accumulate neutrino statistics twenty times faster than the current T2K and will help us determine neutrino parameters. It will also look for proton decay to test a variety of grand unification models.

I hope you will enjoy reading this report on our research.

1 INTRODUCTION

Hirosi Ooguri, Fred Kavli Chair in Theoretical Physics and Mathematics and the Founding Director of the Walter Burke Institute for Theoretical Physics at the California Institute of Technology (Caltech), became the new Director of Kavli IPMU on Oct 15, 2018. H. Ooguri is a world-renowned scientist both in physics and mathematics, and is a recipient of the inaugural Leonard Eisenbud Prize for Mathematics and Physics, awarded by the American Mathematical Society. He has extensive leadership experiences as the Founding Director of the Walter Burke Institute for Theoretical Physics at Caltech and the President of the Aspen Center for Physics. He initiated a long-term strategic planning exercise for the next 10 years, building on our achievements and current scientific activities. H. Ooguri received the 2018 Hamburg Prize for Theoretical Physics. This was the first year the prize covers all areas of theoretical physics. His paper on de Sitter swampland conjecture had a major impact on cosmology and became the most cited paper in high energy theory in 2018.

FY2018 is the second year from the 5-year extension period of the WPI funding. We have proposed the following 9 challenges for the extension period addressing new objectives. Below are brief summaries of our effort to meet each challenge.

1. Creating new areas and tools of statistics, integrating mathematics with observation and experiments

The JST CREST project "Statistical Computational Cosmology" led by N. Yoshida is aimed at developing fast imaging data analysis applications for the Subaru HSC survey. In 2018, they developed the "Dark Emulator" that outputs statistical quantities and spatial clustering of galaxies needed for cosmological parameter inference with weak gravitational lensing observation. The emulator is based on modern statistical techniques, such as Gaussian process and principle component analysis, as well as a large simulation database. It has already been used in several publications by the HSC collaboration. They have also developed a deep-learning method based on generative adversarial networks to reduce the noise in gravitational lensing measurements.

2. Creating new synergies among fields not imagined at the launch

An agreement (2017-2020) has been made between the Kavli IPMU and ISAS/JAXA to transfer hard X-ray and gamma-ray imaging technology to nuclear medicine and to set up a new laboratory at the Kavli IPMU for detector R&D. We also established an agreement between the Kavli IPMU and National Cancer Center and have started in-vivo imaging experiments of small animals using a variety of radio-isotopes. For this research, JSPS Kakenhi (Grant-in-Aid for Scientific Research on Innovative Areas, PI. T. Takahashi) has been granted.

3. Discovering new major framework for geometric thinking in mathematics and physics with the derived and non-commutative geometry, such as to unify various types of dualities

Our mathematicians have made substantial progress in using derived and non-commutative geometry as a new major framework for geometric thinking in mathematics and physics. Y. Toda has developed new concepts of d-critical (i.e., derived critical) loci and flips. This has allowed him to extend several fundamental results of birational geometry, such as wall-crossing equivalences, to a broad class of derived moduli spaces important in physics. One of the tools to study wall-crossing has been the cohomological Hall algebra (COHA), but its precise definition was restricted to quiver-like situations. M. Kapranov, jointly with E. Vasserot, defined and studied COHA for algebraic surfaces, based on ideas of derived geometry. F. Sala, with M. Porta, gave a direct definition of the K-theoretical version using derived moduli spaces. The work of W. Donovan and T. Kuwagaki extended the homological mirror symmetry, originally an equivalence of derived categories, to a certain class of perverse schobers. The latter are natural systems of derived categories analogous to perverse sheaves, introduced earlier by M. Kapranov and V. Schechtman.

4. Executing projects successfully to produce world-competitive results on dark energy, dark matter, and inflation

- The Hyper Suprime-Cam team has measured how cosmic structures including dark matter have evolved as a function of cosmic time using gravitational lensing effects, and determined the parameter of clumpiness of the Universe today with the world's highest-level precision. The construction of the Prime Focus Spectrograph instrument is well underway to start science operation in 2022. All 2550 fiber positioners "Cobra", as well as all science-grade detectors, have been delivered to Hawaii and the team is now carrying out various tests, including image quality and thermal performance.
- XMASS-I detector has been completed, and the xenon has been safely recovered. Seven papers were submitted and five published in 2018. Machine learning has been used for event classification to discriminate events from the detector's inner surface contaminating data sets. The Kavli IPMU is leading the Japanese participation in the XENON1T detector's impending upgrade to XENONnT.
- T2K released new oscillation results at a KEK colloquium in January 2019. These results disfavor CP conservation at the 95% confidence level. Oxford/the Kavli IPMU graduate student T. Vladisavljevic has completed his thesis work to update the T2K flux calculation with replica target data collected by the NA61/SHINE experiment. With his work, the uncertainty on the T2K flux calculation has been reduced from 10% to 5%.
- CMB experiments have been actively led by the Kavli IPMU team. POLARBEAR2 reached to the first light in December 2018. Simons Observatory finished the design review and is now in fabrication phase. LiteBIRD finished Pre-phaseA2 and is in process of down-selection with its outcome in 2019.
- Belle II completed detector construction, where the Kavli IPMU team successfully produced outermost layer devices of SVD, and started data taking in March 2019.

5. Attracting and retaining the best and broadly minded scientists from around the world

We retained the best and open-minded scientists from around the world. T. Takahashi and H. Nakajima were newly appointed as Principal Investigators (PIs), and total number of PIs has become 28 (7 non-Japanese: 25%, 11 on-site: 39%). T. Takahashi is a leading astroparticle physicist on developing hard X-ray and gamma ray detectors in satellite and rocket experiments. He started a new collaboration with JAXA/ISAS and Keio University School of Medicine to apply these detectors to biomedical research. H. Nakajima, who received the Cole Prize in Algebra in 2003, is a distinguished mathematician and conducts research as a leader in a mathematical study of gauge theories, which have their origin in mathematical physics. Former Director H. Murayama became a University Professor of the University of Tokyo and the Hamamatsu Professor of the Kavli IPMU. K. Martens has been appointed the first Director of the Kamioka-branch. This demonstrates the fact that the Kavli IPMU has established a truly international environment and support system, where a foreign researcher whose first language is not Japanese can take such a leadership role.

Our faculty members play leading roles in each field and include PIs of big international projects such as Belle II, T2K, KamLAND-Zen, HSC/PFS, EGADS, and LiteBIRD.

6. Bringing successful system reforms to the rest of the University and other research institutions to help boost the overall competitiveness of Japan on a global scale
Kavli IPMU administrative staff members were awarded the UTokyo's 2018 Special Prize for Business Transformation from the President for the sixth time, following 2008, 2013, 2015, 2016 and 2017. The Kavli IPMU team developed and is running a smartphone app, which provides step-by-step information in English about how to take public transport from the international airport, how to find and ride the free shuttle bus to Kashiwa campus from the train station, and maps that show where individual researcher offices are. This has triggered administrative staff in other departments to start developing their own smartphone apps, further advancing system reforms.

The 2008 achievement for "web site to accept the foreign researchers in Kashiwa Campus" has already been requested to be adopted by administrative sections of many other faculties. The 2013 "thoroughgoing safety education by network distribution of education video and final quiz" has been requested to be adopted by the UTokyo environmental and safety research center in Kashiwa, Graduate school of Engineering UTokyo, Graduate school of Mathematical Science UTokyo and ICRR. The 2015 "language website to explain UTokyo's employee procedures for international researchers" has been used freely through the UTokyo website. The 2016 "Win-Win project towards University Globalization" has been requested by the UTokyo hospital medical administrative section and ICRR. The 2017 "E-learning for Sexual Harassment Prevention" video in English has been adopted as the official education course of the University Harassment Counseling Center.

7. Making a serious attempt to create a new international graduate program with vigorous student exchanges
Several doctoral students in astrophysics or particle physics at U. Oxford are being supervised by faculty members of the Kavli IPMU, and are being provided the opportunity to conduct research in collaboration with Kavli IPMU researchers. The Kavli IPMU is also working with another international graduate program in physics (GSGC), which we hope will be extended to astronomy. Young students are becoming attracted to the Kavli IPMU. A group of UTokyo and Kavli IPMU faculty members, including Y. Kawahigashi (representative), T. Kohno, A. Bondal, M. Kapranov, I. Ueda, and Y. Yamazaki, are planning to submit a proposal for a student exchange program between Hamburg University, entitled "Higher algebraic structures and their concrete", to the JSPS and German Research Foundation (DFG). The proposal includes exchange of several graduate students per year, aiming to start in FY 2021. Five members visited the Hamburg University to discuss the proposal, and a proposal from the German side was submitted in February 2019.

8. Enlarging the force for outreach to young students, by organizing workshops for scientists and high-school teachers
In FY 2018, the Kavli IPMU kept collaborating with CoREF (Consortium for Renovating Education of the Future) to find a way to place the latest advances in scientific research into the high school curriculum. An event was carried out to test the development of an interactive lesson called "From high school physics to frontier research of the Universe", which Kavli IPMU PI H. Murayama spoke and took part in. On July 29, 2018, high school students and teachers were invited to try learning about the universe.

In Japan, the number of women who choose careers in science, particular physics, is still extremely low. Students with an interest in physics are faced with many challenges, including a lack of female leaders who can give them advice, and few peers to share their issues. To help resolve this problem, since 2016 the Kavli IPMU has co-hosted a science career event together with the UTokyo's Institute for Solid State Physics, and the Institute for Cosmic Ray Research, specifically aimed at female undergraduate and graduate students. At the event, a number of speakers talk about their own career paths, and discussion times are extended to encourage participants meet other participants to build up their own support network. Lately, an after-event dinner has been introduced for students wishing to have more time get to know other participants. Co-hosting the event has allowed the hosts to cover a wide range of research fields including particle physics, nuclear physics, astronomy, solid state physics, and engineering. In the past, participants have commented that listening to working women with science careers talk about their own career choices has been a great help in thinking about their own future choices.

H. Murayama appeared on NHK documentary series Last Lecture as "Physicist Hitoshi Murayama". Recording took place in a lecture hall at the UTokyo's Hongo campus. More than 100 university undergraduates and graduate students came to hear Murayama's lecture, which was made for the program. His story about how he became H. Murayama the researcher was well received by viewers, and the episode became the fifth most watched show on NHK's online channel on 22 February. Because of its popularity, NHK-BS1 aired a rerun of the program on 23 February.

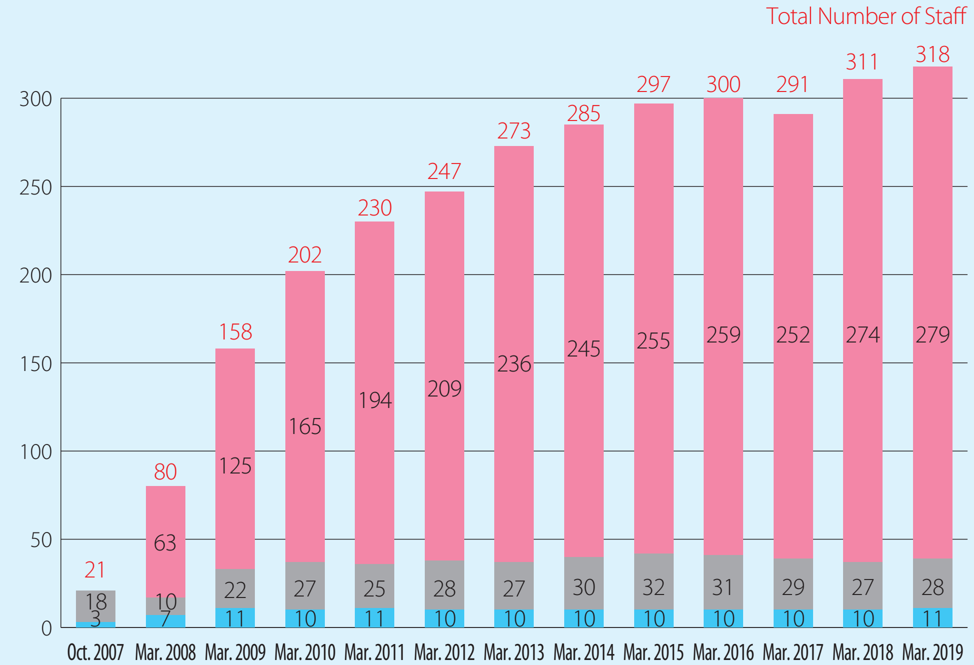
9. Attaining sufficient stability of the organization so that we can bring our research objectives beyond the WPI funding
The positioning of the Kavli IPMU within UTokyo is quite clear. President Gonokami's 'Vision 2020' emphasizes the importance of "Expansion and Establishment of Internationally-renowned Bases for Research". An action to realize this vision 'Action 2020' has been set up to "establish and expand upon internationally-renowned bases for research at UTokyo by carrying out such initiatives as advancing the development of both the University's strongest fields in which it is leading the world and unique areas of original research which should unwaveringly continue to be studied, promoting joint research and international collaboration that goes beyond the framework of UTokyo, and creating new, interdisciplinary knowledge that is the first of its kind in the world." As has already been declared by the President at the WPI Program Committee meeting in recent years, the President recognizes the Kavli IPMU perfectly matches his vision as a role model for the rest of the University. The Kavli IPMU enhances the value of the University, which enables the University to attract new revenues. It is reasonable for UTokyo to support the Kavli IPMU with top priority. We have made the effort to strengthen the University's financial base.

Based on this stance, UTokyo has put together a plan for the extension period and beyond. UTokyo has already provided 10 tenured positions, and permanent assignment of nine administrative staff members. Thanks to MEXT, from FY 2018, the 'university functionality boost' budget from MEXT for 13 positions and for operation has been approved to be a permanent budget. The University will maintain and hopefully expand the Kavli IPMU even after WPI support finishes.

A new budget request in the period from FY 2019 to FY 2021 was ranked as No.1 in UTokyo, and a budget for the first year has been secured. This budget request is crucial to sustain the Kavli IPMU permanently, and we will keep making the request for the following two years.

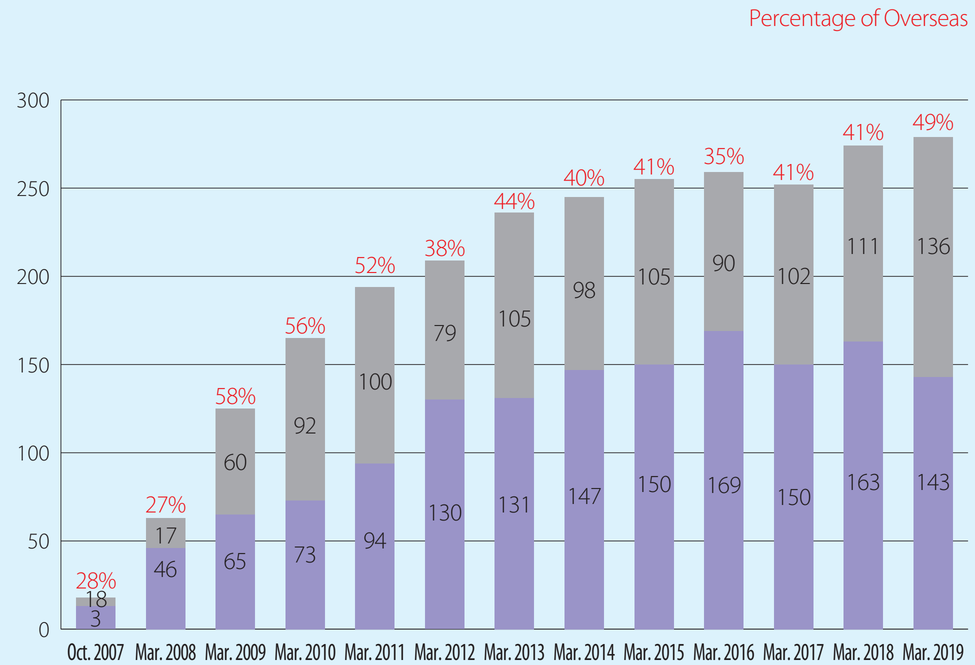
In the following pages, various statistics are shown in plots: the lists of seminar & conferences, publications, and conference talks can be found in Kavli IPMU webpage, https://www.ipmu.jp/en/research-activities on "Research Activities"

STAFF



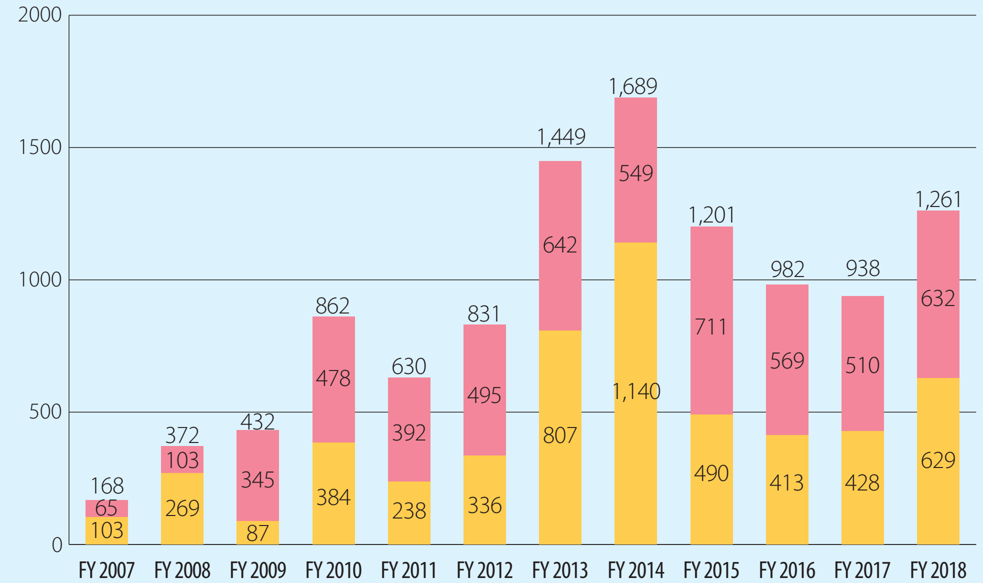
	Oct. 2007	Mar. 2008	Mar. 2009	Mar. 2010	Mar. 2011	Mar. 2012	Mar. 2013	Mar. 2014	Mar. 2015	Mar. 2016	Mar. 2017	Mar. 2018	Mar. 2019
Researchers	18	63	125	165	194	209	236	245	255	259	252	274	279
Research Support Staffs	0	10	22	27	25	28	27	30	32	31	29	27	28
Administrative staffs	3	7	11	10	11	10	10	10	10	10	10	10	11
Total	21	80	158	202	230	247	273	285	297	300	291	311	318

RESEARCHERS



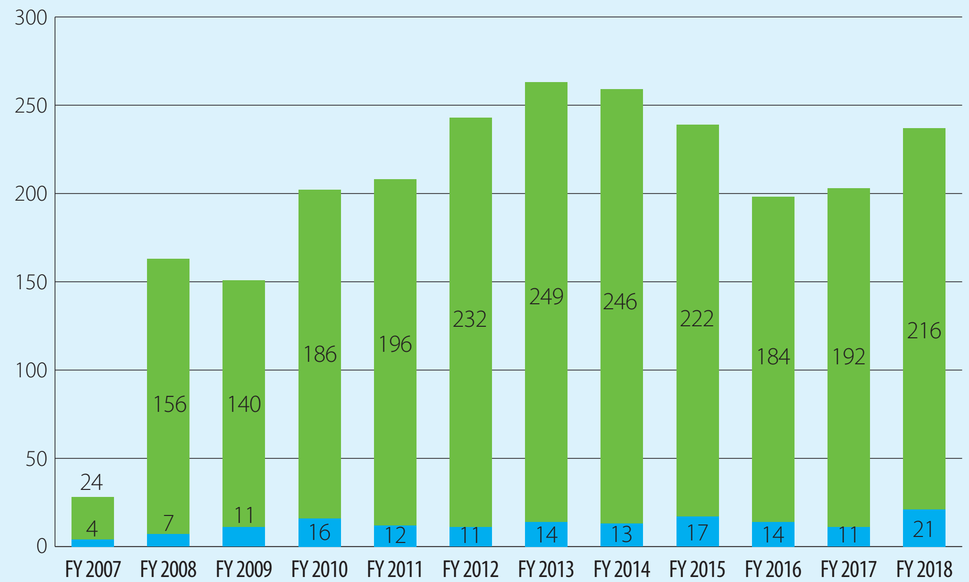
	Oct. 2007	Mar. 2008	Mar. 2009	Mar. 2010	Mar. 2011	Mar. 2012	Mar. 2013	Mar. 2014	Mar. 2015	Mar. 2016	Mar. 2017	Mar. 2018	Mar. 2019
Overseas	5	17	60	92	100	79	105	98	105	90	102	111	136
Domestic	13	46	65	73	94	130	131	147	150	169	150	163	143
% of Overseas	28%	28%	48%	56%	52%	38%	44%	40%	41%	35%	41%	41%	49%
% of Female	0%	2%	5%	6%	5%	2%	5%	5%	6%	4%	6%	8%	9%

RESEARCH ACTIVITIES



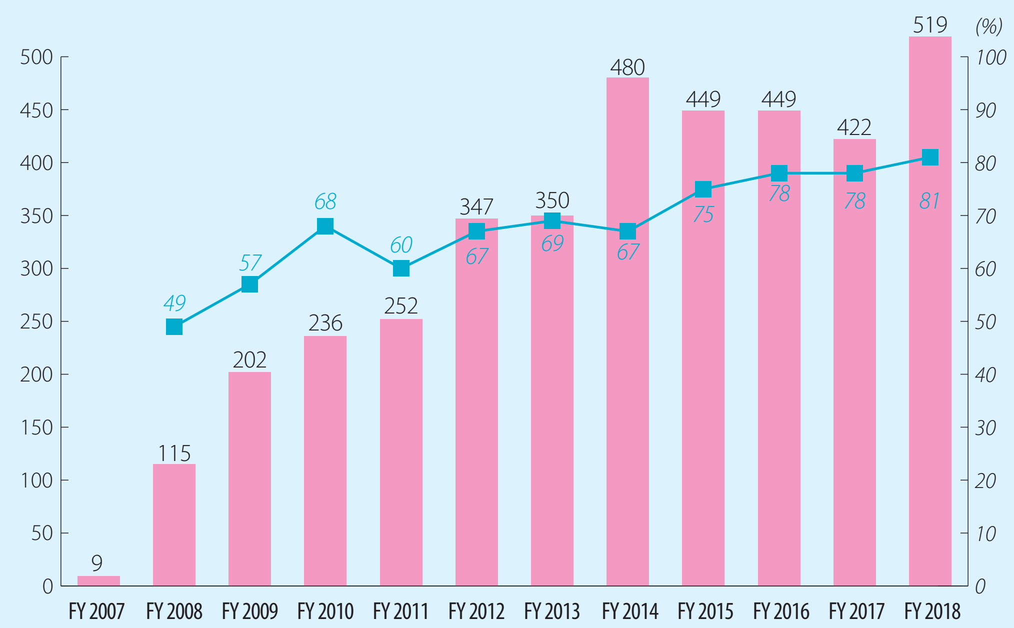
	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018
Visitors (Overseas)	65	103	345	478	392	495	642	549	711	569	510	632
Visitors (Domestic)	103	269	87	384	238	336	807	1,140	490	413	428	629
Visitors (Total)	168	372	432	862	630	831	1,449	1,689	1,201	982	938	1,261

SEMINARS & CONFERENCES



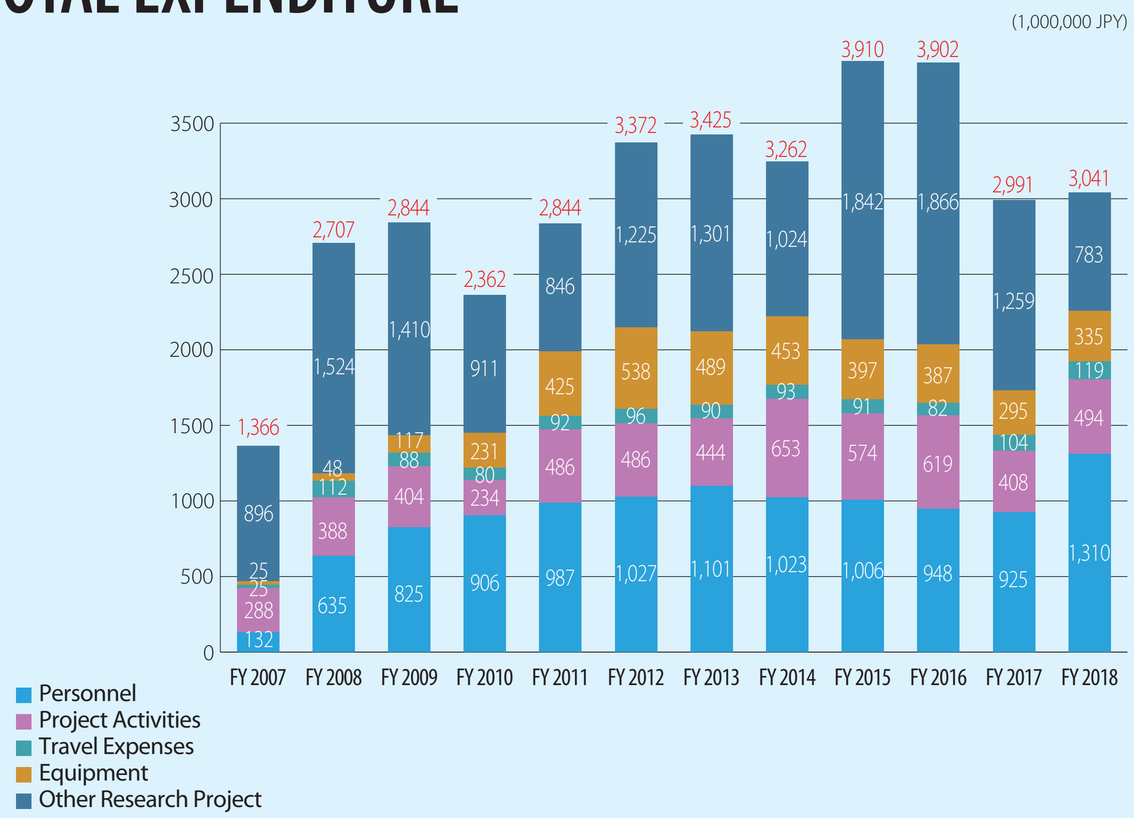
	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018
Seminars	24	156	140	186	196	232	249	246	222	184	192	216
Conferences	4	7	11	16	12	11	14	13	17	14	11	21

PUBLICATIONS

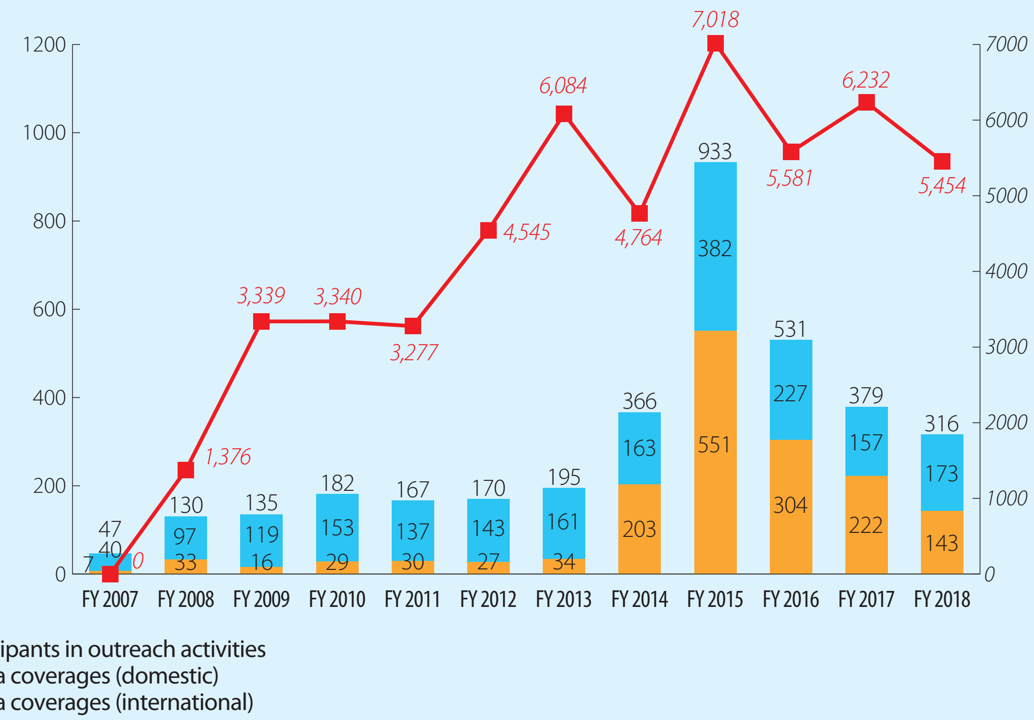


	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018
Publications	9	115	202	236	252	347	350	480	449	449	422	519
% of international collaboration		49%	57%	68%	60%	67%	69%	67%	75%	78%	78%	81%

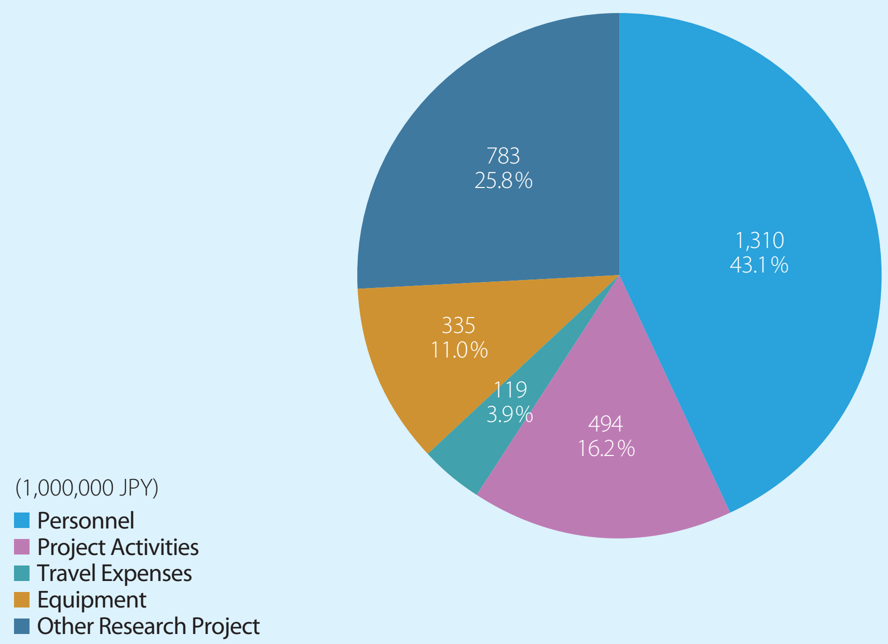
TOTAL EXPENDITURE



MEDIA COVERAGES AND OUTREACH ACTIVITIES



BREAKDOWN OF FY 2018 TOTAL EXPENDITURE



2 NEWS & EVENTS April 2018-March 2019

APRIL
- Researchers studying the Universe will apply their expertise to cancer research
- Focus Week on Quantum Gravity and Holography
- Farthest star ever seen in the Universe detected
- 18th Kavli IPMU-ICRR Joint Public Lecture "Exploring Particles, Describing the Universe with Particles"
- Study finds way to use quantum entanglement to analyze black holes
- Next generation of telescope equipment begins arriving in Hawaii
- Electrons and Positrons collide for the first time in the SuperKEKB Accelerator

MAY
- ALMA finds oxygen 13.28 billion light-years away
- Inner component of Japan's upgraded particle accelerator nears completion

JUNE
- Public Lecture "Universe X World"
- "Science and Metaphysics" by M. Gabriel
- Public lecture "Gravitational Waves and the Dark Ingredients of the Universe"
- RISTEX Symposium "An analysis of the factors that influence women and girls to pursue physics and mathematics"
- New Directions for LHC - Run 2 and Beyond
- MEXT Deputy Minister Yoichi Ito visited Kavli IPMU

JULY
- 1st lecture at "Science Cafe Universe 2018"
- WPI Site Visit 2018
- Simulations uncover why supernova explosions of some white dwarfs produce so much manganese and nickel
- Vertex algebras, factorization algebras and applications

AUGUST
- Booth at the 2018 Super Science High School Student Fair
- UC Santa Cruz Chancellor visits Kavli IPMU

SEPTEMBER
- Technetium-98 nuclear cosmochronometer synthesized by supernova neutrinos
- 7th Hyper-Kamiokande Proto-Collaboration Meeting
- IGM2018: Revealing Cosmology and Reionization History with the Intergalactic Medium
- Cosmological constraints from the first-year Subaru Hyper Suprime-Cam survey
- 2nd lecture at "Science Cafe Universe 2018"

OCTOBER
- Beyond the BSM (The 4th Kavli IPMU -Durham IPPP -KEK -KIAS workshop)
- Caltech Professor Hirosi Ooguri appointed new director of Kavli IPMU
- American Physical Society's 2019 Hans A. Bethe Prize goes to Ken'ichi Nomoto
- FOXSI-3 succeeds in focusing imaging spectroscopic observation in soft x-rays from the Sun for the first time
- Open Campus Kashiwa 2018
- Flavor Physics Workshop 2018

NOVEMBER
- Hirosi Ooguri awarded the 2018 Hamburg Prize for Theoretical Physics
- Kavli IPMU/ICRR joint public lecture - "Particles, Celestial Events, or the World of Mathematics"
- "Actually I Really Love Physics! – Career Paths of Female Physics Graduates"
- Noncommutative deformations and moduli spaces

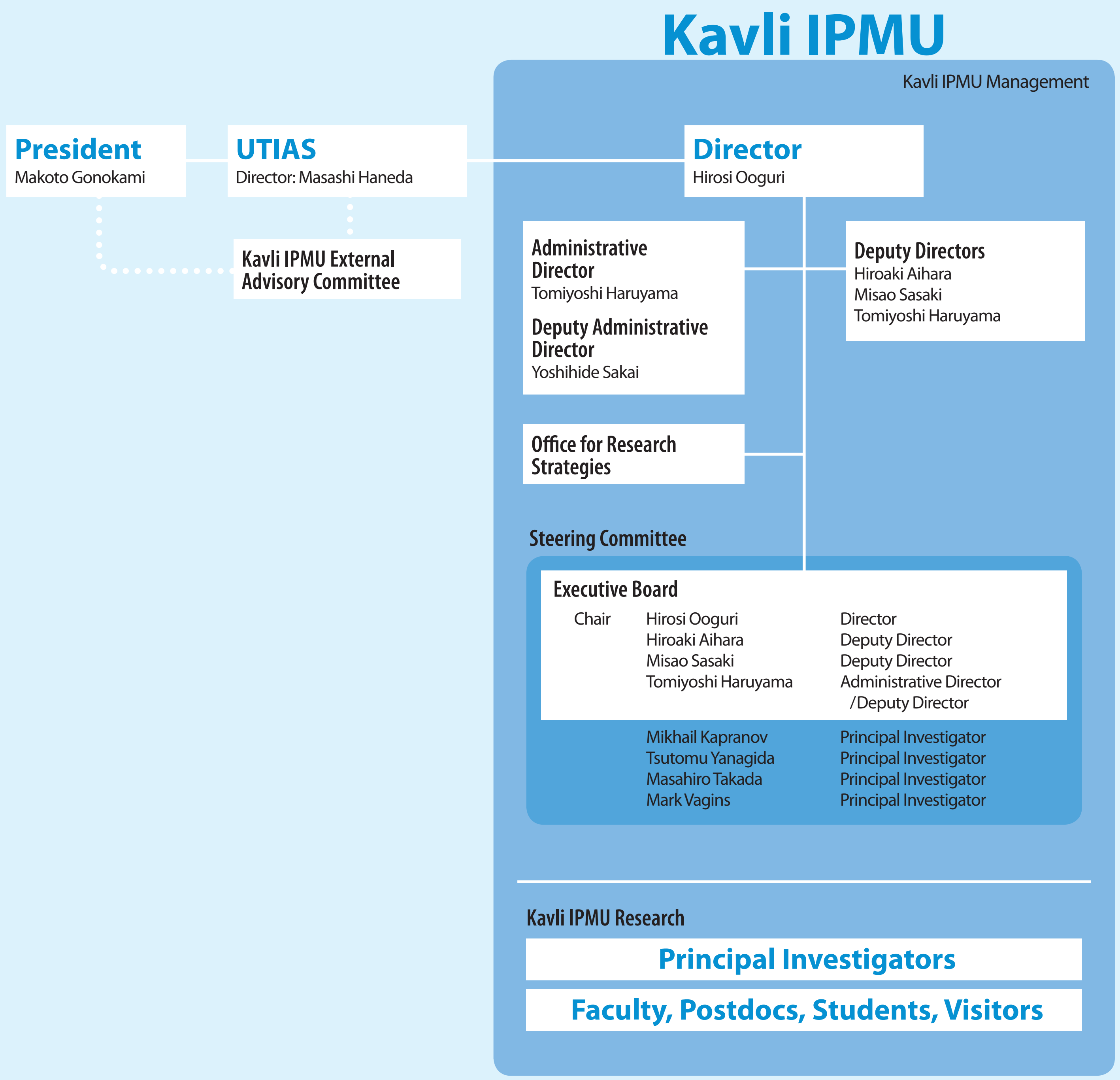
DECEMBER
- Stellar Archaeology as a Time Machine to the First Stars
- Kavli IPMU High School Student Event "Meet the Scientists!"
- Kavli IPMU staff commended at 2018 Business Transformation Awards for their smart tech
- 7th WPI Science Symposium "Transformative Science"

JANUARY
- Berkeley Week
- FOXSI-3's initial data reveals the most accurate solar corona data yet
- Kavli IPMU/ELSI/IRCN Joint Public Lecture: "A Question of Origins"
- Hyper-K Proto-collaboration meeting and Near Detector meeting

FEBRUARY
- Representation theory, gauge theory and integrable systems
- Dark Matter may be hitting the Right Note in Small Galaxies
- Visions for table-top dark matter experiments

MARCH
- Upgraded SuperKEKB accelerator will start taking data
- Masamune Oguri awarded this year's Hayashi Chushiro Prize
- Extremely Big Eyes on the Early Universe
- Hitoshi Murayama named University Professor

3 ORGANIZATION



The Kavli IPMU has a rather unique organization. While research is conducted in a flatstructure manner with loosely defined grouping, the decision making is done in a top-down scheme under the Director's strong leadership. This scheme minimizes the administrative load for the researchers. It is also intended to maximally extract young researcher's creative and challenging minds as well as to encourage daily cross-disciplinary interactions.

The Director is appointed by the President of the University of Tokyo and reports directly to his office. The Director proposes to hire the Principal Investigators to the President. For other hiring of research staff and administrative staff, he has a complete authority. He is also solely responsible for making all other decisions. He is assisted by the three Deputy Directors and the Administrative Director. They constitute the Executive Board (EB) and regularly meet to ensure smooth operation of the Institute. The EB has direct access to the Office of the President for consultations on both scientific and administrative matters.

The Director is obliged to report the appointments of new Principal Investigators and faculty members to the Director of the University of Tokyo Institutes for Advanced Study (UTIAS). Also, to clear the university formality in faculty hiring, the decisions of the Institute have to be endorsed by the Steering Committee of the Kavli IPMU.

The Principal Investigators are world's leading scientists in their fields. They have a large autonomy in the research they conduct. They can make proposals to the Director to hire research staff at the Institute.

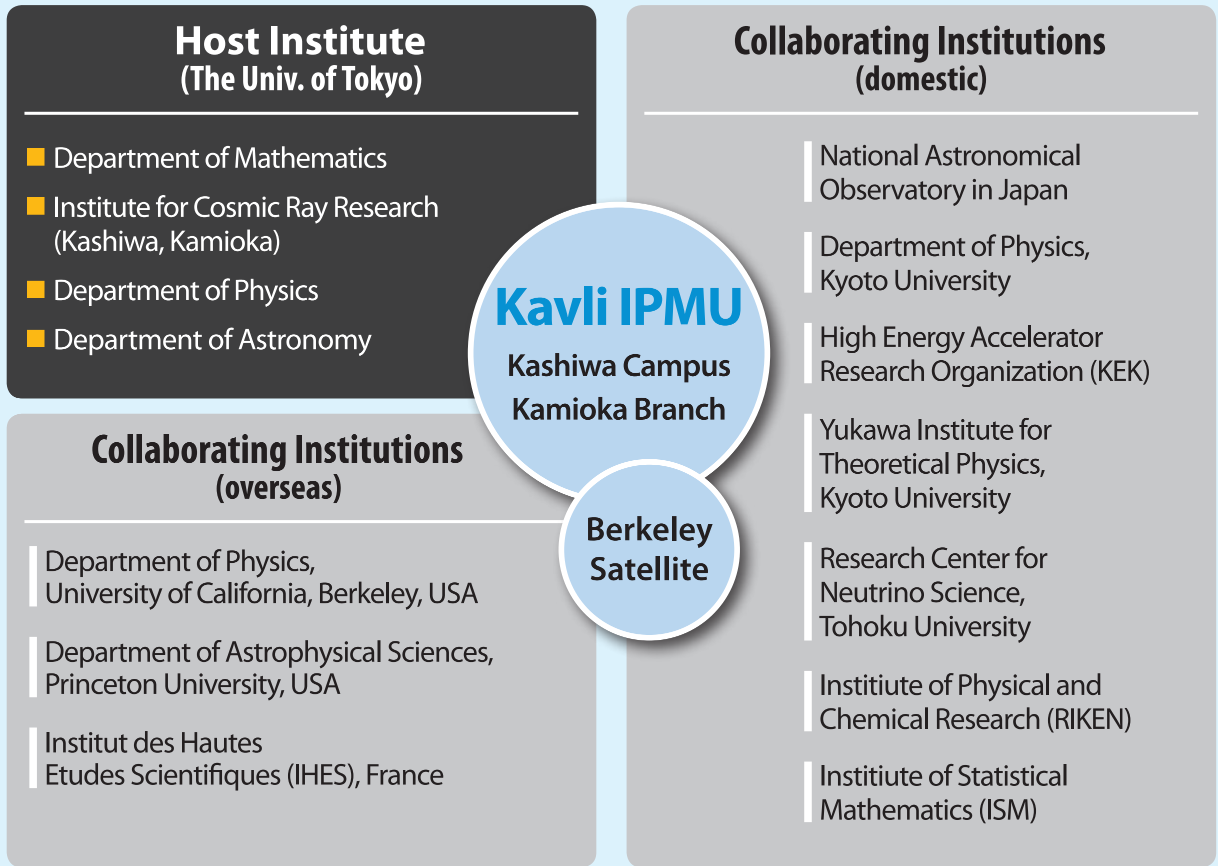
The External Advisory Committee (EAC), appointed by the President of the University of Tokyo, reviews annually the scientific achievement and activities of the Institute and advises the President on scientific priorities and the research activities to keep the Institute stay on the course of its objectives.

The External Advisory Committee Members (March 2019)

John Ellis	King's College London	Particle Theory
Giovanni Felder	ETH Zürich	Mathematics
Joshua Frieman	FNAL/U Chicago; Chair	Astrophysics
Masahiko Hayashi	JSPS Bonn Office	Astronomy
Tatsuya Nakada	EPFL	High Energy Experiment
Youngbin Ruan	U Michigan	Mathematics
Sakura Schafer-Nameki	U Oxford	Mathematical Physics
Nigel Smith	SNOLAB	Astroparticle Physics

The Office for Research Strategies pursues external funds in order to strengthen the research activities.

The main laboratory building on the Kashiwa Campus provides a basis for our researchers. Even most of experimentalists who are involved in Kamioka experiments and astronomical observations spend a good fraction of their time in Kashiwa for analyzing data, sharing seminars and discussing with theorists. The Kamioka Branch is a basis for the Kavli IPMU staff members who are engaging in the underground experiments conducted at the Kamioka underground laboratory. The Berkeley Satellite, besides being a place for research, serves as a contact place to the US scientific community. We also have close collaborative relations with several institutions both in Japan and overseas as well as with other departments within the University of Tokyo.



The Kavli IPMU holds close relations with similar research institutions in the world for encouraging exchanges in research and training of young research staff. We have signed either an agreement or a memorandum of understanding with those institutions.

Foreign institutions/consortia/programs having MOU with the Kavli IPMU

The University of California, Berkeley, Department of Physics
National Taiwan University, Leung Center for Cosmology and Particle Astrophysics (LeCosPA)
The Astrophysics Research Consortium [on the Sloan Digital Sky Survey III]
The Astrophysics Research Consortium [on the Sloan Digital Sky Survey AS3 ("After SDSS III")]
The Astrophysics Research Consortium [on the Sloan Digital Sky Survey IV]
Garching/Munich Cluster of Excellence on "The Origin and Structure of the Universe"
UNIFY (Unification of Fundamental Forces and Applications) [under the EU's Seventh Framework Program]
The Scuola Internationale Superiore di Studi Avanzati (SISSA)
The Academia Sinica Institute of Astronomy and Astrophysics of Taiwan (ASIAA) [on the SuMIRe Project]
The Intermediate Palomar Transient Factory (iPTF)
Steklov Mathematical Institute, Russian Academy of Sciences
Center for Mathematical Sciences, Tsinghua University
The Tata Institute of Fundamental Research
TRIUMF (Canada's National Laboratory for Particle and Nuclear Physics)
Deutsches Elektronen Synchrotron (DESY)
Princeton University
The University of Oxford, Department of Physics
The Kavli Institute for Astronomy and Astrophysics at Peking University (KIAA)
Le Centre National de la Recherche Scientifique (CNRS)
The Mainz Institute for Theoretical Physics (MITP)
Johns Hopkins University

4 STAFF

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5 Research Highlights

5.1 A Mysterious Kac-Moody Factor

Anna Puskás

Lie groups and Lie algebras underlie many of the interesting symmetries in nature and mathematics. The structure of Lie algebras is governed by root systems. A root system may be finite, affine or of general Kac-Moody type. Often an object that is well understood in the finite context is much more subtle in the infinite dimensional setting.
Consider imaginary roots and their multiplicities for a simple example. A finite root system has no imaginary roots. In affine type the imaginary roots are all integer multiples of a single minimal imaginary root and all have multiplicity one. In general Kac-Moody types the imaginary roots are harder to characterize and a closed formula for their multiplicity is not known. Formulas also become more complex when moving from finite to affine and from affine to the general Kac-Moody setting.
Consider Macdonald's beautiful identity about the Poincaré polynomial of the Weyl group W of a finite root system ϕ as an example. (Here ℓ is the length function.)

$$\sum_{w\in W} t^{\ell(w)} = \sum_{w\in W} w\left(\prod_{\alpha\in\Phi^+} \frac{1-te^{\alpha}}{1-e^{\alpha}}\right)$$

This formula no longer holds in the infinite dimensional setting. Instead on the right-hand side one must introduce a correction factor **m** and replace the set ϕ^+ of all positive roots with the set of all positive real roots. This **m** is supported on positive imaginary roots and is invariant under the Weyl group.
This factor **m** appears in many formulas in the theory of infinite dimensional Kac-Moody Lie algebras over *p*-adic fields. The factor **m** is the discrepancy between the correct expression and what would be the naive generalization of the finite-dimensional formula. This is the case for the affine Gindikin-Karpelevich formula by Braverman-Garland-Kazhdan-Patnaik [BGKP14], the affine version of Macdonald's formula for the spherical function [BKP16], and the infinite dimensional analogue of the Casselman-Shalika formula [Pat17]. A version of **m** for a metaplectic root system is featured in my joint work with Patnaik on the metaplectic Kac-Moody Casselman-Shalika formula [PP19]. Bardy-Panse, Gaussent, and Rousseau [BPGR16, Theorem 7.3] generalize Macdonald's formula for the spherical function beyond affine types, and **m** plays a similar role there as well.
Having a good understanding of **m** would therefore mean a better grasp on the important formulas it appears in. However, exactly determining **m** is a hard question. In affine types, its computation turns out to be equivalent to Macdonald's Constant Term Conjecture, which was solved by Cherednik [Che95, Mac82]. However **m** is yet more mysterious beyond affine type. In joint work with Dinakar Muthiah and Ian Whitehead, we investigated **m** in Kac-Moody generality [MPW18]. The correction factor **m** can be written as an infinite product over the positive imaginary root cone Q^+_{im}.

$$\mathbf{m} = \prod_{\lambda\in Q^+_{\text{im}}} \prod_{n\geq 0} (1-t^n e^{\lambda})^{-m(\lambda,n)}$$

For each λ the exponents $m(\lambda, n)$ can be collected into a polynomial. $m_\lambda(t) = \sum_{n\geq 0} m(\lambda, n)t^n$
Computing **m** is equivalent to determining the polynomial $m_\lambda(t)$ for every $\lambda \in Q^+_{\text{im}}$. The constant term $m_\lambda(0)$ agrees with the multiplicity of the root λ. Therefore computing **m** includes the question of determining multiplicities of imaginary roots.
Though no closed formula is available, there are methods to compute $m_\lambda(t)$. We prove a generalization of the Peterson algorithm [MPW18, Section 5.] and the Berman-Moody formula [MPW18, Theorem 6.5] to compute not only multiplicities of roots λ but the entire polynomial $m_\lambda(t)$. Furthermore, $m_\lambda(t)$ turns out to be divisible by $(1-t)^2$ for any Kac-Moody root system [MPW18, Theorem 7.6]. In the affine case the quotient carries information about the corresponding Lie algebra. However the meaning and approximate size of the non-constant coefficients of this quotient remains a mystery beyond the affine setting.

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Research Highlights

5.2 Cosmology from Cosmic Shear Power Spectra Using Subaru Hyper-Suprime Cam Data

Chiaki Hikage

The Λ Cold Dark Matter (ΛCDM) model has been established as the standard cosmological model to describe the expansion history and the growth of the large-scale structure of the Universe. However, we are challenged by a fundamental lack of physical understanding of the main components of the Universe, dark matter and cosmological constant Λ or more generally dark energy. Coherent distorted pattern of distant galaxy images by gravitational lensing of large-scale structure, commonly referred to as the cosmic shear signal, is a unique probe of the total matter distribution in the Universe including dark matter. Cosmic shear is especially sensitive to the combination of the matter density parameter Ω_m and the amplitude parameter of matter fluctuations σ_8, i.e., $S_8(\alpha) \equiv \sigma_8(\Omega_m/0.3)^\alpha$ with $\alpha \sim 0.5$.

We measure cosmic weak lensing shear power spectra with the Subaru Hyper Suprime-Cam (HSC) survey first-year shear catalog covering 137 deg^2 of the sky. The HSC survey is unique due to the combination of its depth (5σ point-source depth of the Wide layer of $i \sim 26$) and excellent image quality (typical i-band seeing of $\sim 0.''58$), which enable us to measure cosmic shear signals up to higher redshifts with lower shape noise than current lensing survey such as KiDS and DES. Thanks to the high effective galaxy number density of 16.5 arcmin^{-2} even after conservative cuts such as magnitude cut of $i < 24.5$ and photometric redshift cut of $0.3 \le z \le 1.5$, we obtain a high significance measurement of the cosmic shear power spectra in 4 tomographic redshift bins, achieving a total signal-to-noise ratio of 16 in the multipole range $300 \le \ell \le 1900$.

In order to obtain robust cosmological constraints from cosmic shear measurements, we perform a blind analysis to avoid confirmation biases affecting our results. We carefully account for various uncertainties in our analysis including the intrinsic alignment of galaxies, scatters and biases in photometric redshifts, residual uncertainties in the shear measurement, and modeling of the matter power spectrum. The accuracy of our power spectrum measurement method as well as our analytic model of the covariance matrix are tested against realistic mock shear catalogs.

For a flat ΛCDM model, we find $S_8 \equiv \sigma_8(\Omega_m/0.3)^\alpha = 0.800^{+0.029}_{-0.028}$ for $\alpha = 0.45$ from our HSC tomographic cosmic shear analysis alone. We find that the effect of possible additional systematic errors can shift the best-fit values of S_8 by up to $\sim 0.6\,\sigma$. In comparison with *Planck* cosmic microwave background constraints, our results prefer slightly lower values of S_8, as shown in Figure 1. Such lower best-fit values of S_8 and Ω_m are also found in other recent weak lensing analyses including KiDS and DES. Although our consistency analysis based on the Bayesian evidence ratio test indicates that these lower values could just be a statistical fluctuation, there is a possibility that these lower values originate from systematic effects that are unaccounted for in our current cosmic shear analysis, or more interestingly, from a possible failure of our fiducial neutrino mass-free ΛCDM model. The full HSC survey data will contain several times more area, and will lead to significantly improved cosmological constraints.

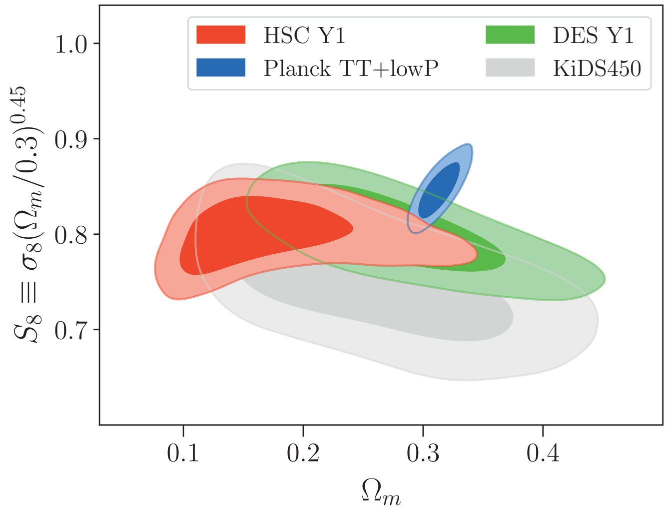

Figure 1: Marginalized posterior contours in the Ω_m-S_8(α = 0.45)plane, where $S_8(\alpha) \equiv \sigma_8(\Omega_m/0.3)^\alpha$, in the fiducial ΛCDM model. Both 68% and 95% credible levels are shown. For comparison, we plot cosmic shear results from KiDS-450 with correlation function (CF) estimators, DES Y1, as well as *Planck* 2015 CMB constraints without CMB lensing.

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5.3 Coulomb Branches of Quiver Gauge Theories with Symmetrizers

Hiraku Nakajima

Coulomb branch of a supersymmetric gauge theory in 3 dimension had been studied by physicists for many years, but its mathematically rigorous definition was given only recently by my joint work with Braverman and Finkelberg [1] based on my earlier work [3]. The construction uses the convolution product, a standard technique in geometric representation theory, applied to a certain infinite dimensional space arising from the gauge theory. An interesting byproduct of this construction is a natural quantization of Coulomb branch, that is a noncommutative algebra deforming the ring of functions on Coulomb branch. Study of its representation theory is a currently hot topic, and new unexpected phenomena have been found.

Quiver gauge theories form an interesting family of gauge theories, whose Coulomb branches and quantization have been studied most intensively [2]. Here a quiver is a finite oriented graph, such as $\circ \longrightarrow \circ \longrightarrow \circ$. The corresponding SUSY gauge theory is given by putting connections on $\circ$, and bifundamental matter fields on $\longrightarrow$. Quiver gauge theories have close connection with the theory of Kac-Moody Lie algebras associated with the Dynkin diagram of the underlying quiver. For example, the above example gives $\mathbf{sl}(4)$ whose Dynkin diagram is $\circ - \circ - \circ$. Quantization of Coulomb branch is the so-called truncated shifted Yangian, which is roughly a deformation of the loop algebra of the Kac-Moody Lie algebra.

This construction realizes only *symmetric* Kac-Moody Lie algebras, as the orientation of arrows in the original quiver is forgotten in the Dynkin diagram. For example, the Dynkin diagram $\circ - \circ \Longrightarrow \circ$ of $\mathbf{so}(7)$ does not appear in this construction.

In my recent joint work with Alex Weekes [4], I modify the definition of Coulomb branch so that it is related to a symmetrizable Kac-Moody Lie algebra, such as the above $\circ - \circ \Longrightarrow \circ$. The corresponding quiver gauge theory is still for $\circ \longrightarrow \circ \longrightarrow \circ$, but we modify the spacetime on which connections and matter fields are defined. Namely connections are defined on the 2-dimensional sphere S^2, the boundary of a small ball in 3-dimensional space. In the new construction S^2 could be different for each $\circ$. The S^2 for the rightmost $\circ$ is the two-fold covering of the S^2 for the left two $\circ$'s. Matter fields are considered after pulling back the connection for the left $\circ$.

We also study representation theory of quantization of these new Coulomb branches, which are truncated shifted Yangian for symmetrizable Kac-Moody. Rather surprisingly, although quantization itself is new as an algebra, its representation theory is essentially the same as the representation theory of a quantization of the Coulomb branch corresponding to a symmetric Kac-Moody Lie algebra. For example, one for $\circ - \circ \Longrightarrow \circ$ is the same as one for $\circ - \circ - \circ - \circ - \circ$. A similar relation was found earlier by Frenkel-Hernandez, Kashiwara-Kim-Oh, and our construction gives its conceptual explanation.

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5.4 Swampland Conditions

Hirosi Ooguri

The unification of quantum mechanics and general relativity is relevant for many questions we study at the Kavli IPMU. They include the origin of the dark energy, the mechanism of the cosmic inflation in the early universe, and the initial conditions of the universe. One of the important tools theorists use in this context is the low energy effective theory. In theories without gravity, it is generally believed that any low energy effective theory that satisfies a minimum set of requirements such as the unitarity and causality within the low energy region should have consistent ultraviolet completion. However, over the last ten years or so, several evidences have emerged suggesting that the situation with gravity is different. There seems to be a set of low energy effective theories including gravity which cannot be realized as low energy limits of mathematically consistent quantum theories. Such a set of low energy effective theories was named the Swampland by Cumrun Vafa in 2005 [1]. One can think of the Swampland as a complement of the Landscape of String Vacua in the space of all possible low energy effective theories. Since then, several conditions have been proposed to delineate the Landscape and the Swampland, which are called Swampland Conditions.

In his 2006 paper [2] with Vafa, Ooguri formulated a Swampland Condition about the space of scalar fields, which has been called the Distance Conjecture. Around the same time, another called the Weak Gravity Conjecture was also proposed in [3]. These two conditions have been tested affirmatively in numerous top-down constructions in string theory. Moreover, surprising connections has emerged between them and to other conjectures such as the Cosmic Censorship Hypothesis.

There is even an older conjecture about quantum gravity. It is that quantum gravity cannot have global symmetry. This conjecture was proposed decades ago based on the behavior of the Hawking radiation from a black hole and the statistical interpretation of the Bekenstein-Hawking entropy formula, but it had not been proven. Since 2015, Ooguri has been working with Daniel Harlow, now an assistant professor at MIT, to prove this conjecture in the context of the AdS/CFT correspondence, which is the only setup where quantum gravity is well-defined. In the fall of 2018, they published two papers, a 5 page announcement [4] of the proof and another 175 paper full exposition [5] of the proof. Their proof makes essential use of the deep connection between the holography of quantum gravity and quantum error corrections in quantum information theory. The short announcement was published in Physical Review Letters and was chosen for its Editors Suggestion.

One of the outstanding mysteries of the universe is the origin of the dark energy, which is responsible for the accelerative expansion. Another is the mechanism of the cosmic inflation in the early universe. Both can be described by the de Sitter solution to the Einstein equations. However, it has been challenging to give a top-down construction of a de Sitter solution from string theory. In the summer of 2019, Ooguri with Georges Opied, Lev Spodyneiko, and Cumrun Vafa, formulated a conjecture about the scalar potential in a low energy effective theory in the Landscape [6]. It is called the de Sitter conjecture since it excludes the de Sitter solution as an exact solution to string theory. The paper became the highest cited paper in high energy theory in 2019, partly because it gave a new direction to phenomenological model building and partly because it inspired string theorists to go back to re-examine earlier attempts to construct the de Sitter solution. Subsequently, Ooguri with Eran Palti, Gary Shiu, and Cumrun Vafa, showed that the de Sitter conjecture related to the distance conjecture and reformulated the conjecture [7]. The Swampland Conditions do not exclude the cosmic inflation, but they put non-trivial constraints on inflation models with observable consequences. It is hoped that these conjectures can be tested in experiments over the next decades such as the LiteBIRD project.

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5.5 Mapping the High-Redshift Cosmic Web in 3D

Khee-Gan Lee

The cosmic web is the characteristic pattern in the large-scale structure of the Universe, caused by the evolution of initial density fluctuations under the influence of gravity and astrophysical processes over cosmic time. While extensively studied using galaxy redshift surveys at low redshifts ($z < 1$), it remains challenging to map the cosmic web at higher redshifts as the galaxy spectroscopy required to establish 3D galaxy positions becomes expensive.

At IPMU, we have instead exploited the hydrogen Lyman-alpha forest absorption from $z \sim 3$ background star-forming galaxies to carry out 3D tomographic mapping of the intergalactic medium (IGM) at high redshifts of $z \sim 2$. With the COSMOS Lyman-Alpha Mapping And Tomography Observations (CLAMOTO) spectroscopic survey using the Keck-I telescope, we have established the observational proof-of-concept over a small footprint (~0.2 sq deg) within the COSMOS field, and made pioneering observations of $z \sim 2$ galaxy protoclusters and cosmic voids.

In FY2018, we worked to expand the applications of IGM tomography. With visiting JSPS/NSF Scholar Ben Horowitz (Berkeley), we worked on the idea of exploiting the nearly linear nature of the gravitational collapse at $z \sim 2$ to perform constrained realization analysis of the cosmic web within an observational volume. Using optimal minimization methods combined with a fast approximate N-body simulation code, we developed methods to solve for the pattern of initial density fluctuations which is the best match for the Lyman-alpha forest absorption seen in a given data set. Applied to high-redshift data, this opens the exciting possibility of *predicting* the future gravitational evolution of cosmic structures observed at $z \sim 2$-3. This will allow us to associate galaxies observed within said structures with their future environments at $z \sim 0$, thereby making a direct link with galaxy environmental studies from the Local Universe.

Apart from using the Lyman-alpha forest, we are also working towards estimating the density field from galaxy survey data. While spectroscopic surveys are expensive at $z > 1$, it is possible to build up sufficient galaxy densities in the COSMOS field by combining the multiple spectroscopic surveys that have observed there. Metin Ata (IPMU postdoc) has been working to carefully correct for the selection functions of the various spectroscopic surveys in order to apply his BIRTH density reconstruction code, which estimates the underlying density field. With both the density field and Lyman-alpha absorption in hand, we will then be able to directly test the prevailing paradigm of the large-scale IGM gas as optically-thin photoionized medium.

These efforts are paving the way for the future implementation of IGM tomography using the Prime Focus Spectrograph (PFS) on the 8.2m Subaru Telescope in Hawaii. With the Subaru Strategic Proposal (SSP) survey planned to begin in 2022, PFS will enable 100x larger cosmic volumes to be mapped compared with CLAMATO.

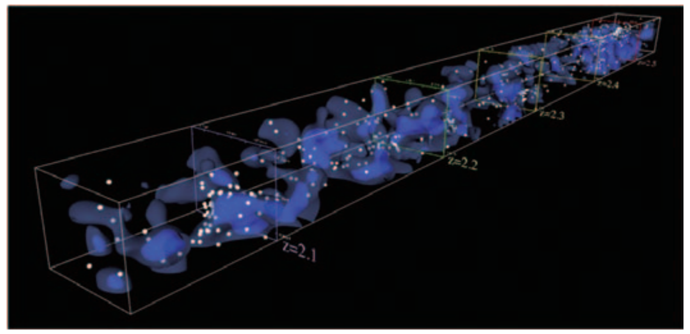
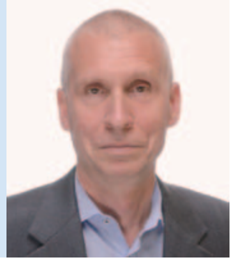


Figure 1: 3D visualization of the reconstructed Lyman-alpha absorption from the CLAMATO observations shown as a blue haze, covering $2.0 < z < 2.5$. For comparison, positions of galaxies with known spectroscopic redshifts are shown as dots.

5.6 Perverse Sheaves and Their Categorical Generalizations



Mikhail Kapranov

Perverse sheaves were introduced in the early 1980's by Beilinson, Berstein and Deligne [1]. Their goal was to asiomatize the geometric structure possessed by solutions of holonomic (maximally overdetermined) systems of linear differential equations. This structure is roughly analogous to the familiar concept of a sheaf (local data given for various domains of definition) but does not reduce to a sheaf (hence the attribute "perverse"). Since then, perverse sheaves have found a variety of applications in algebraic geometry, representation theory and other areas of mathematics.

For several years I was studying perverse sheaves from the point of view of their possible relation to Fukaya categories in symplectic geometry. The Fukaya category has, as objects, Lagrangian submanifolds of a given symplectic manifold. It turns out that Lagrangian skeletons, i.e., possible singular Lagrangian subvarieties in a complex Kähler manifold, play an important role in the classification of perverse sheaves. Namely, a perverse sheaf $\mathcal{F}$ and a Lagrangian skeleton K give rise to an ordinary (non-perverse) sheaf $R_K(\mathcal{F})$ on K, which is a much more transparent object. It can be then analyzed using more traditional methods and used to describe $\mathcal{F}$ completely.

Working with V. Schechtman [6], I first realized this approach for perverse sheaves smooth with respect to a real arrangement of hyperplanes in the complex space $\mathbb{C}^n$. The skeleton K here is the real locus $\mathbb{R}^n$. Remarkably, already this very simple setting leads to far-reaching results. Similar results have been obtained for graphs on surfaces [8] and, just recently, for symmetric product spaces [9], where the classification of perverse sheaves is related to Hopf algebras. This approach also led to the study, joint with R. Bezrukavnikov, of so-called microlocal sheaves on singular curves, which are systems of perverse sheaves whose moduli spaces possess natural symplectic structures.

These classification results lead V. Schechtman and myself [7] to propose a categorical analog of perverse sheaves which we called perverse schobers. While a perverse sheaf is, ultimately, a datum of a system of vector spaces, a perverse schober is a datum of a system of categories. Our proposal was to view perverse schobers as "coefficient data" for forming Fukaya categories, just like perverse sheaves can serve as coefficients for taking cohomology. This concept turned out to be useful for encoding the action fo birational transformations (flops) on the coherent derived categories [3].

Working with M. Kontsevich and Y. Soibelman [5] I related the "algebra of the infrared" of Gaiotto, Moore and Witten [4] with the concept of secondary polytopes which I introduced (jointly with I. M. Gelfand and A. V. Zelevinsky) in the 1990's to describe discriminants of polynomials in several variables. It turns out that this construction can also be put in the schober context: one can speak of the "infrared algebra" in the presense of a shober on the complex plane. More precisely, in the infrared limit, a supersymmetric theory gives the data of the vacua and of the tunnelling transition between the vacua. In our interpretation (work in progress with Y. Soibelman and L. Soukhanov) the vacua (or, rather, their central charges) correspond to the singular points of the schober $\mathfrak{S}$. The local category of D-branes corresponding to a vacuum is interpreted as the category of vanishing cycles of $\mathfrak{S}$. The tunnelling transitions arise as the natural transport functors given by the schober structure. In this way we get that many features of a physical theory are captured by a perverse schober.

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5.7 Closing in on the Ultimate Dark Matter Limits Forecast by the Fermi Gamma-Ray Space Telescope

Oscar Macias

A myriad of astronomical observations indicate that ordinary matter—the kind of stuff that makes up the stars, planets and us—can only account for about fifteen percent of the total matter of the universe. The remaining fraction is in the form of a mysterious substance called *Dark Matter*. Unlike most ordinary matter, it does not appear to emit any form of light that we could detect with our telescopes—which is how we have learned almost all we know about the universe. It is easy to see then why it has been so difficult to discover the true nature of this unknown substance.

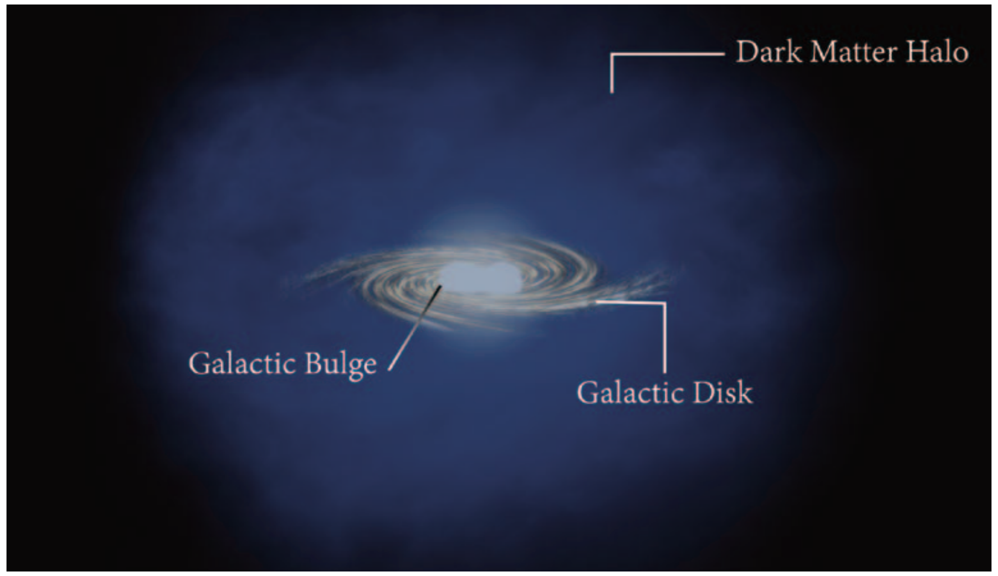


Figure 1: The Milky Way Galaxy is embedded in an enormous halo of *Dark Matter* with the concentration of this strange substance peaking at its heart.

One of the leading theories posits that if *Dark Matter* is made of a special kind of particles, they could collide with each other and disappear in a glow of gamma ray photons billions of times more energetic than visible light. Although such *Dark Matter annihilations* are expected to be incredibly rare in most places in the universe, the odds of detecting this signal can be greatly increased by aiming our gamma ray telescopes to spots in space with very high concentrations of *Dark Matter*. When it comes down to deciding where to find the most intense *Dark Matter* glow, the heart of our Milky Way Galaxy wins every time (Figure 1).

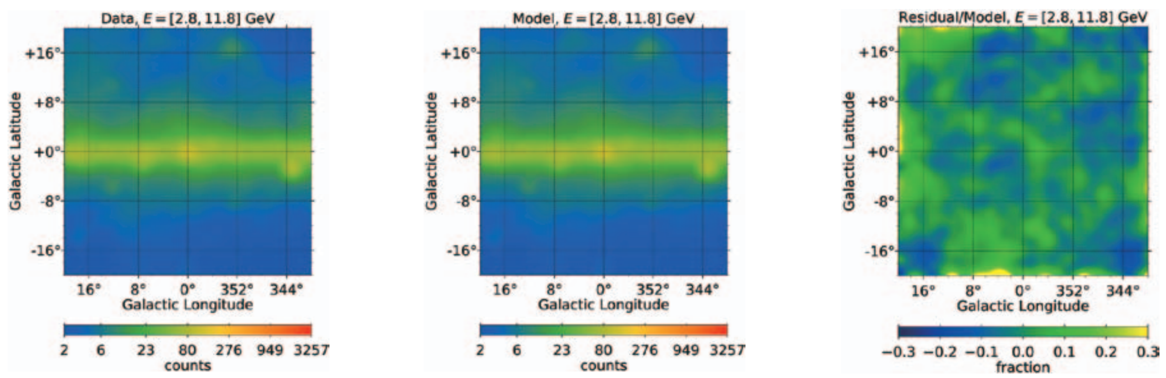


Figure 2: Left: *Fermi* data from the Galactic Center. Middle: Astrophysical model constructed in Macias *et.al.* (2019). Right: Fractional residual image (*Data-Model*)/*Model*. Our model for this region is so sophisticated that it is almost impossible to tell it apart from the actual data. The residual image demonstrates that what remains unexplained in the region is inconsistent with a *Dark matter annihilation* glow, instead it resembles pure random noise.

Using data from the *Fermi* Gamma-Ray Space Telescope, several research teams claimed to have identified an intriguing gamma ray signal at the center of our Galaxy which seemed to have been the first ever detection of a *Dark Matter* annihilation. The excitement in the *Dark Matter* community was palpable, with research articles on the subject being published almost on a weekly basis in the first few years (by ~ 2012–2013) of the discovery claim.

But as someone once said "extraordinary claims require extraordinary evidence" and in this particular case there was just not enough of the latter. This is in part because the center of the Galaxy is a very violent region filled with uncertain amounts of interstellar gas, neutron stars, supernovae remnants and a supermassive black hole—any of which could have been culprit of the excess gamma ray haze. To put an example; a population of rapidly rotating neutron stars (known to generate magnetic fields about a billion times stronger than that of our Sun) can accelerate charged particles to extreme high energies thereby producing a sea of gamma ray photons as a product of microphysics interactions. The mechanisms at play here are well understood, the difficulty is that we currently don't know the exact distribution of gas, starlight and stars at the Center of our Galaxy.

Gradually, as the dust settles, it has become abundantly clear that the Galactic Center excess is not due to *Dark matter annihilations*. Using a wide range of information of the sky at different energies along with hydrodynamic simulations, Macias *et.al.* (2019) have built up a better model of the astrophysical background for the Galactic Center (Figure 2). This has allowed us to reconstruct a much sharper image of the gamma-ray signal for more robust analyses and checks. The key finding of our most recent study is that the excess signal traces stellar populations in the Galactic bulge. The bulge contains a broad mix of old and newborn stars, which motivates astrophysical gamma ray emitters such as young and millisecond pulsars as the source of the Galactic Center excess. As a matter of fact, researchers (e.g., Bartels et al. 2018) using complimentary methods have independently confirmed our results.

As shown in Figure 2, we have demonstrated that there remains little Galactic Center excess emission that might be attributed to *Dark Matter* emission. Our international team is working hard to convert this null detection into some of the strongest constraints yet on the *annihilation rate* for *Dark Matter* particles about a hundred times heavier than a proton. Some of our preliminary results are very encouraging and suggest that we might be not too far from reaching the ultimate Dark Matter limits forecast by the Fermi Gamma-Ray Space Telescope (Figure 3).

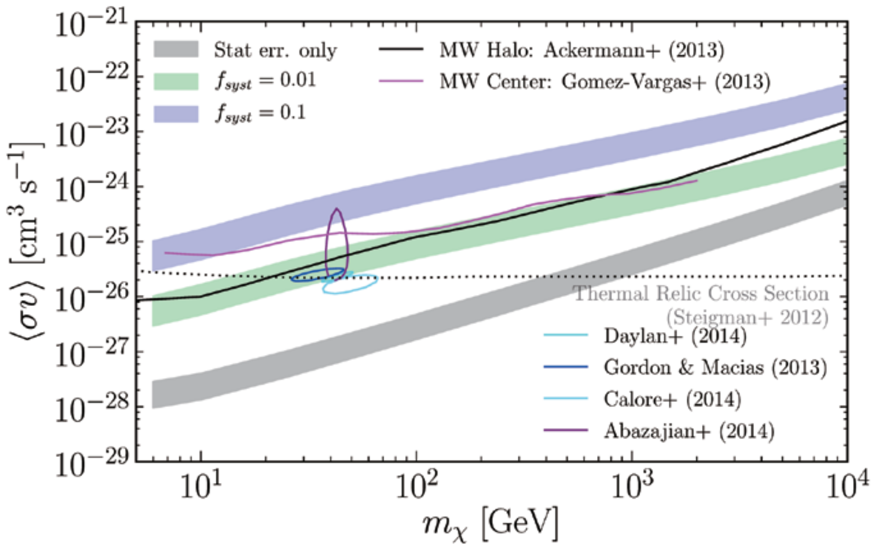
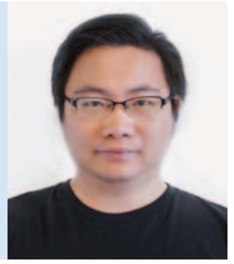


Figure 3: Source: This figure is from Charles *et.al.* (2016)—for the *Fermi* collaboration—reproduced with permission of Physics Reports (Elsevier). The *Dark Matter annihilation rate* versus *Dark Matter mass* in Giga-electron-Volts units. Projected limits for 15 years of *Fermi* data from the Galactic Center region. The Dark Matter particles are assumed to be annihilating into quarks. Different color bands show different levels of background model uncertainties.

Further reading: http://go.nature.com/2CVnzBH.

5.8 Gravitational Waves and Dark Matter



Shi Pi

The first observation of gravitational waves (GWs) from a black hole (BH) merger by the Laser Interferometer Gravitational Wave Observatory (LIGO) on September 14th, 2015 opened a new window to explore the universe. In the near future there will be space-based GW detectors like Laser Interferometer Space Antenna (LISA), Taiji and/or Tianqin, DECIGO and BBO. The targets of these space detectors include mergers of supermassive black holes, extreme mass ratio binary inspirals, and stochastic GW backgrounds. One of the possible origins of stochastic GW backgrounds is primordial; a fossil that preserves the information from the very early universe. Thus detection of it has a tremendous scientific significance. It gives us clues to understand the origins of our universe.

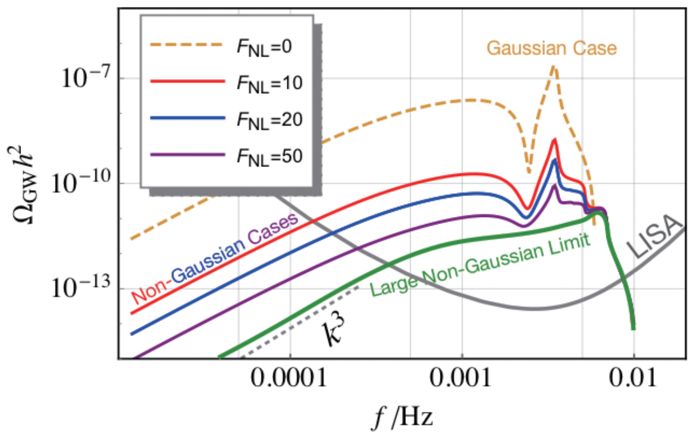
The current astronomical and cosmological observations tell us that about 27% of the energy density of our universe is dark matter, whose origin is a great challenge to modern cosmology and theoretical physics. A possible candidate for dark matter is primordial black holes (PBHs). PBHs are black holes formed in the very early universe from rare peaks of the primordial scalar curvature perturbations which originate from inflation. PBHs may constitute a large portion of or all of the dark matter in our current universe. Black holes evaporate gradually by Hawking radiation. PBHs lighter than 10^{16}g have a lifetime shorter than the age of the universe, hence they have evaporated completely by now. While the abundance of PBHs heavier than 10^{22}g is highly constrained by microlensing observations. However, there exists no observational constraint on PBHs in the mass range $10^{16}\text{g}<M_{PBH}<10^{22}\text{g}$. Therefore, PBHs in this range may constitute all the dark matter of the universe.

GWs are found to play the key role in testing or constraining the scenario of such small PBHs as dark matter. Since PBHs are formed from large amplitude scalar perturbations, their mean square amplitude is expected to be large enough to produce appreciable secondary gravitational waves at nonlinear order. Since these GWs are sourced by the scalar perturbations, we call them the induced GWs. If the abundance of PBHs is large enough to dominate the dark matter component, it may be possible to detect the induced GWs in the future. A lucky coincidence is that the frequency band of the induced GWs corresponding to the only possible mass window for PBHs as dark matter, 10^{17}g to 10^{22}g, exactly matches that of LISA/Taiji/Tianqin, i.e. 10^{-3}Hz to 0.1 Hz.

Recently, we (Rong-Gen Cai (ITP, CAS), Misao Sasaki (IPMU) and I) made a detailed study of the induced GWs from scalar perturbations. We found that if the scalar perturbations are non-Gaussian, there appears a characteristic multi-peak structure in the induced GW spectrum, which can be used as a smoking gun of non-Gaussianity on small scales. We also found that the GW spectrum is large enough to be detected by LISA/Taiji/Tianqin if PBHs dominate dark matter, no matter how large the non-Gaussianity is. The point is that the GW spectrum is completely determined by the non-Gaussian part of the scalar spectrum in the large non-Gaussian limit. Hence, the existence of large peaks of the scalar perturbations that turn into PBHs guarantees a non-negligible amplitude of the scalar perturbation power spectrum independent of whether they are Gaussian or non-Gaussian, which in turn induces detectable stochastic GWs. See the Figure in the case of LISA. The non-Gaussianity is characterized by the parameter F_{NL} with the curvature perturbation R being assumed in the form,

$$R = R_g + F_{NL} R_g^2.$$

where R_g is the Gaussian variable. It is clear that the induced GWs must be detected by LISA if PBHs are the dark matter. Conversely if such a GW background is not observed by LISA, it severely constrains the amount of PBHs in the mass range, 10^{17}g to 10^{22}g, where it seems there is no direct way to constrain it.



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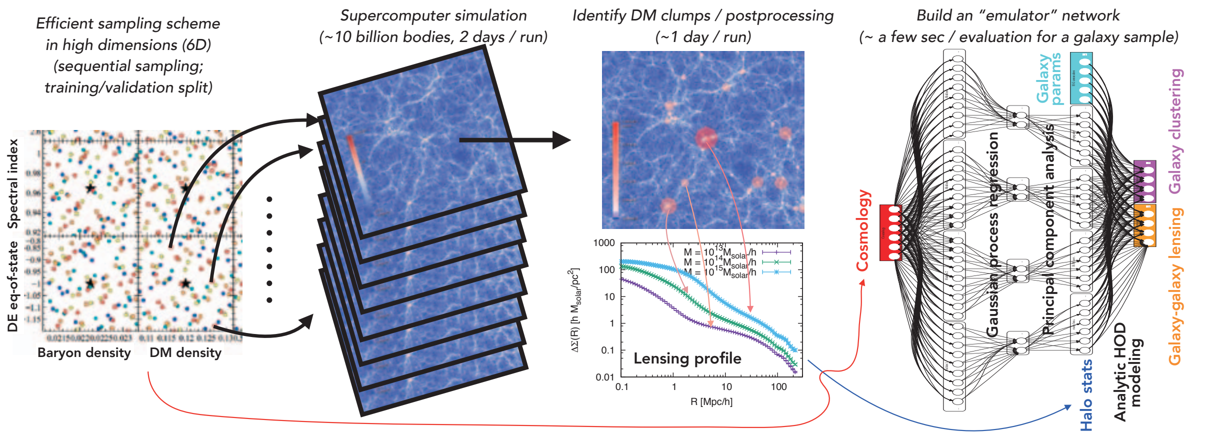
5.9 A Machine-Learning Application to Cosmological Structure Formation

Takahiro Nishimichi

The large scale structure of the universe provides us with useful hints for the understanding of the underlying fundamental theory governing the dynamics of the universe as well as its contents including mysterious dark matter and dark energy. The standard way to put this idea forward is parameter inference based on forward models. Although *N*-body simulations, which follow the gravitational dynamics of a large ensemble of mass elements on supercomputers, have long been recognized as one of the most reliable method to forward model the large scale structure, their computational cost hampers them to be implemented in the parameter inference, where one has to sample typically millions of parameter combinations until a converged estimate is obtained.

Our research group is conducting a simulation campaign called "Dark Quest", which aims to build a simulation database covering a six-dimensional cosmological parameter space to study the structures in the mass scales ranging from galaxies to clusters of galaxies. Based on the initial set of simulations sampled at 100 points in the parameter space, each of which contains about 10 billion mass elements, we have developed a software "Dark Emulator" that *learns* the response of various fundamental statistical measures of the simulated dark matter clumps called "halos" to the input cosmological parameters. It consists of four main ingredients: i) a carefully chosen experimental design that fulfills desirable projection and space-filling properties, ii) a huge dimensionality reduction of the data vector obtained from each simulation based on the weighted principal component analysis, iii) nonparametric regression based on the Gaussian process, and, iv) rigorous cross-validation studies based on the split of training/validation sets, again optimized a priori in the process i).

The high accuracy (typically 2 to 3% precision) and the high evaluation speed (about a few seconds per evaluation per target galaxy sample on a modern laptop computer; this compares to ~ 2 days on a supercomputer using about 600 CPU cores) together with the flexibility in relating the simulated halos to the observed galaxies allow Dark Emulator to be implemented efficiently into the actual parameter inference pipeline to analyze observed galaxy data for the first time. The ongoing galaxy imaging survey with Subaru Hyper Suprime-Cam will be analyzed using our Dark Emulator.



Reference

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5.10 Good Vibrations: Effective Field Theory Harmonics

Tom Melia

The use of effective field theory (EFT) for physics analyses at the Large Hadron Collider, in particular the standard model (SM) EFT, is now commonplace, and will form an important part of the experiment's legacy, as well as providing crucial physics input to future colliders. An operator basis for an EFT encodes the independent physical measurements one can possibly make. It also organizes them in terms of how large their impact is, with what are called lower mass-dimension operators typically - but not always – being more important. The construction of EFT operator bases (in particular the SM EFT at dimension-6, and subsets of the basis at higher dimension) has been demonstrably - with numerous errors in the literature – tricky. The first ATLAS and CMS constraints on SM EFT dimension-8 operators appearing earlier this year further strengthens the case for obtaining a systematic understanding of operator bases.

Why is it so hard to construct an operator basis? The inherent difficulty is in fact familiar to people working with Monte Carlo event generators, where it takes quite a tangible form. In a Monte Carlo computer program, LHC events are generated, with particles that have momenta that is on-shell, and where the total momentum in the event is conserved. Once such an event is generated, the Monte Carlo-er may wish, for a variety of reasons, to tweak parts of the momenta configuration slightly. However, it is here the difficulty is encountered: adjusting e.g. particle 1's momentum in the x-direction alone will cause its invariant mass E^2-p^2 to go off-shell; even if its energy is also adjusted to compensate, one still finds that the total momentum in the event is now non-conserved, requiring further tweaking of the other particles in the event.

A nice solution to the above Monte Carlo-ists' bugbear has a close analogy with the solution to finding good coordinates to parameterise a sphere. The constraint $x^2+y^2+z^2=1$ is similar to the constraint of total momentum conservation in an event; in the case of the sphere we know to switch to spherical coordinates. One should seek the analogous manifold that the particle momenta must lie upon; it turns out that, by working with spinor helicity momentum variables, it is identified as a Stiefel manifold [1,2], see Fig. 1. How coordinates for this manifold can be used for Monte Carlo generation was explored in [3].

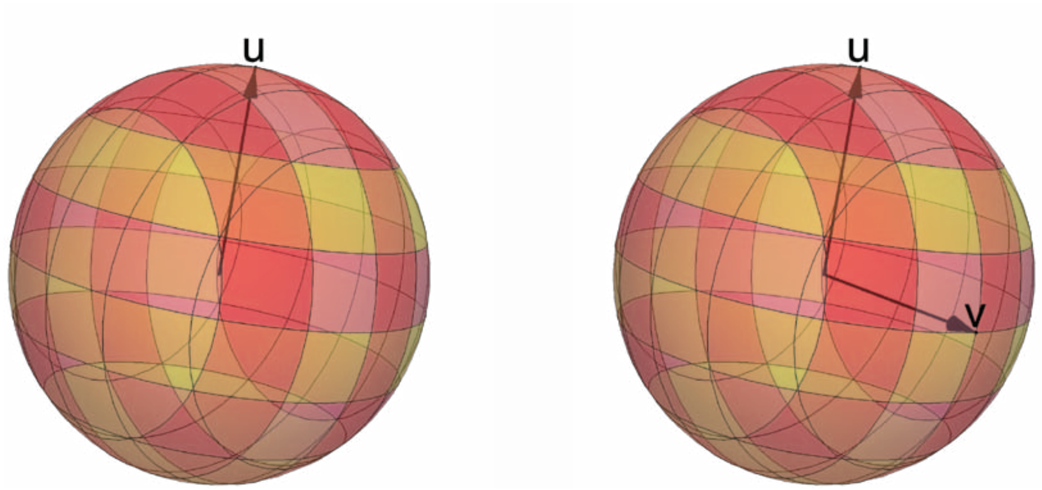

Fig 1: A sphere is the collection of points obtained by pivoting the vector **u** about the origin (left). The (2-frame) Stiefel manifold is the collection of points obtained by pivoting the coordinate frame (**u**,**v**) about the origin (right).

Having identified the kinematic manifold upon which physical observables have support, let us return to the question of how to construct an operator basis, which determines how many independent measurements of physical parameters one can make. We can again use the above sphere analogy, where spherical harmonics provide a basis for any function that lives on the sphere. For our case, it is the harmonics of the Stiefel manifold which will form a basis for physical parameter measurements – these harmonics are in one-to-one correspondence with operators in the EFT.

Phrasing things in the above way reveals some interesting underlying representation theory in the problem [1,2]. The Stiefel manifold has a coset description U(N)/U(N-2) (just as a sphere is identified as the coset O(N)/O(N-1)). The action of the U(N) group plays an important role, through a duality with what has was shown in [4] to be another organizing group action on EFTs, that of the conformal group. It turns out that the representation theory of the U(N) determines the representation theory of the conformal group, and vice versa. Such a mathematical duality has been seen in physics before: in optics, quantum interferometry, and applications of the Laplace and wave equations, to name a few places. Here, it allows for a systematic construction of the "EFT harmonics" [2]. There are also hints that it has manifestations in phenomenology, one example being the unusual structure of the anomalous dimensions matrix that describes the renormalization group evolution of the SM EFT [5]; these will be the subject of future investigation.

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5.11 A Big Step Forward for LiteBIRD to Prove the Inflationary Universe

Tomotake Matsumura

The measurement of the cosmic microwave background (CMB) B-mode polarization allows us to probe the smoking gun of inflation theory. The amplitude of the B-mode polarization, often quoted by the tensor-to-scalar ratio r, has a one-to-one relationship with the energy scale of inflation. The current best upper limit is $\delta r < 0.06$ (95% C.L.), which came from combined data analysis of the ESA Planck mission and the ground-based telescope BICEP on Keck. The observations by Planck ended in 2013, and the analysis efforts are still carried out today. Following the end of the Planck mission, there has been no new data coming from space-based measurements. Despite ongoing effort to probe inflationary B-modes from the ground and from balloons, the community has been searching for the path for the next-generation CMB polarization satellite to follow Planck.

Measuring the CMB polarization from space is a particularly attractive avenue for probing the inflation paradigm. This is because the inflationary B-mode signal is expected to appear at large angular scales, $2 \leq \ell \leq 200$, which can be accessible by the full sky survey in a satellite platform. Furthermore, after the Planck and BICEP experiences, the community has identified the great importance of component separation between the CMB polarization and polarized emissions from the Galaxy. For this reason, broadband observation is crucial in order to separate the components using the differences between their spectral shapes. The observational bands of space-borne missions are not limited by the atmosphere, as is the case for ground or balloon missions. For these reasons, there have been a number of proposals for a next-generation CMB satellite, yet none had been approved until recently.

LiteBIRD (Fig. 1) is a next-generation CMB polarization satellite that is dedicated to probing inflationary B-modes. The science goal of LiteBIRD is to measure the tensor-to-scalar ratio with the sensitivity of $\delta r = 0.001$ for $r = 0$, or 5σ for each bump for $r \geq 0.1$. In this way, we test the major large-single-field slow-roll inflation models. The concept of LiteBIRD emerged in 2008 as a small satellite to focus on probing the inflationary B-mode signal from space. The LiteBIRD working group was established under the Steering Committee for Space Science. Since then, the LiteBIRD team has undertaken over ten years of the groundbreaking effort in the concept design, key technology demonstrations, and developing the team into a serious international collaborative effort. The importance of the science has been recognized, and LiteBIRD's activity has been supported by the Japanese scientific community including radio astronomy and high energy physics. Kavli IPMU has played an important role from these early days. The proposal to the Master Plan was submitted from Kavli IPMU, and it was selected as one of the important large projects in Master Plan 2014 by the Science Council of Japan. Over the last two years, the team underwent the ISAS/JAXA pre-phaseA to solidify the concept demonstration. After the successful reviews at the end of pre-phaseA2, ISAS/JAXA selected LiteBIRD as the second large-class mission in June 2019. This decision is also reported to the space policy committee in the Cabinet office.

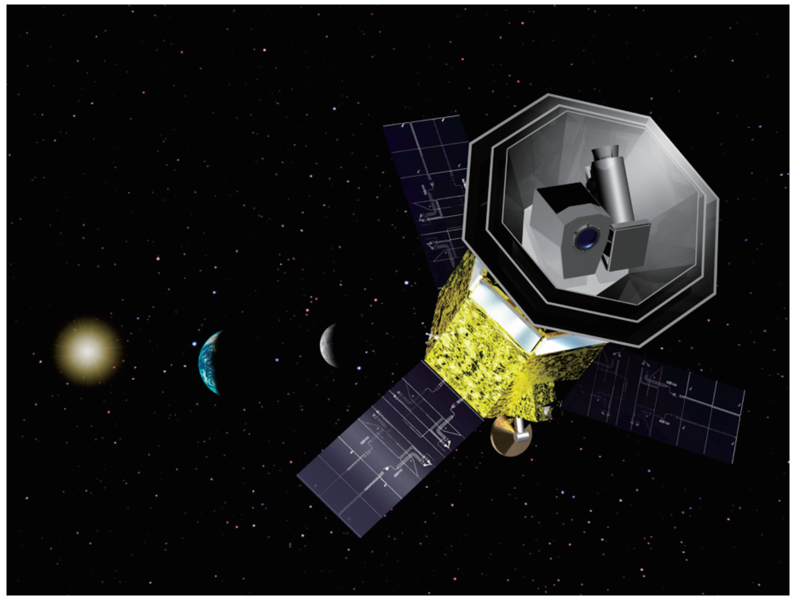


Figure 1: The artist image of LiteBIRD. (Figure courtesy of ISAS/JAXA.©)

LiteBIRD is now the only space-agency selected satellite mission aiming for CMB B-mode measurements in the world (Fig. 2). The overview of the LiteBIRD mission is as follows: The prospective launch year is the 2027 Japanese fiscal year. The full-sky survey will be carried out for three years from the second Sun-Earth Lagrange point. LiteBIRD contains three telescopes – low, mid, and high frequency telescopes, covering from 34 to 448 GHz with 15 bands. The international partnership has evolved in recent years. The US team is in charge of the transition edge sensor bolometer focal plane unit, and the Canadian team is responsible for the warm electronics. Multiple European nations (France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, UK) are in charge of the mid and high frequency telescope unit, as well as the sub-Kelvin cooler. The detailed responsibility breakdown will be addressed in the forthcoming phase.
In Japan, ISAS/JAXA is responsible for the low frequency telescope antenna, the cryogenic system, and the satellite system. KEK is in charge of the integration and the ground calibration. Kavli IPMU is responsible for the development and delivery of the polarization modulator (Fig. 3), which is one of the key instruments to reduce inevitable excess low frequency noise and systematics of the telescope. Kavli IPMU is also in charge of leading the data analysis.

Figure 2: Handing over "THE" torch from Planck HFI PI Jean-Loup Puget to LiteBIRD PI Masashi Hazumi at the ISAS/JAXA LiteBIRD Kickoff symposium on July 1 and 2.
(Photograph courtesy of Ms. Tada from IPNS/KEK.)

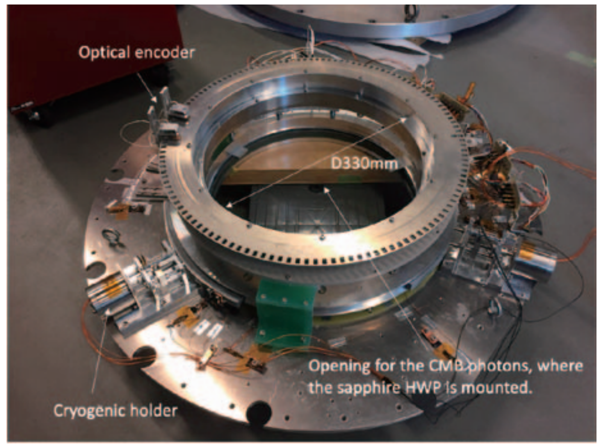


Figure 3: The breadboard model of the polarization modulator developed by the Kavli IPMU LiteBIRD team during the pre-phaseA2.

The team plans to go through PhaseA1 during a timescale of two to three years. This is particularly critical phase. The purpose of this phase is to turn the dream of scientists into a real-world space telescope in a collaborative effort between cosmologists, engineers, and the space industry. This team of scientists and engineers must work in tandem to converge the ambitious science goals with cutting-edge engineering and technologies. The LiteBIRD team at Kavli IPMU will continue to lead the development of the polarization modulator unit. We will also undertake knowledge transfer from the concept demonstration stage in lab-B at Kavli IPMU to the production of the demonstration model with the space industrial partner company. Whilst some of the activities will shift toward the space industry, the scientists at Kavli IPMU will be busy on a number of related activities. We will also prepare for the final performance characterization of the polarization modulator, for which only scientists can be responsible. This requires testing of the polarization modulator with a superconducting detector system. We must also evaluate the effects of the space environment on the polarization modulator, such as interactions with cosmic radiation. Furthermore, we need to plan for the calibration of the polarization modulator. In parallel, we will accelerate the effort to make a bridge between the science goal and the hardware using simulations.
Overall, the news of LiteBIRD's selection as the ISAS/JAXA strategic large class mission is a big step forward for the LiteBIRD team as well as the cosmology community as a whole. At the same time, this is an opportunity to confront a number of challenges in order to make LiteBIRD happen. Please look forward for further progress in our endeavor of inflation search from LiteBIRD and the Kavli IPMU team!

5.12 Medical Applications of Gamma-ray Imaging

Tadayuki Takahashi

In November 2017, a new collaboration was formed between Kavli-IPMU, JAXA's ISAS and Institute for Advanced Medical Research at Keio University, with a project titled "Hard X-ray and Gamma-ray Imaging". Based at Kavli-IPMU, a number of interdisciplinary activities centered around the development of advanced hard X-ray and gamma-ray detectors that can overcome longstanding obstacles faced by researchers at the cutting-edge of nuclear medicine were initiated. Since 2018, we have also started a research program under the Grant-in-Aid for Scientific Research on Innovative Areas, titled "Toward new frontiers: Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams", which will broaden the scope of our experimental activities. To carry out these programs at Kavli IPMU, we have brought together researchers from the field of physics, engineering, medicine and pharmaceutical sciences. (Fig. 1).

Fig 1: Photo of experiments at EPOC

In vivo and three-dimensional gamma-ray imaging, by means of a probe that includes a small amount of radioactive material that emits gamma-rays, plays a key role in providing improved and novel methods for the diagnosis and treatment of cancer in the pre-clinical phase. It enables us to visualize and measure cell activity and biological process.
In 2018, we succeeded in establishing a joint research agreement with a group at the Exploratory Oncology Research and Clinical Trial Center (EPOC) at the National Cancer Center. Since then, we have performed various experiments by using our equipment and instruments installed at EPOC. By combining a multi-pinhole collimator with 200-μm diameter pinholes and a 250-μm pitch Cadmium Telluride (CdTe) double sided detector, we have successfully demonstrated that the system has sufficiently high energy resolution of 1-2 keV (FWHM) to distinguish between different radionuclides in 10-150 keV energy range; where present SPECT (Single Photon Emission Computed Tomography) systems based on scintillators find it difficult to distinguish these radionuclides.
With these improved SPECT performances, it will become possible to simultaneously measure and distinguish the distribution of multiple cancer-seeking molecules (tracers), each labeled with different radionuclides, that emits gamma-rays at unique energies. Currently, we are carrying out in vivo imaging experiments of small mouse tissues visualized by three tracers labeled by different radionuclides.
Additionally, we have performed experiments using one very promising radionuclide, ^{211}At, which is being used as a new alpha-ray cancer therapy and for cancer diagnostics. The monitoring of the movement of drugs in the human body and its distribution in tissue are of particular importance, and the development of an imaging system that can image hard X-rays emitted from ^{211}At sources is required. We have demonstrated that for small ^{211}At droplets captured in a phantom are clearly resolvable by our prototype system down to a spatial separation of about 200-μm with a good spectral resolution (Fig. 2).

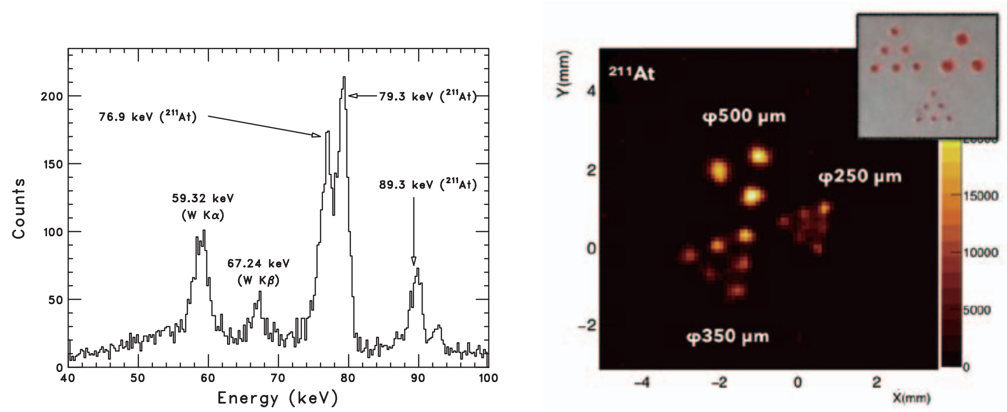


Fig 2: ^{211}At spectrum and image taken with the CdTe imager

6 AWARDS

Hirosi Ooguri Awarded the 2018 Hamburg Prize for Theoretical Physics

On May 24, 2018, it was announced that Hirosi Ooguri, Director of the California Institute of Technology's Walter Burke Institute for Theoretical Physics and Kavli IPMU Principal Investigator, has been awarded the 2018 Hamburg Prize for Theoretical Physics. This prize is awarded by the Joachim Herz Stiftung in partnership with the University of Hamburg and Deutsches Elektronen-Synchrotron (DESY). This is the first year the prize covers all areas of theoretical physics (previously it was given to theorists in quantum information, quantum optics, and quantum many-body systems). With a new endowment established for the prize, the prize money has been increased from 40,000 euros to 100,000 euros, making it one of the most valuable science prizes in Germany. The award ceremony will be held on November 7, 2018 at Planetarium Hamburg.

American Physical Society's 2019 Hans A. Bethe Prize Goes to Ken'ichi Nomoto

Ken'ichi Nomoto, a Kavli IPMU Senior Scientist, has been awarded the 2019 Hans A. Bethe Prize, which was announced by the American Physical Society on October 23, 2018. This award recognizes outstanding work in theory, experiment, or observation in the areas of astrophysics, nuclear physics, nuclear astrophysics, or closely related fields. The prize, consisting of $10,000 and a certificate, is presented annually.

The 2019 Selection Committee awarded Professor Nomoto with this year's award for his "lasting contributions to our understanding of the nuclear astrophysics of the universe, including stellar evolution, the synthesis of new elements, the theory of core-collapse and thermonuclear supernovae, and gamma-ray bursts." An award ceremony will be held during the American Physical Society April 2019 Meeting in Denver, Colorado.

Masami Ouchi Awarded 15th JSPS Prize and Japan Academy Medal

Masami Ouchi, University of Tokyo Institute for Cosmic Ray Research Associate Professor and Kavli IPMU Scientist, was awarded the 15th JSPS (Japan Society for the Promotion of Science) Award and the 15th Japan Academy Medal in recognition of his work "Observational Studies of the Early Universe with Ly α Emitters." An award ceremony was held at The Japan Academy on February 7, 2019.

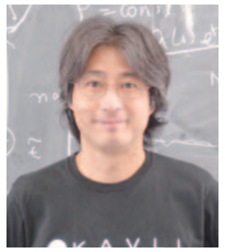
The JSPS Prize recognizes young researchers with fresh ideas, who have the potential to become world leaders in their field. The purpose of the Japan Academy Medal is to honor outstanding young researchers. Up to six awardees (6 researchers this year) are selected every year from among the annual winners of the JSPS Prize (25 researchers this year).

Masamune Oguri Awarded This Year's Hayashi Chushiro Prize

Masamune Oguri, the University of Tokyo Research Center for the Early Universe Assistant Professor and Kavli IPMU Associate Scientist, has been awarded the fiscal year 2018 Hayashi Chushiro Prize.

The prize recognizes researchers who have made significant contributions to planetary science, astronomy, or astrophysics, and has been awarded since 1996 by the Astronomical Society of Japan. The prize itself was made to commemorate the lifetime achievements of outstanding Japanese theoretical astrophysicist Chushiro Hayashi.

Oguri has been recognized for his contribution to the fundamental understanding of gravitational lensing in astronomy. He has for a long time studied gravitational lensing from a theoretical and observational point-of-view, which has provided valuable insight into studies in cosmology and astronomy.



Hitoshi Murayama Named University Professor

On March 27, 2019, the University of Tokyo announced that Kavli IPMU Principal Investigator Hitoshi Murayama had been given the new title of University Professor. The university established this new title to recognize important individuals within the institution who are making significant contributions to his or her academic field internationally, and who are continuing to lead research activities that will contribute to further developments in their field in the future. Murayama is one of four academics to be given this title, which took effect from April 1.

Kavli IPMU Staff Commended at 2018 Business Transformation Awards for Their Smart Tech

For their efforts in helping new international researchers and visitors navigate their way to the Kavli IPMU on their own, a team of Kavli IPMU administrative staff led by Project Specialist Rieko Tamura has been recognized by this year's University of Tokyo Business Transformation Awards. These awards are given out every year to recognize administrative staff and individual departments that have made a significant contribution to reforming the university.

Tamura's team received this year's Special Prize for their work in developing and running a smartphone app, which provides step by step information in English about how to take public transport from the international airport, how to find and take the free shuttle bus to Kashiwa campus from the train station, and maps that show where individual researchers' offices are. It also serves all existing researchers at Kavli IPMU by becoming an information hub on seminars of the day, who was visiting that day, and where to find certain administrative staff members.

An awards ceremony was held at the Yasuda Auditorium on the University of Tokyo's Hongo campus on December 19, 2018. Nine groups including the Kavli IPMU team were commended by the University of Tokyo President Makoto Gonokami or by Executive Vice President Tomoka Satomi.

7 CONFERENCES

Conference title Date, Place	Attendees (from abroad)
Focus Week on Quantum Gravity and Holography 2-6 April 2018, Lecture hall	47 (21)
RISTEX Symposium "An analysis of the factors that influence women and girls to pursue physics and mathematics" 17 June 2018, Lecture hall	47 (0)
New Directions for LHC - Run 2 and Beyond 18 June 2018, Lecture hall	52 (2)
Vertex algebras, factorization algebras and applications 14-21 July 2018, Lecture hall	47 (18)
RISTEX Workshop "An analysis of the factors that influence women and girls to pursue physics and mathematics" 10 August 2018, National Graduate Institute for Policy Studies	10 (0)
7th Hyper-Kamiokande Proto-Collaboration Meeting 9-13 September 2018, Lecture hall	80 (73)
IGM2018: Revealing Cosmology and Reionization History with the Intergalactic Medium 18-22 September 2018, Lecture hall	110 (74)
Beyond the BSM (The 4th Kavli IPMU -Durham IPPP -KEK -KIAS workshop) 1-4 October 2018, Hotel Tenbo, Gunma	49 (24)
Flavor Physics Workshop 2018 30 October - 2 November 2018, Lecture hall	64 (1)
Noncommutative deformations and moduli spaces 19-23 November 2018, Lecture hall	40 (17)
Stellar Archaeology as a Time Machine to the First Stars 3-7 December 2018, Lecture hall	86 (56)
Berkeley Week 8-11 January 2019, Lecture hall	38 (14)
8th Hyper-Kamiokande Proto-Collaboration Meeting 27 January -1 February 2019, Lecture hall	102 (53)
Representation theory, gauge theory and integrable systems 4-8 February 2019, Lecture hall	72 (21)
Visions for table-top experiments on dark matter 26-27 February 2019, Lecture hall	64 (10)
Extremely Big Eyes on the Early Universe 25-29 March 2019, Lecture hall	86 (52)

8 CONFERENCE PRESENTATIONS AND SEMINAR TALKS

Invited talks given by the Kavli IPMU researchers (Selected 10 of 171)

Date	Presenter	Presentation title	Conference name
May 12, 2018	Hirosi Ooguri	How to Quantize Gravity	Feynman Centennial Symposium
Jun. 11, 2018	Gabi Zafrir	D-type Conformal Matter and SU/USp Quivers	VIII Workshop on Geometric Correspondences of Gauge Theories
Jul. 4, 2018	Serguey Petcov	Neutrino Theory (Including Leptogenesis)	International Conference of High Energy Physics (ICHEP 2018)
Aug. 5, 2018	Masahiro Takada	Cosmology with Subaru Hyper Suprime-Cam imaging survey	Recontres du Vietnam "Windows on the Universe"
Aug. 18, 2018	Hiraku Nakajima	3d N=4 QFT and ring objects on the affine Grassmannian	String-Math 2018
Aug. 27, 2018	Shigeki Matsumoto	Dark Matter Search at 240-250GeV Lepton Colliders	COSMO 2018
Sep. 14, 2018	Mikhail Kapranov	Perverse schobers and semi-orthogonal decompositions	Vlkadimir Voevodsky Memorial Conference
Sep. 15, 2018	Tom Melia	Lovely phase space for good vibrations	PRL 60th anniversary symposium
Jan. 25, 2019	Khee-Gan Lee	Lyman-Alpha Forest Tomography: Mapping the Shadows of the Cosmic Web at High Noon	JSPS San Francisco Office 15th Anniversary Symposium
Mar. 2, 2019	Hitoshi Murayama	Swampland viewed from bottom up	Accelerating Universe in the Dark

9 OUTREACH AND PUBLIC RELATIONS

TITLE	DATE	VENUE	number of participants
18th Kavli IPMU-ICRR Joint Public Lecture “Exploring Particles, Describing the Universe with Particles”	Apr. 14, 2018	Amuser Kashiwa, Chiba	333
Kavli IPMU Public Lecture "Universe X World"	Jun. 10, 2018	Miraikan, Tokyo	215
Kavli IPMU, IRCN joint seminar "Science and Metaphysics"	Jun. 11, 2018	Hongo Campus, The Univ. of Tokyo	60
"Gravitational Waves and the Dark Ingredients of the Universe"	Jun. 17, 2018	Koshiba Hall, The Univ. of Tokyo	196
Science Cafe 2018 "Universe"	Jul. 8, 2018	Tamarokuto Science Center, Tokyo	30
Learning and Creating Physics- From High School to the Forefront Research of the Universe	Jul. 29, 2018	Hongo Campus, The Univ. of Tokyo	51
Booth at the 2018 Super Science High School Student Fair	Aug. 8-9, 2018	Kobe International Exhibition Hall, Hyogo	800
Science Cafe 2018 "Universe"	Sep. 29, 2018	Tamarokuto Science Center, Tokyo	29
Open Campus Kashiwa 2018	Oct. 26-27, 2018	Kashiwa Campus, The Univ. of Tokyo	2,905
Kavli IPMU/ICRR joint public lecture - "Particles, Celestial Events, or the World of Mathematics"	Nov. 11, 2018	Yasuda Auditorium, The Univ. of Tokyo	282
Actually I Really Love Physics! –Career Paths of Female Physics Graduates	Nov. 17, 2018	Kavli IPMU	13
Kavli IPMU High School Student Event "Meet the Scientists!"	Dec. 4, 2018	Kashiwa Library, The Univ. of Tokyo, Chiba	34
WPI 7th Science Symposium	Dec. 27, 2018	Toyota Auditorium, Nagoya Univ., Aichi	820
Kavli IPMU/ELSI/IRCN Joint Public Lecture: "A Question of Origins"	Jan. 20, 2019	Miraikan, Tokyo	226
AAAS 2019 Annual Meeting	Feb. 14-17, 2019	Marriot Wardman Park, Washington DC, USA	260

Kavli IPMU
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