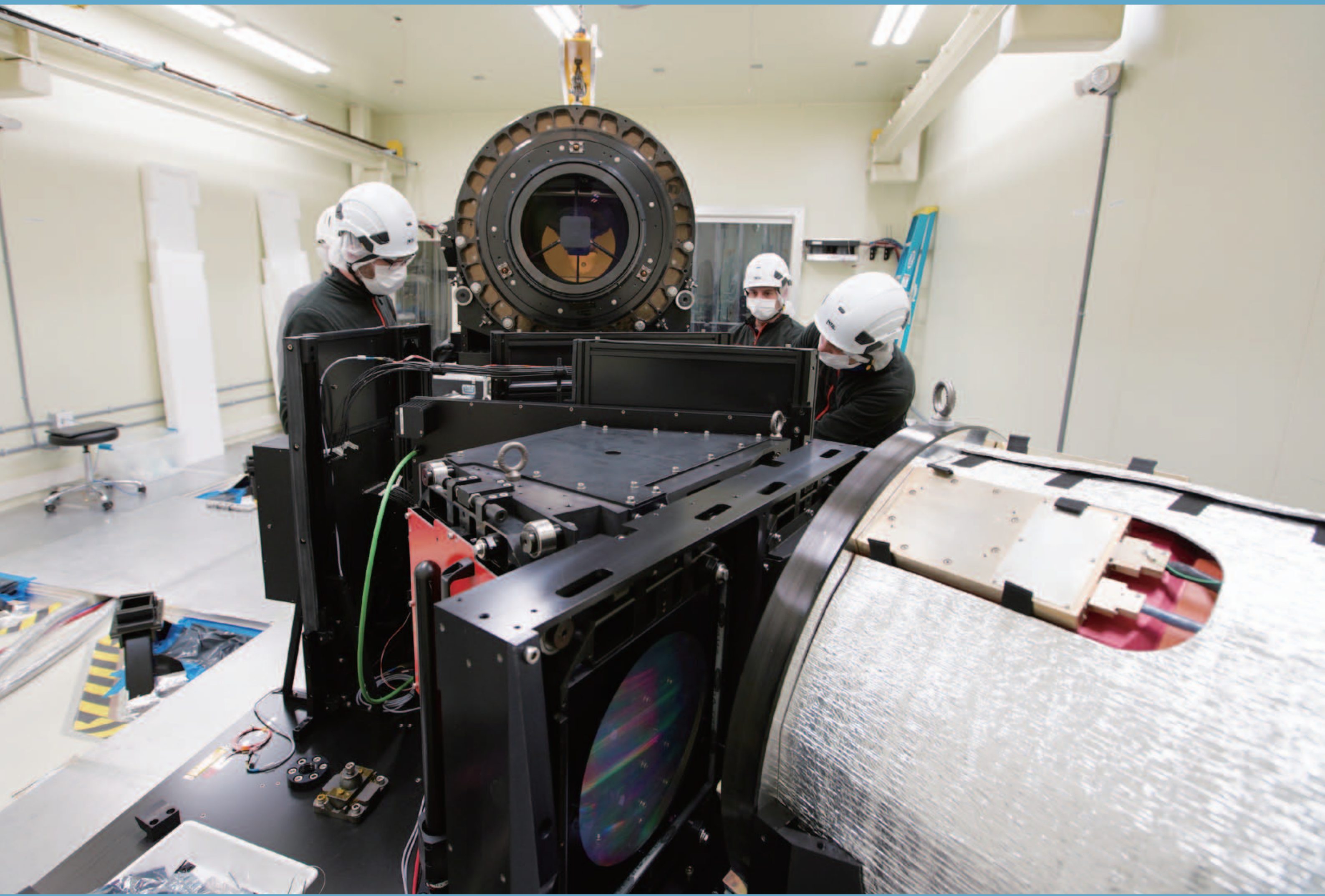


April 2019–March 2020

Kavli IPMU

ANNUAL REPORT 2019

THE UNIVERSITY OF TOKYO

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

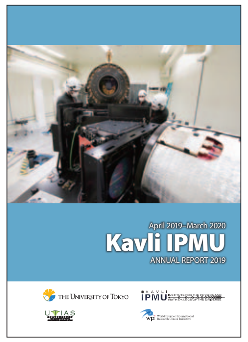
UTIAS 東京大学国際高等研究所 THE UNIVERSITY OF TOKYO INSTITUTES FOR ADVANCED STUDY

wpi World Premier International Research Center Initiative

KAVLI IPMU

Editors: Tomiyoshi Haruyama (Chair), Chiaki Hikage, Misao Sasaki, Junichi Kanzaki
Editing Staff: Shoko Ichikawa
Kavli Institute for the Physics and Mathematics of the Universe
UTIAS, The University of Tokyo
5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8583, Japan
Tel: +81-4-7136-4940 Fax: +81-4-7136-4941
https://www.ipmu.jp/

CONTENTS



On the cover:
The PFS first spectrograph module under integration inside the dedicated clean room at the Subaru Telescope observatory on Maunakea. The photograph shows the process of mounting one of the two visible cameras on the optical bench (Credit: PFS project).

FOREWORD

Hirosi Ooguri
Director

I hope this will find you safe and healthy during this difficult time. The COVID-19 pandemic has been posing challenges to every aspect of operations of our institute. I am grateful to our staff members for their dedicated services and for their support to our scientists. They have done exceptional work under the circumstance where none of them were trained for. This annual report covers the period from April 2019 to March 2020, which ended at the time when the pandemic started to impact our operations seriously. We will report on our activities in the time of the pandemic in our annual report next year.

Kavli IPMU's long term strategic planning exercise was completed in August 2019 and its recommendations were reported to me. The planning report identified astrophysics surveys, cosmic microwave background (CMB) experiments, and Kamioka underground experiments as our three priority areas. The report also recommended a couple of new initiatives, which we will explore in coming years. These recommendations will guide us in the coming years, when we make a transition from an institute with a fixed-term funding from the WPI program to a permanent institute with stable funding.

In our astrophysics survey projects, wealth of data coming from the Hyper Suprime-Cam (HSC) at the Subaru Telescope is providing new insights into our universe. New limits on primordial black holes from HSC data in Section 5.4, and transient survey at HSC is discussed in Section 5.10. Construction of the Prime Focus Spectrograph (PFS) is in progress, as reported in Section 5.7.

Construction of Hyper-Kamiokande started in April, 2019. The Super-Kamiokande Gadolinium Project is on schedule, and we expect the first detection of diffuse neutrino background detection in a few years. Section 5.1 discusses progress in the T2K experiment.

In CMB experiments, we are excited that ISAS/JAXA approved the launch of the LiteBIRD satellite to test the cosmic inflation.

Belle II experiment has started and is opening a new window to physics beyond the Standard Model of Particle Physics, as described in Section 5.2.

Interdisciplinary research activities are also thriving at the Kavli IPMU, including collaborations between string theory and condensed matter physics as described in Section 5.6 and between mathematics and string theory as described in Section 5.8.

In my inaugural address as the Director of the Kavli IPMU in October 2018, I stated my commitment to provide an inclusive and supportive environment to the diverse group of people in our community. To realize our mission – solving the most fundamental questions about our Universe – it is essential that all of us treat each other with respect, maintain our professional working environment free of harassment, challenge our preconceptions, and educate ourselves on our own biases, so that everyone can bring out the best in themselves. Since then, I have introduced several initiatives to improve our diversity at the Kavli IPMU. We are also conducting scientific research on gender gap at STEM programs, as described in Section 5.11.

Writing this preface reminded me of the wonderful days when our building was bustling with scientists and administrative staffs working together to advance fundamental sciences. During the COVID-19 pandemic, our community has not only persevered, but excelled, and we are learning new ways to communicate and collaborate. I am certain that we will come out better and stronger.

1 INTRODUCTION

FY2019 is the third 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 Hyper Suprime-Cam (HSC) survey. In 2019, they released a catalog of 1800 supernovae detected by the first HSC transient survey and developed a deep neural network that automatically classifies the detected supernovae into multiple types. Another science project is mass density reconstruction through weak gravitational lensing effect. They have applied a generative adversarial network to HSC16A data and successfully reduce the noise. They aim at performing cosmological parameter inference using the denoised mass maps. They have been awarded the highest score A+ in a final review of the CREST project and will receive further financial support as a JST AIP program in 2020-2022.

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

In vivo and three-dimensional gamma-ray imaging, which enables us to visualize and measure cell activity and biological processes, provides improved and novel methods for the diagnosis and treatment of cancer in the pre-clinical phase. A team led by T. Takahashi performs interdisciplinary activities centered around the development of an advanced hard X-ray and gamma-ray detector. In 2019, they have performed various experiments at the Exploratory Oncology Research and Clinical Trial Center (EPOC) at the National Cancer Center. They have established a method to resolve lines from multiple isotopes using an algorithm developed in X-ray astronomy and thereby individual radiation doses can be accurately quantified in phantom experiments. They have also performed experiments using a very promising radionuclide, ^{211}At, which is used as a new alpha-ray cancer therapy and for cancer diagnostics. They have developed a new slat type collimator made of Tungsten by using 3D printing technology, which covers a large area of ~10 cm^2 with high efficiency.

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

Our mathematicians have advanced a new framework for geometric thinking provided by noncommutative and derived geometry. In particular, Y. Toda used derived moduli spaces to refine the Donaldson-Thomas invariants to certain monoidal categories, thus categorifying several important duality (wall-crossing) phenomena. His work uses earlier work of F. Sala and M. Porta on Cohomological Hall algebras (COHAs) which have become an important tool in the study of wall-crossing. W. Donovan, with M. Wemyss, used noncommutative deformations to describe the derived monodromy on the stringy Kahler moduli space of a flopping curve in a 3-fold. M. Kapranov, with V. Schechtman, related shuffle algebras, appearing in many descriptions of COHAs and wall-crossing, with the Goresky-MacPherson procedure of intersection cohomology extensions of local systems.

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

- The HSC team explored how cosmic large-scale structures evolve as a function of cosmic time using the first two years data and determined the parameter characterizing the clumpiness of the Universe today with the world's highest-level precision. The Prime Focus Spectrograph (PFS) team achieved important milestones for the project including a successful engineering trial of the metrology camera and re-assembling the first spectrograph modules shipped to Hawaii Observatory.
- The Kavli IPMU is directly involved in the analysis of T2K data with M. Hartz serving as co-Analysis Coordinator and our former project researcher B. Quilain as the leader of the Japanese oscillation analysis effort. T2K for the first time measured the phase that governs CP violation with enough significance and the result has been published in Nature Journal.
- Cosmic microwave background (CMB) experiments have been actively led by the Kavli IPMU team. POLARBEAR team released the science papers including the measurement of the large angular scale B-mode to aim the signal band of the primordial B-mode. LiteBIRD has been selected as the JAXA/ISAS large class second strategic satellite project and the team accelerates the design study.
- Belle II has finally launched a decade-long operation of collecting e^+-e^- collision data using the silicon vertex detector produced in the Kavli IPMU. The first physics paper about searches for a new gauge boson Z' has been accepted for publication in Physical Review Letters.
- EGADS team led by M. Vagins finished preparations of the Super-Kamiokande detector for the addition of gadolinium (Gd), which is expected to start in April 2020.

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. The total number of Principal Investigators (PIs) is 28, among which the number of on-site PIs are 11. All of our 28 PIs (7 non-Japanese: 25%) are world-leading scientists and ensure an international environment for research activities at the Kavli IPMU. H. Ooguri was conferred the 2019 Medal of Honor with Purple Ribbon, which is one of the most prestigious awards in Japan, by the Emperor of Japan for his contribution to the theory of elementary particles. This is an honor following the 2018 Hamburg Prize for Theoretical Physics, which was the first year the prize covered all areas of theoretical physics. H. Murayama has been appointed as a University Professor of UTokyo and also Hamamatsu Professor from FY 2019. T. Takahashi is a leading astro-particle physicist working in the H.E.S.S. collaboration, which for the first time detected a gamma-ray burst in very-high-energy gamma light and also identified very high-energy gamma ray region in Crab Nebula in 2019. He has been developing hard X-ray and gamma ray detectors in satellite and rocket experiments and started a new collaboration with JAXA/ISAS and Keio University School of Medicine to apply these detectors to biomedical research. The collaboration completed a successful clinical trial using a newly-developed imaging diagnosis device. On-site PIs in mathematics, M. Kapranov, Y. Toda, and H. Nakajima, are distinguished mathematicians and conduct research as leaders in mathematical studies in algebraic variety, derived category, and gauge theories. M. Vagins has led the EGADS project, and the refurbishment work of the SK detector was successfully completed in January 2019, to apply the concept (SK-Gd). The SK resumed data taking with pure water, and is expecting to collect the world's first diffuse supernova neutrinos before 2020. M. Takada is the leader of the HSC project, where fruitful scientific results continue to come out following the publication of the Publications of the Astronomical Society of Japan with 40 papers. Other faculty members also play leading roles in each field and include PIs of big international projects such as Belle II, T2K, KamLAND-Zen, PFS, 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

A group of Kavli IPMU administrative staff members has been awarded the UTokyo's Special Prize for Business Transformation from the President six times: 2008, 2013, 2015, 2016, 2017 and 2018. The 2008 achievement for developing a "website 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. In 2018, the Kavli IPMU team developed and manages 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.

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 the University of 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. So far, we have accepted eight students and three have defended their Ph.D. theses. 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, have been 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. One of members visited the Hamburg University to discuss the proposal.

8. Enlarging the force for outreach to young students, by organizing workshops for scientists and high-school teachers

In FY 2019, the Kavli IPMU kept collaborating with CoREF (Consortium for Renovating Education of the Future) to experience the latest advances in scientific research for high-school students. 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 and graduate student Y. Katagiri took part in. On August 5, 2019, high school students were invited to try learning about the universe. Another activity to stimulate young female undergraduate and graduate students was carried out under the program "Yes we love Physics-career path for female students majored Physics" on November 30, 2019. The Kavli IPMU has co-hosted this science career event together with the Institute for Solid State Physics and the Institute for Cosmic Ray Research in UTokyo.

9. Attaining sufficient stability of the organization so that we can bring our research objectives beyond the WPI funding

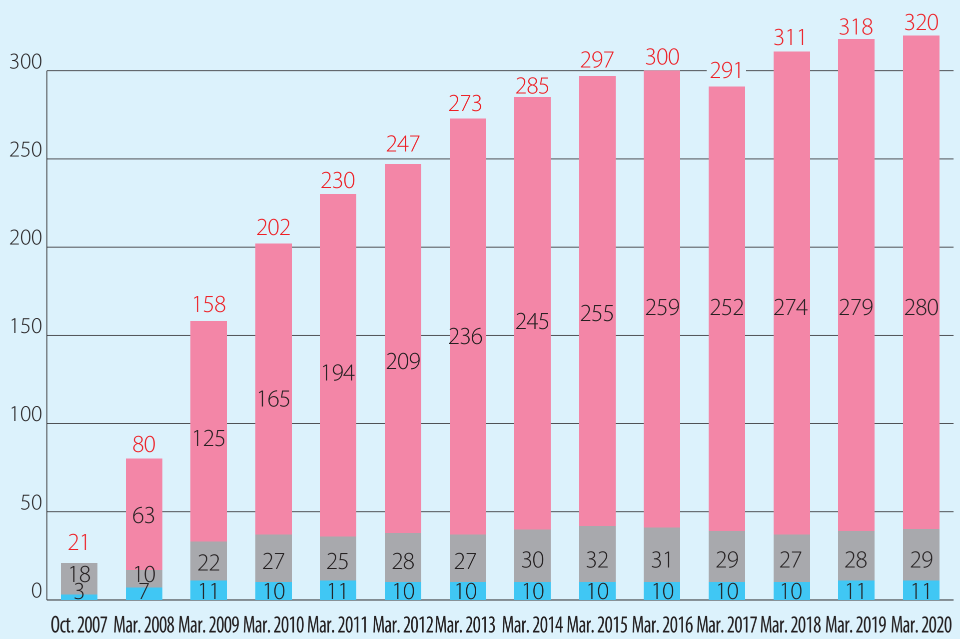
The positioning of the Kavli IPMU within UTokyo is quite clear. President Gonokami's 'Vision 2020' emphasizes the importance of "Expansion and Establishment of Internationally-renowned Bases for Research". An action to realize this vision 'Action 2020' has been set up to "establish and expand upon internationally-renowned 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 funding for the second year has been secured. This budget request is crucial to sustain the Kavli IPMU permanently, and we will make the request for the final year.

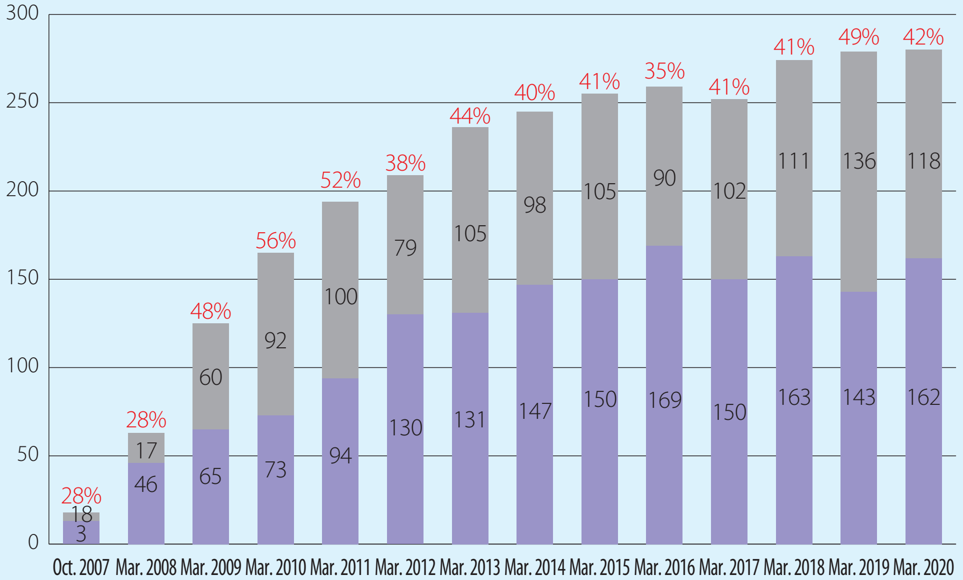
In the following pages, various statistics are shown in plots: the lists of seminars & conferences, publications, and conference talks can be found in Kavli IPMU webpage, https://www.ipmu.jp/en/research-activities on "Research Activities"

STAFF



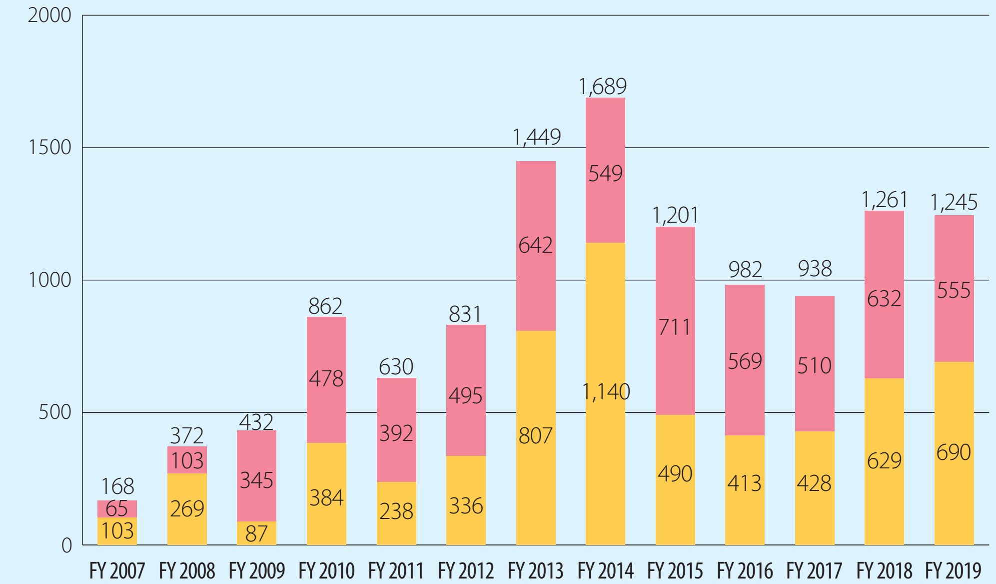
	Oct. 2007	Mar. 2008	Mar. 2009	Mar. 2010	Mar. 2011	Mar. 2012	Mar. 2013	Mar. 2014	Mar. 2015	Mar. 2016	Mar. 2017	Mar. 2018	Mar. 2019	Mar. 2020
Researchers	18	63	125	165	194	209	236	245	255	259	252	274	279	280
Research Support Staffs	0	10	22	27	25	28	27	30	32	31	29	27	28	29
Administrative staffs	3	7	11	10	11	10	10	10	10	10	10	10	11	11
Total	21	80	158	202	230	247	273	285	297	300	291	311	318	320

RESEARCHERS



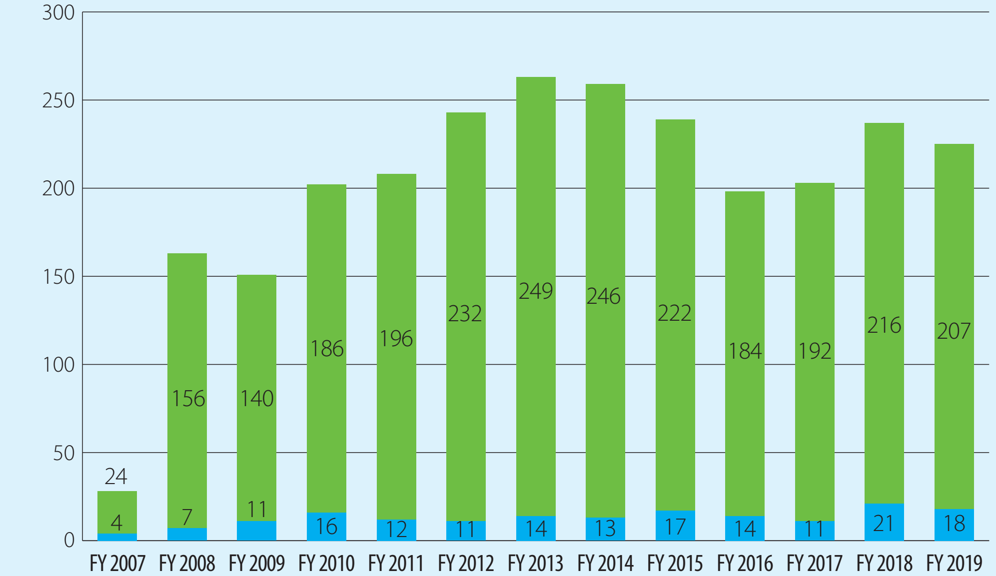
	Oct. 2007	Mar. 2008	Mar. 2009	Mar. 2010	Mar. 2011	Mar. 2012	Mar. 2013	Mar. 2014	Mar. 2015	Mar. 2016	Mar. 2017	Mar. 2018	Mar. 2019	Mar. 2020
Overseas	5	17	60	92	100	79	105	98	105	90	102	111	136	118
Domestic	13	46	65	73	94	130	131	147	150	169	150	163	143	162
% of Overseas	28%	28%	48%	56%	52%	38%	44%	40%	41%	35%	41%	41%	49%	42%
% of Female	0%	2%	5%	6%	5%	2%	5%	5%	6%	4%	6%	8%	9%	10%

RESEARCH ACTIVITIES



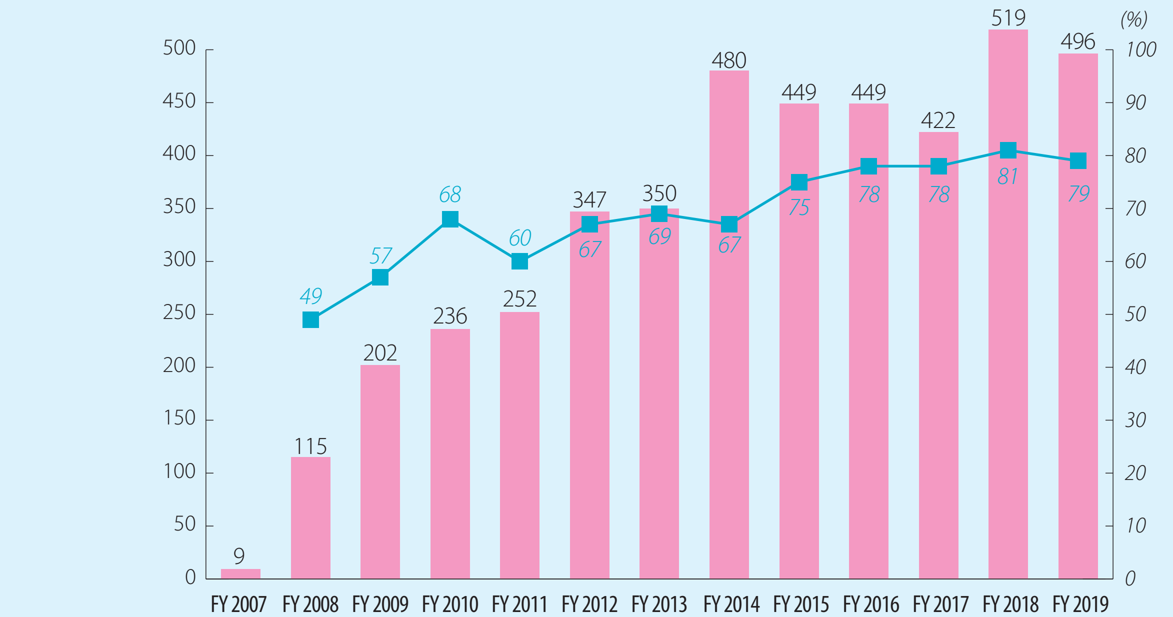
	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
Visitors (Overseas)	65	103	345	478	392	495	642	549	711	569	510	632	555
Visitors (Domestic)	103	269	87	384	238	336	807	1,140	490	413	428	629	690
Visitors (Total)	168	372	432	862	630	831	1,449	1,689	1,201	982	938	1,261	1,245

SEMINARS & CONFERENCES



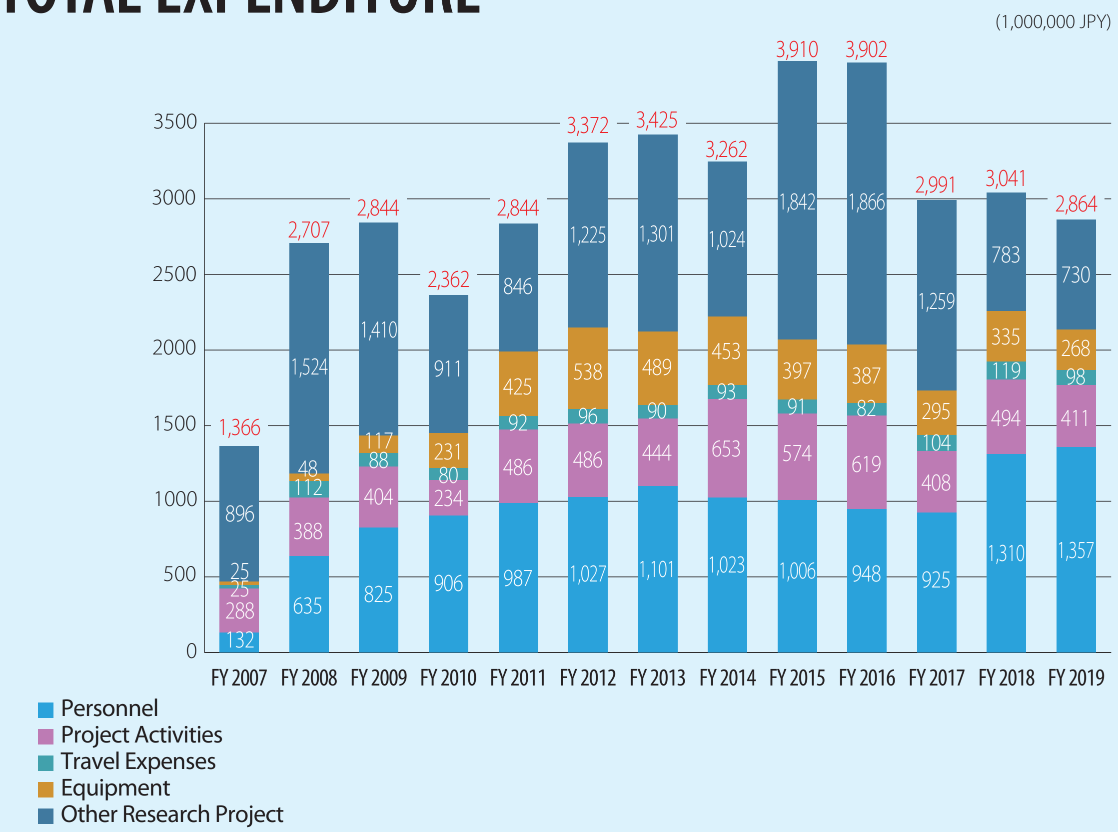
	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
Seminars	24	156	140	186	196	232	249	246	222	184	192	216	207
Conferences	4	7	11	16	12	11	14	13	17	14	11	21	18

PUBLICATIONS

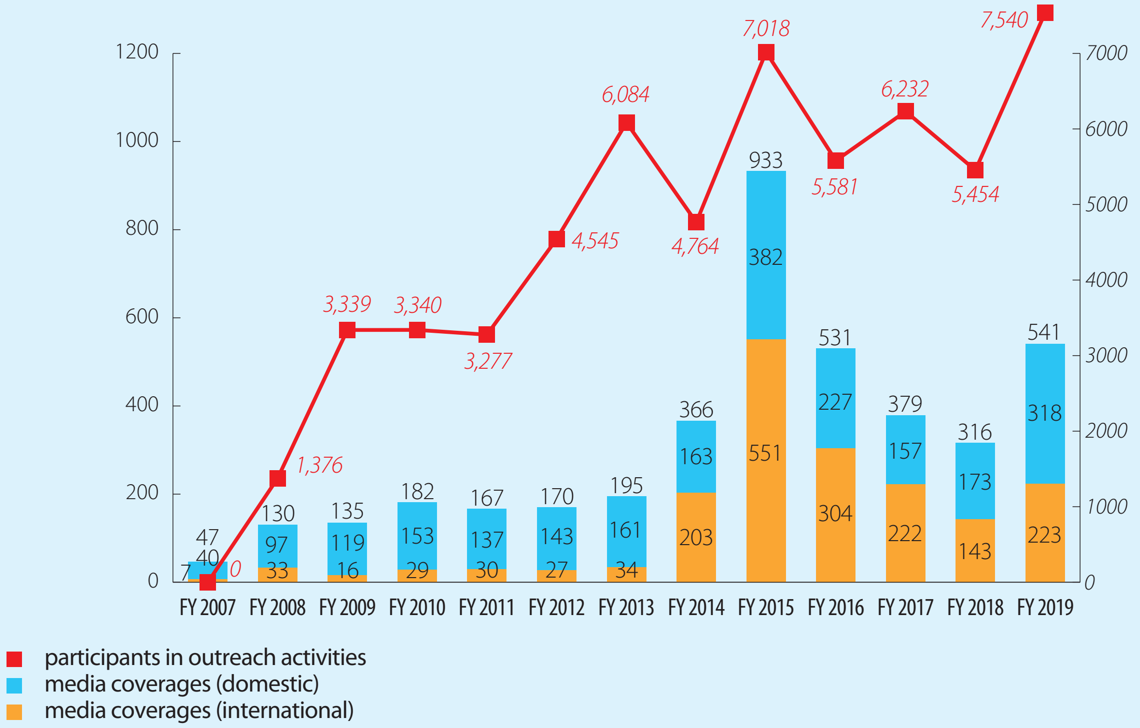


	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
Publications	9	115	202	236	252	347	350	480	449	449	422	519	496
% of international collaboration	49%	57%	68%	60%	67%	69%	67%	75%	78%	78%	81%	79%	

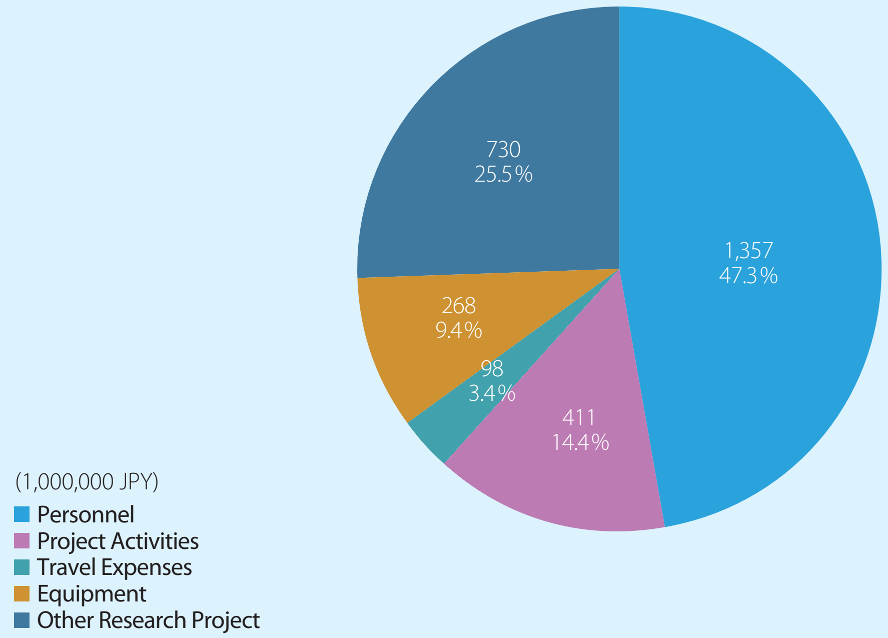
TOTAL EXPENDITURE



MEDIA COVERAGES AND OUTREACH ACTIVITIES



BREAKDOWN OF FY 2019 TOTAL EXPENDITURE



2 NEWS & EVENTS April 2019-March 2020

APRIL
- >> Hitoshi Murayama named new Hamamatsu Professor
- >> Subaru Telescope helps determine that dark matter is not made up of tiny primordial black holes
- >> Prospects of Neutrino Physics
- >> MEXT Deputy Minister Yoshio Yamawaki visits Kavli IPMU
- >> 20th Kavli IPMU/ICRR joint public lecture "Think about the beginning of the universe"

MAY
- >> Hyper-Kamiokande Coordination Meeting
- >> Quantum Entanglement in Cosmology
- >> Explosions of universe's first stars spewed powerful jets
- >> Subaru Telescope captures 1800 exploding stars

JUNE
- >> 43rd Johns Hopkins Workshop
- >> 6th Galaxy Evolution Workshop
- >> Researchers find quantum gravity has no symmetry

JULY
- >> Cryogenics and applied superconducting technologies to probe the physics of early universe
- >> Former and current members of Japan's National Diet visit Kavli IPMU
- >> Toward new frontiers : Encounter and synergy of state-of-the-art
- >> Under development medical camera could help cut time and cost of procedures

AUGUST
- >> Booth at the 2019 Super Science High School Student Fair
- >> AI learns to model our Universe

SEPTEMBER
- >> 9th Hyper-Kamiokande Proto-Collaboration Meeting
- >> 15th exhibition at Kashiwa Library "Beautiful Mathematics"
- >> WPI Site visit
- >> Science Cafe "Universe 2019"

OCTOBER
- >> The cosmos at high energies: exploring extreme physics through novel instrumentation
- >> Parental gender attitudes associated with Japanese girls' reduced university participation
- >> Open Campus Kashiwa 2019
- >> Open Campus Kashiwa 2019 public lecture: "Who is the Man from the 9 Dimensions"

NOVEMBER
- >> Hirosi Ooguri to receive Medal of Honor from the Emperor of Japan
- >> Researchers identify very high-energy gamma ray region in Crab Nebula
- >> Subaru Telescope 20th Anniversary Conference
- >> IPMU Annual Report 2018 released
- >> First detection of gamma-ray burst afterglow in very-high-energy gamma light
- >> "Actually I Really Love Physics!"–Career Paths of Female Physics Graduates

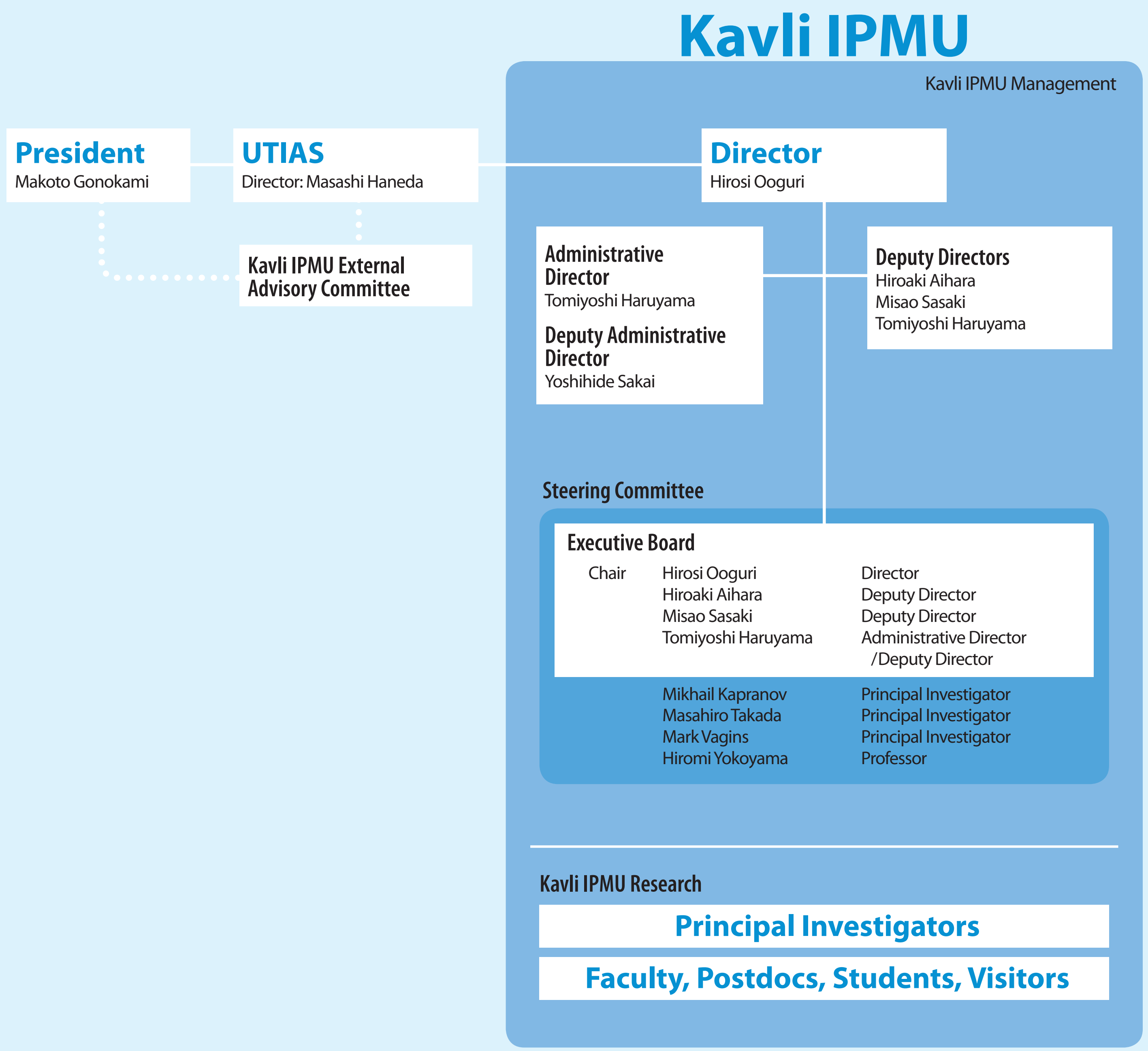
DECEMBER
- >> Focus Week on Primordial Black Holes
- >> Science and Everyday Life - Series vol.11 Symmetry
- >> 21st Kavli IPMU/ICRR joint public lecture "The Forefront of Universe Exploration"
- >> 24th Takagi Lectures
- >> MEXT Minister Koichi Hagiuda visits Kavli IPMU

JANUARY
- >> Expansion rate of the Universe calculated from gravitational lensing technique
- >> 8th WPI Science Symposium "The Power of Mathematics: Bridging Worlds Together"
- >> 14th Kavli Asian Winter School on Strings, Particles and Cosmology
- >> East Asia Core Doctoral Forum in Mathematics 2020
- >> Berkeley Week
- >> Astrophysics of Gravitational Wave Sources in LIGO/Virgo Third, Observational Run (O3)
- >> Integral Geometry, Representation Theory and Complex Analysis

FEBRUARY
- >> Researchers find way to show how the tiniest particles in our Universe saved us from complete annihilation
- >> Artificial Intelligence tool developed to predict the structure of the Universe
- >> Hyper K Proto-collaboration Meeting
- >> Kavli IPMU/ELSI/IRCN Joint Public Lecture "A Question of Origins"
- >> Cosmic Acceleration

MARCH
- >> Researchers find string theory link in a class of complex numbers
- >> Successful engineering trial of Metrology Camera at Subaru Telescope
- >> Electron-capture supernova: electron-eating neon causes star collapse

3 ORGANIZATION



The Kavli IPMU has a rather unique organization. While research is conducted in a flat-structure 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.

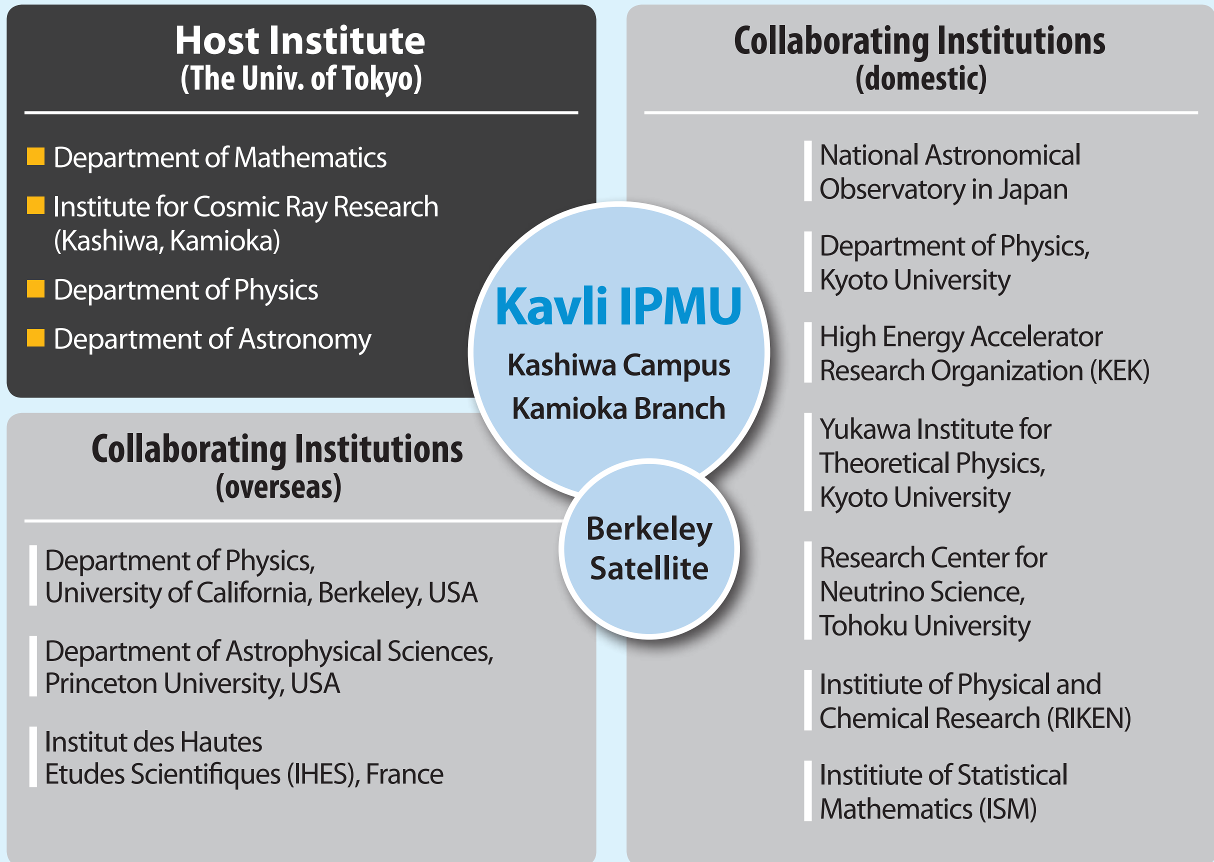
The External Advisory Committee Members (March 2020)

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

Organization

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
The University of Bonn

4 STAFF

Director

Hirosi Ooguri, Mathematical Physics

Deputy Directors

Hiroaki Aihara, High Energy Physics
Tomiyoshi Haruyama, High Energy Physics
Misao Sasaki, Cosmology

Principal Investigators

Hiroaki Aihara, (U Tokyo), High Energy Physics
Alexey Bondal, (Steklov Math. Inst.), Mathematics
Kentaro Hori, String Theory
Kunio Inoue, (Tohoku U), Neutrino Physics
Takaaki Kajita, (U Tokyo, ICRR), Neutrino Physics
Mikhail Kapranov, Mathematics
Stavros Katsanevas, (European Gravitational Observatory), Experimental Physics
Masahiro Kawasaki, (U Tokyo, ICRR), Cosmology
Young-Kee Kim, (U Chicago), High Energy Physics
Toshiyuki Kobayashi, (U Tokyo, Math Sci), Mathematics
Toshitake Kohno, (Meiji U), Mathematics
Eiichiro Komatsu, (MPI for Astrophysics), Cosmology
Kai Uwe Martens, Experimental Physics
Shigeki Matsumoto, Cosmology
Shigetaka Moriyama, (U Tokyo, ICRR), Neutrino Physics
Hitoshi Murayama, (UC Berkeley), Particle Theory
Masayuki Nakahata, (U Tokyo, ICRR), Astroparticle Physics
Hiraku Nakajima, Mathematics
Mihoko Nojiri, (KEK), Particle Theory
Yasunori Nomura, (UC Berkeley), Particle Theory
Hirosi Ooguri, (CALTECH), Mathematical Physics
David Spergel, (Princeton U), Cosmology
Naoshi Sugiyama, (Nagoya U), Cosmology
Masahiro Takada, Cosmology
Tadayuki Takahashi, Experimental Physics
Yukinobu Toda, Mathematics
Mark Robert Vagins, Astroparticle Physics
Naoki Yoshida, (U Tokyo), Astronomy

Faculty Members

Tomoyuki Abe, Mathematics
Alexey Bondal, (Steklov Math. Inst.), Mathematics (2019/8/1-2020/2/15)
Mark Patrick Hartz, Neutrino Physics
Tomiyoshi Haruyama, High Energy Physics
Simeon John Hellerman, String Theory
Takeo Higuchi, High Energy Physics
Chiaki Hikage, Cosmology
Kentaro Hori, String Theory
Yukari Ito, Mathematics
Mikhail Kapranov, Mathematics
Nobuhiko Katayama, High Energy Physics
Alexandre Kozlov, Neutrino Physics (till 2019/6/30)
Khee-Gan Lee, Astronomy
Kai Uwe Martens, Experimental Physics
Shigeki Matsumoto, Cosmology
Tomotake Matsumura, Experimental Physics
Thomas Edward Melia, Theoretical Physics
Todor Eliseev Milanov, Mathematics
Hitoshi Murayama, (UC Berkeley), Particle Theory
Hiraku Nakajima, Mathematics
Yasunori Nomura, (UC Berkeley), Particle Theory (2019/5/18-8/20)
Hirosi Ooguri, (CALTECH), Mathematical Physics
Tadashi Orita, Experimental Physics
Misao Sasaki, Cosmology
Satoshi Shirai, Particle Theory
John David Silverman, Astronomy
Hajime Sugai, Experimental Physics
Nao Suzuki, Astronomy
Yoichiro Suzuki, Astroparticle Physics
Yuji Tachikawa, Particle Theory
Masahiro Takada, Cosmology
Tadayuki Takahashi, Experimental Physics
Shinichiro Takeda, Experimental Physics
Naoyuki Tamura, Astronomy
Yukinobu Toda, Mathematics
Mark Robert Vagins, Astroparticle Physics
Taizan Watari, Theoretical Physics
Atsushi Yagishita, Experimental Physics
Masahito Yamazaki, String Theory
Naoki Yasuda, Astronomy
Hiromi Yokoyama, Science and Society
Naoki Yoshida, (U Tokyo), Astronomy
Yutaka Yoshida, String Theory

Postdoctoral Researchers

Rodrigo Alonso De Pablo, Particle Theory (till 2019/12/31)
Metin Ata, Cosmology
Neil David Barrie, Particle Theory
Marco Bertolini, Particle Theory (till 2019/8/31)
Tobias Binder, Theoretical Physics
Yalong Cao, Mathematics
Pietro Caradonna, Experimental Physics
Dmitry Chernyak, Experimental Physics (till 2019/6/21)
Peter Jonathan Cox, Particle Theory (till 2019/8/31)
Thomas Rafael Czank, Experimental Physics
Anton Reyes De la Fuente, String Theory (from 2019/9/16)
Zhiyuan Ding, Mathematics (from 2019/9/1)
Matthew Dodelson, String Theory (till 2020/1/31)
Anne Laure Marie Ducou, Cosmology (till 2019/4/30)
Martin Felix Fluder, String Theory (till 2019/8/31)
Dmitrii Galakhov, String Theory (from 2019/9/1)
Shao-Feng Ge, Theoretical Physics (till 2019/9/30)
Ryuichiro Hada, Cosmology
Seyed Morteza Hosseini, String Theory
Chang-Tse Hsieh, Theoretical Physics
Yuko Ikkatai, Science and Society
Jian Jiang, Astronomy
Changwoo Joo, High Energy Physics (till 2019/8/31)
Daisuke Kaneko, High Energy Physics
Miho Katsuragawa, Experimental Physics
Lalitwadee Kawinwanichakij, Astronomy
Ilya Khrykin, Astronomy (from 2019/6/16)
Fabian Koehlinger, Cosmology (till 2019/8/15)
Robin Rinze Kooistra, Astronomy
Naoki Koseki, Mathematics (2019/4/1-9/30)
Tatsuki Kuwagaki, Mathematics
Chiara La Licata, Experimental Physics
Ting-Wen Lan, Astronomy (till 2020/2/29)
Chervin Laporte, Astronomy (from 2020/1/16)
Shing Chi Leung, Astronomy (till 2019/9/30)
Yin Li, Cosmology (2019/4/1-9/29)
Hsueh-Yung Lin, Mathematics (from 2019/9/1)
Wentao Luo, Astronomy
Oscar Macias, Astronomy
Andrew William Macpherson, Mathematics (till 2020/2/29)
Ryu Makiya, Astronomy (till 2019/10/31)
Frederick Takayuki Matsuda, Experimental Physics
Hideaki Matsumura, Experimental Physics (till 2019/6/30)
Tomoko Morii, High Energy Physics
Yuki Moritani, Astronomy
Dinakar Muthiah, Mathematics
Yusuke Nakajima, Mathematics
Keigo Nakamura, Neutrino Physics
Taira Oogi, Astronomy
Shusuke Otabe, Mathematics
Hyunbae Park, Cosmology
Youngsoo Park, Cosmology
Shi Pi, Astronomy

Anna Puskas, Mathematics (till 2020/1/19)
Benjamin Pascal Jean-Marie Guillaume Quilain, Neutrino Physics (till 2019/12/31)
Alexis Roquefeuil, Mathematics (from 2019/10/2)
Ipsita Saha, Particle Theory
Yuki Sakurai, Experimental Physics
Francesco Sala, Mathematics (till 2019/11/30)
Yoshiki Sato, Particle Theory (2019/4/1-9/30)
Kallol Sen, Theoretical Physics (till 2019/9/10)
Yota Shamoto, Mathematics
Jingjing Shi, Cosmology (from 2019/11/16)
Yevgeny Stadnik, Theoretical Physics (from 2019/8/1)
David Vincent Stark, Astronomy (till 2019/8/31)
Samantha Lynn Stever, Astronomy
Tomomi Sunayama, Cosmology
Ichiro Takahashi, Astronomy
Satoru Takakura, Astronomy
Po-Yen Tseng, Particle Theory (till 2019/8/31)
Izumi Umeda, Medical Application of Gamma-ray Imaging
Valeri Vardanyan, Cosmology (from 2019/11/2)
Wenting Wang, Astronomy (till 2019/8/31)
Matthias Weissenbacher, String Theory (till 2019/10/15)
John Welliaveetil, Mathematics
Kenneth Christopher Wong, Astronomy
Kiyoto Yabe, Astronomy
Ryo Yamagishi, Mathematics
Gabi Zafrir, Particle Theory (till 2019/10/31)

Joint Appointments

Sergey Blinnikov, (ITEP), Astronomy (2019/9/18-11/7)
Mark Patrick Hartz, (TRIUMF), Neutrino Physics
Masashi Hazumi, (KEK), High Energy Physics
Alexander Kusenko, (UCLA), Particle Theory (2019/10/9-12/8)
Hitoshi Murayama, (UC Berkeley), Particle Theory
Hirosi Ooguri, (CALTECH), Mathematical Physics
Serguey Todorov Petcov, (SISSA), Particle Theory (2019/4/1-22,9/17-20,11/1-22)
Edwin L Turner, (Princeton U), Astronomy (2019/10/25-11/10)
Naoki Yoshida, (U Tokyo), Astronomy

Affiliate Members

Kou Abe, (U Tokyo, ICRR), Astroparticle Physics
Mina Aganagic, (UC Berkeley), String Theory
Shin'ichiro Ando, (U Amsterdam), Astroparticle Physics
Bruce Berger, (LBNL), Neutrino Physics
Melina Bersten, (CONICET), Astronomy
Sergey Blinnikov, (ITEP), Astronomy
Raphael Bousso, (UC Berkeley), Cosmology
Kevin Allen Bundy, (UC Santa Cruz), Astronomy
Andrew Bunker, (U Oxford), Astronomy
Martin Gilles Bureau, (U Oxford), Astronomy
Scott Huai-Lei Carnahan, (U Tsukuba), Mathematics
Cheng-Wei Chiang, (Natl Taiwan U), Particle Theory
Yuji Chinone, (U Tokyo), Astronomy
Neal K Dalal, (Perimeter Institute), Astronomy
Patrick Decowski, (U Amsterdam/GRAPPA), Neutrino Physics
Jason Detwiler, (U Washington, Seattle), Neutrino Physics
Mamoru Doi, (U Tokyo, IoA), Astronomy
Chris Done, (Durham U), Astronomy
Yuri Efremenko, (U Tennessee), Neutrino Physics
Motoi Endo, (KEK), Particle Theory
Sanshiro Enomoto, (U Washington, Seattle), Neutrino Physics
Andrea Ferrara, (Scuola Normale Superiore di Pisa), Astronomy
Gaston Folatelli, (CONICET), Astronomy
Andreu Font-Ribera, (UCL), Cosmology
Brian Fujikawa, (LBL, Berkeley), Neutrino Physics
Kenji Fukaya, (SCGP), Mathematics
Masataka Fukugita, (U Tokyo), Astronomy
Shao-Feng Ge, (Shanghai Jiao Tong U), Theoretical Physics (from 2019/10/1)
Lawrence J Hall, (UC Berkeley), Particle Theory
Koichi Hamaguchi, (U Tokyo), Particle Theory
Jiaxin Han, (Shanghai Jiao Tong U), Astronomy
Tilman Hartwig, (U Tokyo), Astronomy
Tetsuo Hatsuda, (RIKEN), Nuclear Physics
Yoshinari Hayato, (U Tokyo, ICRR), Neutrino Physics
Karsten Heeger, (Yale U), Neutrino Physics
Katsuki Hiraide, (U Tokyo, ICRR), Astroparticle Physics
Raphael Hirschi, (Keele U), Astronomy
Junji Hisano, (Nagoya U), Particle Theory
Petr Horava, (UC Berkeley), String Theory
Glenn Horton-Smith, (Kansas State U), Neutrino Physics
Shinobu Hosono, (Gakushuin U), Mathematical Physics
Masahiro Ibe, (U Tokyo, ICRR), Particle Theory
Koichi Ichimura, (U Tokyo, ICRR), Astroparticle Physics
Hirokazu Ikeda, (JAXA), Experimental Physics
Motoyasu Ikeda, (U Tokyo, ICRR), High Energy Physics
Shiro Ikeda, (ISM), Mathematics
Yoshiyuki Inoue, (RIKEN), Astronomy
Ken'ichi Izawa, (Tokushima U), Particle Theory
Nicholas Kaiser, (École normale supérieure), Cosmology
Jun Kameda, (U Tokyo, ICRR), Neutrino Physics
Yousuke Kanayama, (RIKEN), Experimental Physics
Amanda Irene Karakas, (Monash U), Astronomy
Masaki Kashiwara, (Kyoto U), Mathematics
Akishi Kato, (U Tokyo, Math Sci), Mathematical Physics
Yasuyuki Kawahigashi, (U Tokyo, Math Sci), Mathematics
Edward T. Kearns, (Boston U), Neutrino Physics
Sergey Ketov, (Tokyo Metropolitan U), High Energy Physics
Nobuhiro Kimura, (U Tokyo, ICRR), High Energy Physics
Anatol N. Kirillov, (Kyoto U), Mathematics
Yasuhiro Kishimoto, (Tohoku U), Neutrino Physics
Ryuichiro Kitano, (KEK), Particle Theory
Chiaki Kobayashi, (CAR, U of Hertfordshire), Astronomy
Kazuyoshi Kobayashi, (U Tokyo, ICRR), Astroparticle Physics
Masayuki Koga, (Tohoku U), Neutrino Physics

Kazunori Kohri, (KEK), Cosmology (from 2019/6/20)
Satoshi Kondo, (Middle East Technical U), Mathematics
Yusuke Koshio, (Okayama U), Neutrino Physics
Akito Kusaka, (U Tokyo), Experimental Physics (from 2019/6/21)
Alexander Kusenko, (UCLA), Particle Theory
Alexie, Solange Leauthaud Harnett, (UC Santa Cruz), Astronomy
Shiu-Hang (Herman) Lee, (Kyoto U), Astronomy
Si Li, (Tsinghua U), Mathematical Physics
Marco Limongi, (INAF), Astronomy
Keiichi Maeda, (Kyoto U), Astronomy
Kazuo Makishima, (U Tokyo), High Energy Physics
Brice Menard, (Johns Hopkins U), Astronomy
Makoto Minowa, (U Tokyo), Experimental Physics
Makoto Miura, (U Tokyo, ICRR), High Energy Physics
Hironao Miyatake, (Nagoya U), High Energy Physics
Hiroshi Mizuma, (RIKEN), Experimental Physics
Anupreeta Sadashiv More, (IUCAA), Astronomy
Surhud Shrikant More, (IUCAA), Astronomy
Takeo Moroi, (U Tokyo), Particle Theory
Tomoki Morokuma, (U Tokyo, IoA), Astronomy
David Robert Morrison, (UC Santa Barbara), Mathematics
Shinji Mukohyama, (Kyoto U), Cosmology
Motohico Mulase, (UC Davis), Mathematics
Kentaro Nagamine, (Osaka U), Astronomy
Yasuhiro Nakajima, (U Tokyo, ICRR), Neutrino Physics
Kengo Nakamura, (Tohoku U), Neutrino Physics
Kenzo Nakamura, (KEK), Neutrino Physics
Tsuyoshi Nakaya, (Kyoto U), High Energy Physics
Kazunori Nakayama, (U Tokyo), Cosmology
Shoei Nakayama, (U Tokyo, ICRR), Neutrino Physics
Yu Nakayama, (Rikkyo U), Theoretical Physics
Takahiro Nishimichi, (Kyoto U), Cosmology (from 2019/10/23)
Ken'ichi Nomoto, (U Tokyo), Astronomy
Hirokazu Odaka, (U Tokyo), High Energy Astrophysics
Hiroshi Ogawa, (Nihon U), Astroparticle Physics (from 2019/6/28)
Masamune Oguri, (U Tokyo), Cosmology
Shinnosuke Okawa, (Osaka U), Mathematics
Kimihiro Okumura, (U Tokyo, ICRR), Neutrino Physics
Teppei Okumura, (Academia Sinica), Cosmology
Yoshiyuki Onuki, (U Tokyo, ICEPP), High Energy Physics
Domenico Orlando, (INFN), String Theory (from 2020/1/21)
Masaki Oshikawa, (U Tokyo, ISSP), Theoretical Physics
Masami Ouchi, (U Tokyo, ICRR), Astronomy
Andrei Pajitnov, (U Nantes), Mathematics
Myeonghun Park, (SEOULTECH), Particle Theory
Serguey Todorov Petcov, (SISSA), Particle Theory
Andreas Piepke, (U Alabama), Neutrino Physics
J. Xavier Prochaska, (UC Santa Cruz), Astronomy
Anna Puskas, (U Queensland), Mathematics (from 2020/1/20)
Robert Michael Quimby, (San Diego State U), Astronomy
Susanne Reffert, (U Bern), String Theory (from 2020/1/21)
Jason Rhodes, (NASA JPL/Caltech), Cosmology
Joshua Ruderman, (New York U), Particle Theory (from 2019/12/13)
Wiphu Rujopakarn, (Chulalongkorn U), Astronomy
Kyoji Saito, (Kyoto U), Mathematics
Ryo Saito, (Yamaguchi U), Astronomy (from 2019/6/18)
Shun Saito, (Missouri U of Sci. and Tech.), Cosmology
Yoshihisa Saito, (Rikkyo U), Mathematics
Yoshio Saito, (U Tokyo, ICRR), High Energy Physics
Hidetaka Sakai, (U Tokyo, Math Sci), Mathematics
Francesco Sala, (U Pisa), Mathematics (from 2020/1/1)
Katsuhiko Sato, (JSPS), Astroparticle Physics
Vadim Schechtman, (U Toulouse III-Paul Sabatier), Mathematics (from 2020/2/15)
Christian Schnell, (SUNY, Stony Brook), Mathematics
Kate Scholberg, (Duke U), Neutrino Physics
Hiroyuki Sekiya, (U Tokyo, ICRR), Neutrino Physics
Masato Shiozawa, (U Tokyo, ICRR), High Energy Physics
Aurora Simionescu, (SRON Netherlands Inst. for Space Research), Astronomy
Fedor Smirnov, (LPTHE), Mathematics
Michael Smy, (UC Irvine), Neutrino Physics
Charles Louis Steinhardt, (U Copenhagen), Astronomy
James L. Stone, (Boston U), High Energy Physics
Shigeki Sugimoto, (Kyoto U), Theoretical Physics
Toshikazu Suzuki, (U Tokyo, ICRR), Gravity
Atsushi Takahashi, (Osaka U), Mathematics
Fuminobu Takahashi, (Tohoku U), Particle Theory
Tadashi Takayanagi, (Kyoto U), String Theory
Atsushi Takeda, (U Tokyo, ICRR), Astroparticle Physics
Yasuhiro Takemoto, (U Tokyo, ICRR), Experimental Physics
Yasuo Takeuchi, (Kobe U), Astroparticle Physics
Hidekazu Tanaka, (U Tokyo, ICRR), Neutrino Physics
Masaomi Tanaka, (Tohoku U), Astronomy
Atsushi Taruya, (Kyoto U), Astronomy
Takayuki Tomaru, (NAOJ), Experimental Physics
Nozomu Tominaga, (Konan U), Astronomy
Werner Tornow, (Duke U), Neutrino Physics
Akihiro Tsuchiya, (Nagoya U), Mathematics
Sachiko Tsuruta, (Montana State U), Astronomy
Edwin L Turner, (Princeton U), Astronomy
Kazushi Ueda, (U Tokyo, Math Sci), Mathematics
Hokuto Uehara, (Tokyo Metropolitan U), Mathematics
Mikhail Verbitsky, (HSE, National Research U) Mathematics (till 2020/3/10)
Alexander Voronov, (U Minnesota), Mathematics
Christopher W. Walter, (Duke U), Neutrino Physics
Shin Watanabe, (JAXA), Experimental Physics
Bryan Webber, (U Cambridge), Particle Theory
Roger Alexandre Wendell, (Kyoto U), Neutrino Physics
Marcus Christian Werner, (Duke Kunshan U), Mathematical Physics

Benda Xu, (Tsinghua U, Beijing), Experimental Physics
Masaki Yamashita, (Nagoya U), Astroparticle Physics
Tsutomu Yanagida, (Shanghai Jiao Tong U), Particle Theory
Jun'ichi Yokoyama, (U Tokyo, RESCEU), Cosmology
Masashi Yokoyama, (U Tokyo), High Energy Physics
Shuichiro Yokoyama, (Nagoya U), Cosmology

Graduate Students

Kazuyuki Akitsu, Cosmology
Weiguang Cao, Theoretical Physics (from 2019/9/1)
Laurence Cook, (U Oxford), Neutrino Physics
Henrique De Campos Affonso, Mathematics
Yuichi Enoki, Particle Theory
Kento Furukawa, Experimental Physics
Tommaso Ghigna, (U Oxford), Astroparticle Physics
Alexander Goldsack, (U Oxford), Neutrino Physics
Shunichi Horigome, Particle Theory
Takumi Ichikawa, Particle Theory
Keita Kanno, Particle Theory
Taisuke Katayose, Theoretical Physics
Tenyo Kawamura, Experimental Physics
Tasuki Kinjo, Mathematics
Nozomu Kobayashi, Particle Theory
Yosuke Kobayashi, Cosmology
Asahi Kojima, Particle Theory
Toshiki Kurita, Theoretical Physics
Yasunori Lee, Particle Theory
Xiangchong Li, Cosmology
Tianle Mao, Mathematics
Alexander Nicholas Mason, (U Oxford), Particle Theory (till 2019/9/30)
Kairi Mine, Experimental Physics
Yuto Moriwaki, Mathematics (from 2020/1/8)
Kai Murai, Particle Theory
Ryoma Murata, Cosmology
Colm Murphy, (U Oxford), High Energy Physics (from 2019/10/1)
Shunsaku Nagasawa, Experimental Physics
Shigenori Nakatsuka, Mathematics (from 2020/1/8)
Mang Chiu Ng, Particle Theory
Tian Qiu, Cosmology
Yotaro Sato, Theoretical Physics
Yusuke Sato, Mathematics
Yuta Sato, Particle Theory
Ryota Shimoda, Theoretical Physics
Yusuke Suetake, String Theory
Sunao Sugiyama, Theoretical Physics
Shenli Tang, Astronomy
Shintaro Toita, Particle Theory
Satoshi Toki, Cosmology
Ryota Tomaru, Experimental Physics
Yutaka Tsuzuki, Experimental Physics
Yota Watanabe, Cosmology (till 2019/4/30)
Yu Watanabe, Particle Theory
Xia Xiaokun, Mathematics
Goro Yabu, Experimental Physics
Hiroki Yoneda, Experimental Physics
Chenghan Zha, Mathematics

Berkley satellite Members

Mina Aganagic, (UC Berkeley), String Theory
Raphael Bousso, (UC Berkeley), Cosmology
Lawrence J Hall, (UC Berkeley), Particle Theory
Petr Horava, (UC Berkeley), String Theory
Yasunori Nomura, (UC Berkeley), Particle Theory

Administration

Tomiyoshi Haruyama, Administrative Director, Project Professor
Yoshihide Sakai, Deputy Administrative Director, Project Professor
Shinji Kikuchi, General Manager
Akira Takeda, Deputy General Manager

Accounting

Shigeru Kobayashi*
Naoko Ishida
Hiromi Yoshida
Yukiko Yoshikawa

Budget Control

Daisuke Hamada*
Madoka Okamoto
Tomoko Shiga
Kaori Watanabe

Contract & General Purchasing

Kenji Irie*
Yoshiya Ohtaka
Takako Okawa
Sachiko Shimada
Tomoko Yamanaka

General Management

Kazumi Ichimura*
Yuuko Enomoto
Hisami Kuboshima
Mika Miura
Ayako Nakada
Rieko Tamura

International Relations and Researchers Support

Toshiko Furukawa*
Rie Kohama
Eri Kuromoto
Masami Nishikawa
Eri Shinoda
Atsuko Ishizaki

Network and Web Service

Tatsuhiro Yano (till 2020/1/31)
Satoko Inoshita (from 2019/7/1)

PFS Project

Yuki Ishizuka

Planning & Assessment

Shoko Ichikawa

Public Relations

Motoko Kakubayashi
Marina Komori (Project Assistant Professor)
Aya Tsuboi

Kamioka Branch

Fumitoshi Sakai*
Yoshimi Kakioka
Masako Ishikura
Hitoshi Nakagawa

(*section head)

5 Research Highlights

5.1 T2K Probes Matter-Antimatter Asymmetry in Neutrino Oscillations

Mark Hartz

In 1928, Paul Dirac found that the relativistic version of the quantum mechanical wave equation for electrons predicted a new type of particle with the same mass as electrons but opposition charge. These new particles, called positrons, where discovered among cosmic rays by Carl D. Anderson in 1932. Since then it has been established through theory and experiment that each particle has a corresponding antiparticle with the same mass but opposite charge and other internal quantum numbers. The quantum mechanical laws of electromagnetism are symmetric under the interchange of all particles with antiparticles, a transformation called charge conjugation, or **C** for short. However the weak nuclear interaction was found to be asymmetric under both the **C** transformation and the transformation that takes the mirror image of the system, called parity or **P** for short. The symmetry between matter and antimatter, however appeared to be preserved if the **C** and **P** transformations were taken at the same time, called the **CP** transformation. Even this symmetry fell by the wayside when it was discovered in 1964 by Cronin and Fitch that neutral kaons decays are not symmetric under the **CP** transformation.

The phenomenon of **CP** violation relates to another mystery in our understanding of the universe. If the Big Bang created matter and antimatter in equal parts, why is the universe composed of matter? In 1967 Andrei Sakharov proposed three conditions to produce an excess of matter in the early universe, and one of these is the presence of **CP** violation. However, it was ultimately found that the **CP** violation in the quarks and hadrons, such as the neutral kaons, was not sufficient to explain the imbalance in our universe. Hence, we look for new sources of **CP** violation, and one candidates is the phenomenon of oscillations neutrinos.

When neutrinos are produced in one flavor (muon, electron or tau) and transform to another flavor as they propagate over a distance, we call this neutrino oscillations. This processes happens for both neutrinos and their antimatter partners, antineutrinos. The probability to change flavor may be different for neutrinos and antineutrinos, representing a new source of **CP** violation. In neutrino oscillations, this potential **CP** violation is parameterized by a phase δ_{cp}. If δ_{cp} takes any value other than 0° or 180°, CP violation is present in neutrino oscillations.

The Tokai-to-Kamioka (T2K) experiment is a neutrino oscillation experiment in Japan, with a beam of muon neutrinos or muon antineutrinos generated at the J-PARC accelerator complex that is detected 295 km away in the Super-Kamiokande detector, as shown in Fig. 1. T2K studies the oscillations of muon neutrinos or antineutrinos to electron neutrinos or antineutrinos and looks for a difference in the oscillation rate between neutrinos and antineutrinos.

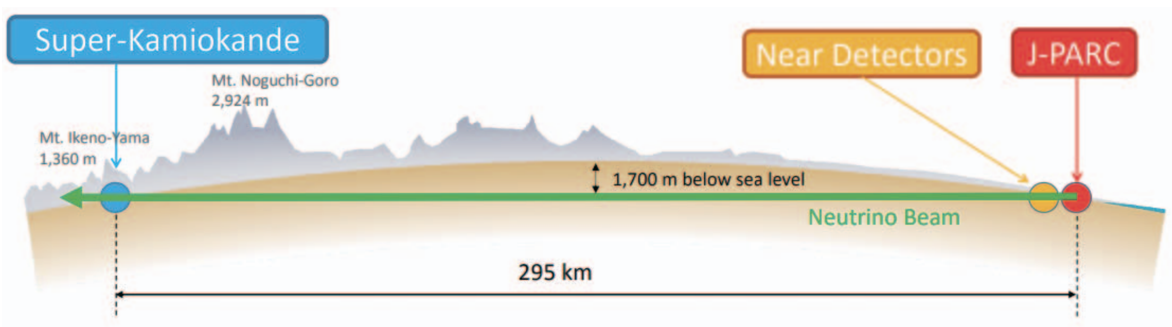


Fig. 1: Cross section of the T2K experiment.

Starting operation in 2009, T2K recently published new results with data collected through 2018 with the nearly equal operation in the neutrino and antineutrino beam configurations. From this data, T2K has extracted a constraint of the parameter δ_{cp}. However, the analysis of T2K data is not as simple as checking if the electron neutrino and electron antineutrino event rates are the same or not. While the neutrino beam can be changed between matter and antimatter, the rest of the T2K experiment, including the earth through which the neutrinos travel and the Super-Kamiokande detector, are made out of matter. This creates asymmetries in the rates of observed neutrinos and neutrinos, even if there is no CP violation in the neutrino oscillations. To deal with this, the T2K collaborators must apply a sophisticated analysis that accounts for these asymmetries that are intrinsic to the experimental apparatus. This analysis is an area where Kavli IPMU researchers have played a key role in both the modeling of the neutrino and antineutrino production, and the fitting procedures to extract the allowed values of δ_{cp} and other parameters that govern neutrino oscillations.

With the collected data and analysis framework, T2K has produced a measurement of δ_{cp} that was published in Nature 580 (2020) 7803, 339–344. As shown in Fig. 2, T2K prefers a value δ_{cp} that is close to –90°, the value at which the neutrino oscillation rate is largest relative to the antineutrino oscillation rate. One CP symmetric value at 0° is disfavored at the 99.7% confidence level, while the other CP symmetric value at 180° is still allowed. The value at 90°, corresponding to the maximum enhancement of the antineutrino oscillation rate is disfavored at more than the 99.7% confidence level.

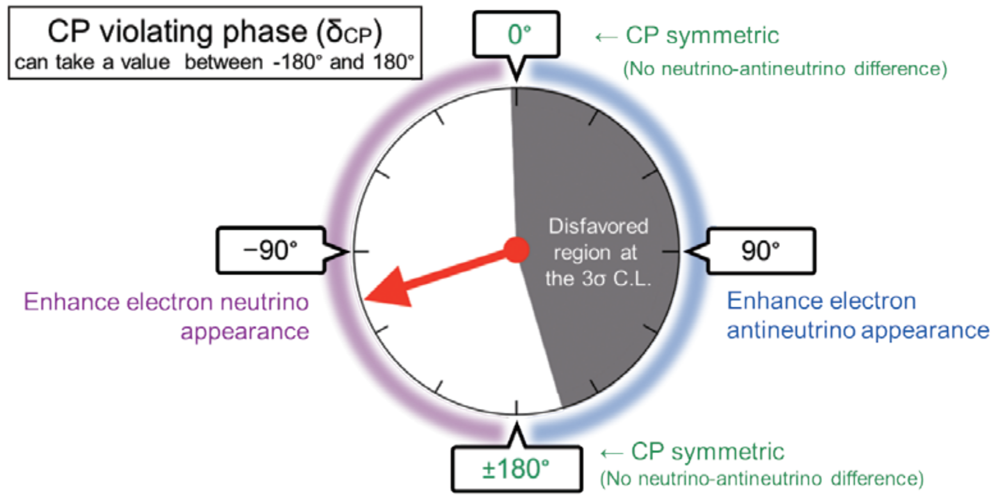


Fig. 2: The favored and disfavored values of δ_{cp}. The dark gray region is values that are disfavored at a 99.7% confidence level.

These results represent an exciting hint that there could be significant CP violation in the oscillations of neutrinos. To definitively establish where CP violation is present, and to measure the magnitude of CP violation will require larger data sets and the reduction of systematic uncertainties in the analysis of the data. T2K and J-PARC will soon begin upgrades to improve the T2K near detector and increase the neutrino beam power. Kavli IPMU researchers are participating in these upgrades through collaboration on the development of a high intensity beam monitor. With these upgrades, T2K will collect more data and refine the measurement of δ_{cp}. Beyond T2K, the Hyper-Kamiokande (Hyper-K) experiment has been approved and has started construction with expected operation in 2027. The centerpiece of the Hyper-K project is a new detector that will be 8 times larger than Super-Kamiokande, allowing data to be collected that much faster. Kavli IPMU researchers are excited to be participating in the Hyper-K project with the goal of fully probing the hint of new phenomena that has been suggested by these T2K results.

5.2 New Physics Search Kicked Off at the Electron-Positron Collider Experiment Belle II

Takeo Higuchi

Despite the great success of the Standard Model (SM) of particle physics, the SM is not believed as the Theory of Everything because several phenomena in the Universe remain unexplained yet by the SM, and thus, the existence of a new physics beyond the SM is strongly believed. In quest of the new physics, a high-energy collider experiment Belle II was fully started in Japan in March 2019. In Belle II, the properties B, τ, and other particles produced from e^+- e^- collisions provided by the SuperKEKB accelerator are measured, and the evidence of the new-physics effect in the measured properties is elucidated by comparing the measured properties with the SM prediction.

By successfully squeezing the beams at the e^+- e^- interaction region, the SuperKEKB had already set the best peak luminosity to $1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is the half of the predecessor accelerator's record. By the end of FY2019, about 20 fb^{-1}collision data had been collected.

The performance of the individual Belle II subdetectors was estimated using the cosmic-ray data and e^+- e^- collision data. The transverse momentum resolution of a charged track with $p_t = 2$ GeV/c was found to be 0.41%, and the kaon detection efficiency and the pion fake rate for a charged kaon with $p_t = 2$ GeV/c were found to be ~0.9 and ~0.1, respectively; they are sufficiently good for the upcoming data analyses. Good integrated performance of the subdetectors was demonstrated by analyzing the neutral B-meson decay $B^0 \to D^{*-}\ell^+\nu$ and its charge conjugate. Two neutral B mesons pair-produced from the e^+- e^- collision have the opposite flavor until the first B-meson decay at $t = t_1$. After the first decay, the flavor of the second B meson starts to oscillate between B^0 and $\bar{B}^0$ due to the B^0- $\bar{B}^0$ mixing mechanism; the oscillation continues until the second B-meson decay at $t = t_2$. Hence, the decay final state of the two B mesons can be one of , $(B^0, \bar{B}^0)$, $(B^0, \bar{B}^0)$, (B^0, B^0) and $(\bar{B}^0, \bar{B}^0)$, where the first two and the second two are denoted by opposite flavor (OF) and same flavor (SF) states, respectively. The flavor of each B meson is determined by the charge information of the decay lepton. The ratio of the number of the SF events to the SF and OF events was found to be $X_d = (17.3 \pm 3.6)$ % [1], which was consistent with the previous experiments' average $X_d = (18.58 \pm 0.11)$ %. Finally, excellent vertex-detector performance was demonstrated by measuring the differential ratio of the number of the OF events to the SF and OF events as a function of the second B-meson flight time $\Delta t \equiv t_2 - t_1$. The Δt was obtained by dividing the displacement of the two B-decay vertices, which are precisely determined by the vertex detector, by the speed of the B meson. The measured differential ratios are drawn as the black crosses in Figure 1; they nicely match the Monte Carlo (MC) expectation shown as the blue squares in the same figure.

The first physics paper from the Belle II collaboration was accepted by Physical Review Letters in February 2020 [2]. A new gauge boson Z' decaying to invisible particles, which can be a dark-sector particle, was searched for in the decay of $e^+e^- \to \mu^+\mu^- Z'$ and its lepton-flavor violating version $e^+e^- \to e^\pm\mu^\mp Z'$, where the Z' production occurs via radiation off a final state muon, in the collision data of 0.28 fb^{-1}. The Z' signature is a peak in the distribution of the invariant mass of the system recoiling against a lepton pair. No significant peak in the recoil-mass spectrum above the estimated background level was seen for either $\mu^+\mu^-$ or $e^\pm\mu^\mp$ combinations. Figure 2 shows the spectrum for the $\mu^+\mu^-$ combinations.

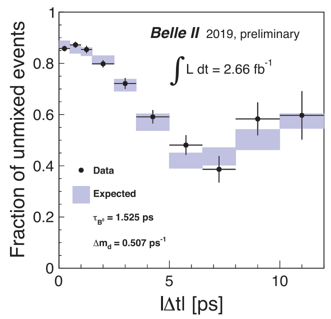


Figure 1:
The differential ratio of the number of OF events to the SF and OF events as a function of the second B-meson flight time Δt. The black crosses and blue squares indicate measurement and MC prediction, respectively. The data points nicely match the MC prediction.

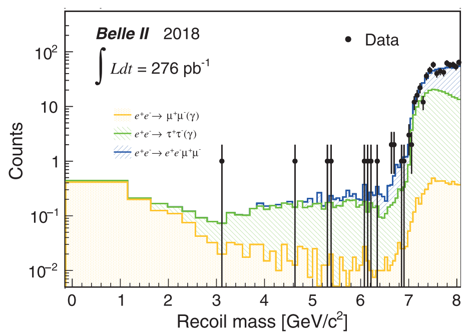


Figure 2:
The invariant mass distribution of the system recoiling against the muon pair. The black points indicate the reconstructed recoil mass in the collision data, and the colored region indicates the MC-estimated background level. No significant peak above the background level is seen in the distribution.

The Belle II detector continues with collecting the collision data for the next decade. By the end of FY2020, it will have collected about 100 fb^{-1} data. The Belle II collaboration will keep delivering exciting reports about various new-physics search results using the vast data samples.

References

[1] Y. Yusa, "Time-dependent studies with early Belle II data", Proc. of Sci. (Beauty 2019) 053 (2020).
[2] I. Adachi *et al.*, Phys. Rev. Lett. **124**, 141801 (2020).

5.3 Black Hole Microstates and Holography

Seyed Morteza Hosseini

There has been a recent progress in understanding black holes' puzzles, especially deriving the macroscopic entropy of black holes in asymptotically anti de Sitter (AdS) spacetimes. The Bekenstein-Hawking entropy of a black hole behaves very much like a thermodynamic entropy. Though if we really would like to make sense of it as the thermodynamic entropy we need to ask if it has a microscopic origin à la Maxwell-Boltzmann $S_{BH} = k_B \log d_{\mathrm{micro}}$, where k_B is the Boltzmann constant and d_{micro} is the number of black hole microstates.

My research focus in the past five years has been to investigate the quantum properties of black holes in AdS spacetimes and explain the microscopic origin of their entropy. In my recent works [1, 2], my collaborators and I constructed dyonic asymptotically AdS_5 and AdS_7 rotating black strings by uplifting a class of four-dimensional rotating black holes and gave a statistical description of their entropy by using a charged version of the Cardy formula. To this aim, we derived the general anomaly polynomial for a class of two-dimensional conformal field theories (CFTs) arising as twisted compactifications of a higher-dimensional theory on compact manifolds, including the contribution of the isometries. This result is then used to extract the central charges and the levels of the U(1) symmetries in the two-dimensional CFT that are the main ingredients of the charged Cardy formula.

In [3, 4], a geometric approach (based on certain global, topological data) for computing the central charge of a class of two-dimensional $N = (0, 2)$ theories obtained by twisted compactifications of D3-brane gauge theories living at a toric Calabi-Yau three-fold has been proposed. In my recent joint work with Alberto Zaffaroni [5], I proved the equivalence of this construction with c-extremization [6] for an arbitrary toric Calabi-Yau. Then, in [7], we investigated the similar problem for a class of theories obtained by twisted compactifications of M2-branes living at a Calabi-Yau four-fold. The latter is dual holographically to a class of asymptotically $\mathrm{AdS}_4 \times Y_7$ magnetically charged BPS black holes, where Y_7 is a Sasaki-Einstein seven-manifold. The Bekenstein-Hawking entropy of these black holes can be obtained by extremizing the topologically twisted indices of the dual three-dimensional field theories. This principle is known as I-extremization. We showed that the I-extremization procedure is equivalent to its geometric dual for theories without baryonic symmetries and for theories whose twisted index can be computed in the large N limit, and depends only on three mesonic fluxes.

In another step, we provided a unifying entropy functional and an extremization principle for black holes and black strings in $\mathrm{AdS}_4 \times S^7$ and $\mathrm{AdS}_5 \times S^5$ with arbitrary rotation and generic electric and magnetic charges [8]. This is achieved by gluing *gravitational blocks*, basic building blocks that are directly inspired by the holomorphic blocks appearing in the factorization of supersymmetric partition functions in three and four dimensions. Generalizations to higher-dimensional black objects were also discussed in the same paper.

References

[1] S. M. Hosseini, K. Hristov, and A. Zaffaroni, "Microstates of rotating AdS_5 strings", *JHEP* **11** (2019) 090, arXiv:1909.08000 [hep-th].
[2] S. M. Hosseini, K. Hristov, Y. Tachikawa, and A. Zaffaroni, "Anomalies, Black strings and the charged Cardy formula", arXiv:2006.08629 [hep-th].
[3] C. Couzens, J. P. Gauntlett, D. Martelli, and J. Sparks, "A geometric dual of c-extremization", *JHEP* **01** (2019) 212, arXiv:1810.11026 [hep-th].
[4] J. P. Gauntlett, D. Martelli, and J. Sparks, "Toric geometry and the dual of c-extremization", *JHEP* **01** (2019) 204, arXiv:1812.05597 [hep-th].
[5] S. M. Hosseini and A. Zaffaroni, "Proving the equivalence of c-extremization and its gravitational dual for all toric quivers", *JHEP* **03** (2019) 108, arXiv:1901.05977 [hep-th].
[6] F. Benini and N. Bobev, "Two-dimensional SCFTs from wrapped branes and c-extremization", *JHEP* **06** (2013) 005, arXiv:1302.4451 [hep-th].
[7] S. M. Hosseini and A. Zaffaroni, "Geometry of I-extremization and black holes microstates", *JHEP* **07** (2019) 174, arXiv:1904.04269 [hep-th].
[8] S. M. Hosseini, K. Hristov, and A. Zaffaroni, "Gluing gravitational blocks for AdS black holes", *JHEP* **12** (2019) 168, arXiv:1909.10550 [hep-th].

5.4 Primordial Black Holes: Theory Meets Astronomy

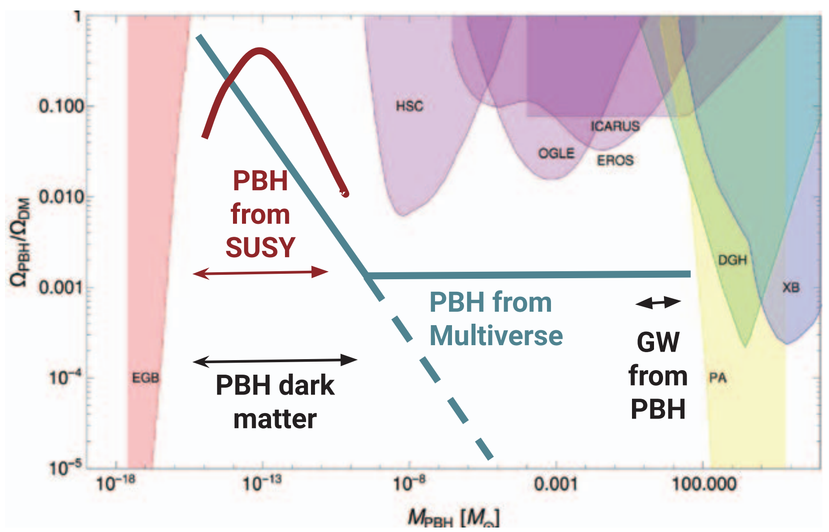
Alexander Kusenko

Kavli IPMU is home to many interdisciplinary projects which benefit from the wide range of expertise available at the institute. One of such projects is the study of primordial black holes (PBHs) from the points of view of fundamental theory, astrophysics, and astronomical observations. Primordial black holes could account for all or part of dark matter, they could be responsible for some of the observed gravitational waves signals, they could seed supermassive black holes, and their interactions with neutron stars could help synthesis of heavy elements.

The early universe was so dense that any positive density fluctuation of more than 50% would create a black hole. However, cosmological perturbations that seeded galaxies are known to be much smaller. Nevertheless, a number of processes in the early universe could have created large enough fluctuations. One possibility is that inflation produced large perturbations on small scales. The physics and astrophysical consequences of this process have been studied by the Kavli IPMU members, including Masahiro Kawasaki, Alexander Kusenko, Misao Sasaki, and Tsutomu Yanagida.

Another possibility, pointed out recently by Kavli IPMU and UCLA researchers, is that a spectator scalar field could develop an instability leading to large fluctuations and PBHs. Scalar self-interactions can provide an attractive force stronger than gravity. Just as gravitational instability causes hydrogen gas to form stars, the scalar force causes an instability that makes the scalar field distribution inhomogeneous in the early universe. The lumps of scalar fields can serve as building blocks of black holes under some very generic conditions. If the scalar field in question is related to supersymmetry, the masses of primordial black holes fall into the range where they can account for all dark matter in the universe.

Finally, primordial black holes could form from the "baby universes" created by inflation. A team of Kavli IPMU and UCLA scientists including Alexander Kusenko, Misao Sasaki, Sunao Sugiyama, Masahiro Takada, Volodymyr Takhistov, and Edoardo Vitagliano have shown that the black holes from the "multiverse" scenario can be searched using the HSC on Subaru, building on the success of the earlier search for PBHs by Masahiro Takada and his team. That search produced not only an exclusion limit, but also a very intriguing candidate event consistent with a PBH from the "multiverse". The new observations have been scheduled on the Subaru telescope to extend the search and to provide a definitive test whether the PBHs from the multiverse scenario can explain dark matter.



5.5 Our Origin and Gravitational Wave

Hitoshi Murayama

Why do we exist? This is one of the five questions Kavli IPMU is pursuing. Even though the question may sound philosophical, there are clear scientific questions behind it. For example, we need to understand where chemical elements came from. We understand that they were synthesized at the core of giant stars and spread out into space after their supernova explosions. This idea was proven when our friends working on the Kamiokande experiment observed neutrinos coming from SN1987A. In 2017, we learned that elements heavier than iron were forged when two neutron stars, cinders after supernova explosions, merge into a black hole. We are making a great progress!

Unfortunately, this is not enough. For stars to form, we need protons and electrons, both *matter* particles. But we also know that they have *anti-matter* counterparts. When the Universe started with the Big Bang, the tremendous energy turned into matter using Einstein's famous equation $E=mc^2$. But when this happens, matter is created together with anti-matter always 1 : 1. So the Universe must have been filled with a huge number of matter and anti-matter particles of the *same number*. When energy can create matter and anti-matter, the opposite can also happen. Matter and anti-matter particles can meet and *annihilate* into pure energy, again 1 : 1. If so, as the Universe expanded and cooled, every matter particle and anti-matter particle must have met and disappeared. The Universe must be empty! But we are here. What happened?

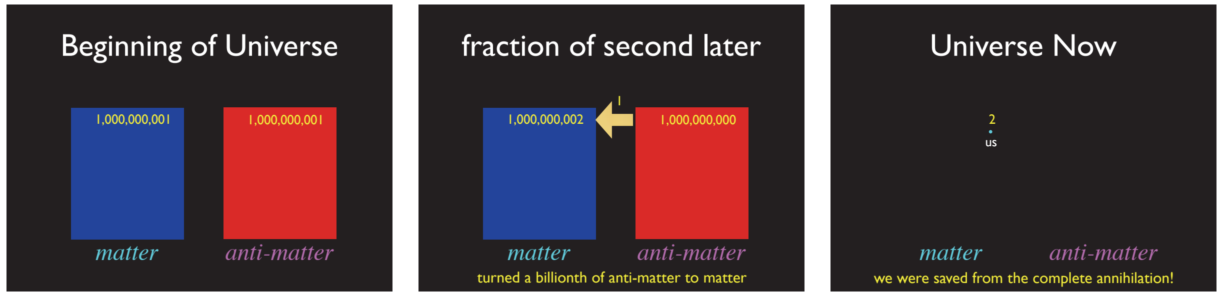


Figure 1

After the Big Bang created an equal number of matter and anti-matter particles, let us say a billion and one each, somehow one out of a billion anti-matter particles must have turned into a matter particle (see Fig. 1). Then there is a tiny imbalance between them, a billion and two versus a billion. When they meet, a billion of them annihilate, but two of them are left over. Namely, we survived at the expense of a billion friends! The big question is how a tiny amount of anti-matter could turn into matter. Who is the superhero who saved us from the complete annihilation?

There is a bold theory proposed by two of our emeriti PIs, Masataka Fukugita and Tsutomu Yanagida [1]. They say the superhero is neutrinos.

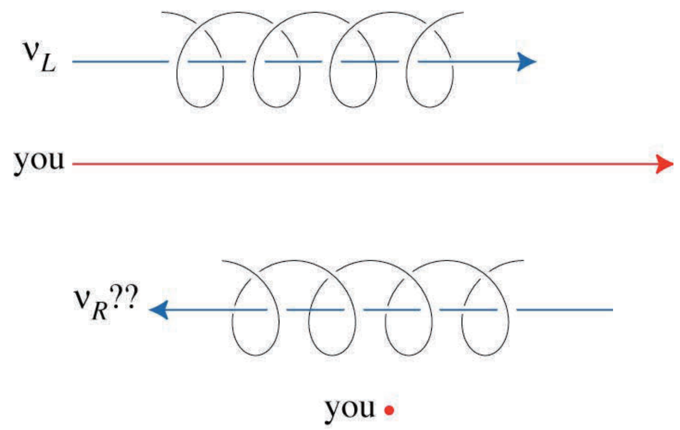


Figure 2

Every matter particle is spinning, either clockwise or counterclockwise. Experimentally, every neutrino we have seen is spinning counterclockwise. This was OK when we believed that neutrino did not have a mass and always traveled at speed of light. But the Super-Kamiokande experiment, led by our PI Takaaki Kajita, discovered that it has a tiny mass and is *not* traveling at speed of light. Then you can in principle go faster and look back at the neutrino (see Fig. 2). It is then moving backwards, and it is spinning clockwise. Such a particle was not supposed to exist. But we know anti-neutrinos spin clockwise. Is it possible that a neutrino, after you overtake it, becomes an anti-neutrino? Then neutrino can turn matter into anti-matter and the other way around!

Fukugita and Yanagida went one step further. To give a tiny mass to neutrinos, they hypothesized a clockwise neutrino nobody has seen. But if it is very very heavy, it makes sense that we haven't been able to produce it because it requires an enormous energy (again, $E=mc^2$). This heavy neutrino has no distinction between matter and anti-matter. It is both. For neutrino to acquire mass, it needs to turn into this clockwise neutrino, but since it is so heavy, it has to turn back to the ordinary neutrino very quickly. This is why neutrino can obtain only a tiny mass. But the heavy neutrinos could be produced when the Universe was very very hot, when it was only 10^{-26} seconds old. Eventually all decay into ordinary neutrinos or anti-neutrinos. They showed the probability may not be exactly 1 : 1, but a little different. Then voilà! There is a slight difference in the number of matter and anti-matter particles, and we could survive.

How do we know if this is true? One important point is to observe that anti-neutrino can turn into neutrino. We know it is very rare, not even once in 10^{26} years. But our PI Kunio Inoue is running a world-leading experiment called KamLAND-ZEN in this search. Another important point is to find a reason why matter was chosen but not the anti-matter. Namely neutrinos and anti-neutrinos must behave a little differently. Our own Mark Hartz is one of the leaders of the T2K experiment looking for this subtle difference. They reported just this year that they are 95% certain there is such a difference.

I've been asking myself for some time if there could be more evidence we can look for. I discussed this question with our affiliate member Kaz Kohri, ICRR postdoc Takashi Hiramatsu, Berkeley postdoc Jeff Dror, and Graham White who was a postdoc at TRIUMF and is now coming to Kavli IPMU.

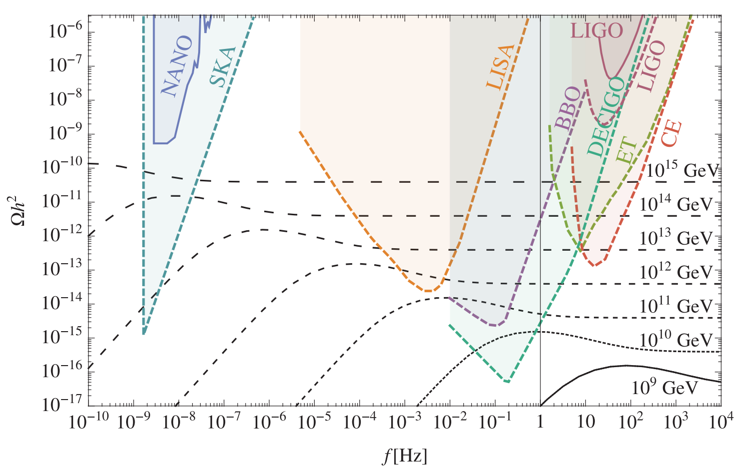


Figure 3

We pointed out that this theory could well lead to gravitational waves with nearly scale-invariant spectrum. The reason is that the clockwise neutrinos are heavy, but not as heavy as they could be: the energy scale of quantum gravity. It suggests that the Universe underwent a phase transition, like a normal metal turning into a superconductor, and the clockwise neutrinos acquired mass because of it. Just like ordinary superconductors, the Universe trapped magnetic field into thin tubes called cosmic strings. And cosmic strings are known to reconnect, shrink, and keep emitting gravitational waves. Future missions can cover practically the entire range of signals (see Fig. 3).

I presented this observation at Kavli IPMU workshop "Prospects of Neutrino Physics" in April 2019 for the first time. Yanagida was very happy. After making sure all the details work out, we published the paper in the best journal, Physical Review Letters, and the paper was chosen to *Editor's Suggestion*. Now I'm happy, too!

References
[1] Masataka Fukugita and Tsutomu Yanagida, Baryogenesis Without Grand Unification, Phys. Lett. B 174, 45-47 (1986).
[2] Jeff A. Dror, Takashi Hiramatsu, Kazunori Kohri, Hitoshi Murayama, and Graham White, Testing the Seesaw Mechanism and Leptogenesis with Gravitational Waves, Phys. Rev. Lett. **124**, 041804 (2020).

5.6 Anomaly of Electromagnetic Duality of Maxwell Theory Determined

Yuji Tachikawa and Chang-Tse Hsieh

Classical electromagnetism is described by Maxwell's equations, introduced by James Clerk Maxwell almost 150 years ago [1]. These equations are long known to respect a certain symmetry, called the electromagnetic duality, which exchanges the electric charge and the magnetic charge, as shown in the figure. This duality entails the existence of magnetic monopoles, hypothetical particles carrying single magnetic poles, which in turn implies that all electric charges in the universe are integer multiples of the minimal charge, as originally found by Paul Dirac in 1931 [2]. This is called the Dirac quantization of charges.

It is natural to ask what happens to this electromagnetic duality when considered quantum mechanically. This natural question, however, has not been studied much, particularly in a situation where there are nontrivial duality actions if we go around some path in the spacetime. In this work by Chang-Tse Hsieh and Yuji Tachikawa at IPMU and Kazuya Yonekura at Tohoku University (who is also a former IPMU member), the duality was found to have an anomaly, meaning that it is slightly violated quantum mechanically but in a controllable manner.

Developments in the last several years by condensed-matter physics tells us that the anomaly of a d-dimensional system is best studied as appearing on the boundary of a (d+1)-dimensional symmetry-protected topological phase of matter. One famous example is that gapless fermions appear on the surface of topological insulators. In this work, the 3+1 dimensional Maxwell theory was considered as living on the boundary of a hypothetical 4+1 dimensional topological phase of matter. In particular, Hsieh had determined the anomaly of 3+1 dimensional fermions from this point of view in his previous work [3]. In this work, the anomaly of Maxwell theory was found to be 56 times that of a fermion.

The original motivation for this study came from string theory, which requires ten spacetime dimensions with a higher dimensional analog of Dirac quantization. It was also known that there exist objects in string theory, called orientifolds, which violate Dirac quantization conditions, potentially rendering string theory inconsistent. A partial resolution of the inconsistency was found by Tachikawa and Yonekura [4] by generalizing previous works by Witten and others, where the anomaly of fermions canceled against the violation of Dirac quantization conditions. There were however still cases where the inconsistency remained. The present work shows that the consistency in a number of remaining cases can be achieved by incorporating the anomaly of the Maxwell theory.

It has repeatedly happened that an apparent inconsistency in string theory was saved by a subtle and unexpected mechanism; this work can be thought of as another instance of these repeated occurrences. This work might also be of interest to physicists not particularly interested in string or M-theory, since this work demonstrates that, even after 150 years since the introduction of the Maxwell equations, there are still so much to be uncovered. This study appeared as [5] and was chosen as an Editors' Suggestion of Physical Review Letters.

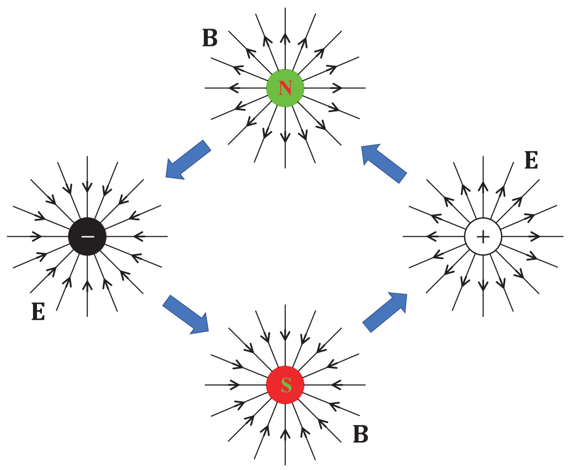


Figure 1

References
[1] J. C. Maxwell, "A dynamical theory of the electromagnetic field", https://doi.org/10.1098/rstl.1865.0008
[2] P. A. M. Dirac, "Quantised singularities in the electromagnetic field", https://doi.org/10.1098/rspa.1931.0130
[3] C.-T. Hsieh, "Discrete gauge anomalies revisited", https://arxiv.org/abs/1808.02881
[4] Y. Tachikawa and K. Yonekura, "Why are fractional charges of orientifolds compatible with Dirac quantization?", https://doi.org/10.21468/SciPostPhys.7.5.058 https://arxiv.org/abs/1805.02772
[5] C.-T. Hsieh, Y. Tachikawa and K. Yonekura, "Anomaly of the Electromagnetic Duality of Maxwell Theory", https://doi.org/10.1103/PhysRevLett.123.161601 https://arxiv.org/abs/1905.08943

5.7 Prime Focus Spectrograph (PFS): Subsystems are Coming Together for On-Sky Commissioning

Naoyuki Tamura

We at Kavli IPMU are working on a major astronomical instrument called PFS (Prime Focus Spectrograph), a next generation facility instrument on the Subaru telescope. It is a very wide-field, massively multiplexed, and optical & near-infrared spectrograph, and Kavli IPMU is the leading institute in both aspects of the instrument development and the planning of a 360-night observation campaign on the Subaru telescope for cosmology, galaxy evolution, and galactic archaeology science. Exploiting the Subaru's prime focus, 2394 reconfigurable fibers will be distributed in the 1.3 degree-diameter field of view. The spectrograph system has been designed with 3 arms of blue, red, and near-infrared cameras to simultaneously deliver spectra from 380 nm to 1260 nm in one exposure. From the Subaru's prime focus, the Hyper Suprime Cam (HSC) has been continuously delivering superb imaging data over a large area of the sky. Conducting spectroscopic follow-up using PFS is crucial to complete a large census of the universe. This is unique not only because it exploits the unique capabilities of the Subaru Telescope such as the light-gathering power of the 8.2 m primary mirror, and the wide field of view on the prime focus, but also because HSC and PFS enable deep imaging and spectroscopic surveys of the same patches of the sky using the same 8.2 m telescope, so one can well understand various systematics in the data which is essential for robust understandings of statistical properties of the universe.

The instrumentation has been carried out by the international collaboration managed by the PFS Project Office hosted by Kavli IPMU. The team is actively integrating and testing the hardware and software of the subsystems, and some of them have been delivered to the Subaru Telescope observatory at the summit of Maunakea in Hawaii. Metrology Camera System (MCS), which was developed at Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) in Taiwan, arrived at Subaru in 2018, and tests were successfully completed on the telescope through the two nighttime engineering runs, one in October 2018 and the other in August 2019 with sufficient hardware and software optimizations accommodated (Figure 1). Soon after that, the first spectrograph module with visible cameras was delivered from Laboratoire d'Astrophysique de Marseille (LAM) to Subaru in November 2019 and was successfully reintegrated in December (Figure 2). The performance was confirmed by tests in early 2020, and now data of calibration lamps are continually taken for the characterization of the instrument and data stabilities, and for data reduction pipeline development. In parallel to these activities, the integration and test of the other subsystems and subcomponents are progressing at the sites of PFS partner institutes (Figure 3) for their deliveries to the Subaru Telescope observatory later in 2020 onwards. The software development is also rapidly progressing. The instrument control software is being fleshed out as the subsystem testing progresses, and in addition, we managed to make good progress in its development at the system level that orchestrates the operations of the subsystems exploiting the MCS engineering runs. The developments of data reduction pipeline and data processing mechanism by Princeton University, National Astronomical Observatory of Japan (NAOJ) and Kavli IPMU are being accelerated as more data are taken from the spectrograph. The prototyping of science database by NAOJ, Johns Hopkins University (JHU) and Kavli IPMU is also continuing and now it is being upgraded to Ver. 2.5. The team is aiming to start on-telescope engineering observations from mid 2021, and scientific operation of the PFS instrument from 2023.

Figure 1: The Metrology Camera System installed at the Cassegrain focus of the Subaru Telescope.

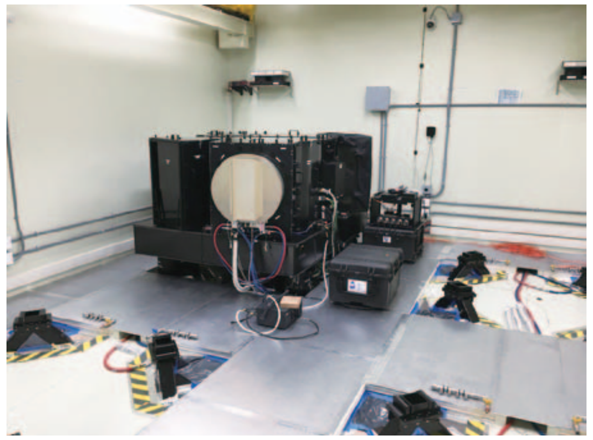


Figure 2: The first spectrograph module fully reassembled in the dedicated clean room in the Subaru telescope enclosure building.

Figure 3: Left -- The fiber cable under integration at Laboratório Nacional de Astrofísica (LNA) in Brazil that will be installed on the telescope and will transmit light from the Prime Focus Instrument on the Subaru prime focus to Spectrograph System. Right -- The focal plane of Prime Focus Instrument under integration by ASIAA and their partner ASRD (Aeronautical Systems Research Division) of CSIST (Chung-Shan Institute of Science and Technology) in Taiwan.

As the instrument development is progressing, the collaboration is in parallel trying to develop a timely plan of large-sky survey observation to be proposed and conducted in the framework of Subaru Strategic Program (SSP). Having the three main survey components labelled as cosmology, galaxy & AGN evolution, and Galactic archaeology, the team is aiming at addressing key questions in the modern cosmology and astrophysics by multiple approaches over multiple scales of dark matter density structure, leading to comprehensive challenges to the ΛCDM cosmology. The team has been continuously updating and refining the plan in detail through discussions regularly by remote meetings and e-mails and occasionally by in-person meetings such as the science meeting in October 2019 at Columbia University, and the 11th general collaboration meeting in December 2019 at California Institute of Technology (Figure 4).

Figure 4: Group photo of the 11th PFS general collaboration meeting at California Institute of Technology in Decmeber 2019.

As we are approaching the period of on-sky engineering observations, start of science operation and thus start of the PFS SSP survey, the interplays between the science team and technical team are more and more crucial, to share not only the basic performances but also the other detailed characteristics of the instrument, and mutually optimize the software components, data flow, and survey management. The members in Kavli IPMU will be playing key roles not only in the integration and commissioning of the PFS instrument, but also in the coagulation of the entire collaboration during the coming key phases of the project in the following fiscal years for ultimate scientific and technical success of PFS.

5.8 The *L*-function of a CM Elliptic Curve and CFT Correlation Functions

Taizan Watari and Satoshi Kondo

In between the field of rational numbers $\mathbb{Q}$ and the field of complex numbers $\mathbb{C}$, there are infinitely many intermediate fields. Those intermediate fields form an intricate network under the relation of one of them containing another; this network remains to be a rich subject of research in number theory.

Think of an algebraic variety X whose defining equation involves polynomials with all the coefficients in some intermediate field; an example is $X := \{(x, y) \mid y^2 = 4x^3 - g_2 x - g_3\}$ with $g_2, g_3 \in k$ for some intermediate field k. The L-function $L(X/k, s)$ is believed to encode the information of the number of solutions (x, y) to the polynomial equation in k. An intriguing observation by number theorists more than a half century ago suggests that such L-functions have corresponding modular forms or automorphic forms. This conjecture has been a subject of intensive study since then; for X as an elliptic curve and $k = \mathbb{Q}$, there is now a proof.

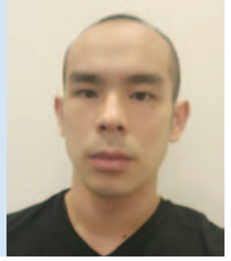
By giving a mathematical proof, one acquires confidence in the validity of a well-defined statement (such as the conjectured one-to-one correspondence between the L-functions of elliptic curves and certain kinds of modular forms). It is yet another question, however, why there is such a correspondence between seemingly unrelated objects. Incidentally, string theory probes a geometry (space-time) by translating the geometry into a conformal field theory on Riemann surfaces, where physical observables often take the form of modular forms. So, a collaboration of Satoshi Kondo (Middle East Technical University, with joint appointment at Kavli IPMU) and Taizan Watari (Kavli IPMU) posed the following question: whether the modular forms that correspond to the L- functions have something to do with the modular forms that appear as physical observables in string theory.

Let X be an elliptic curve of Shimura type, where the imaginary quadratic field of complex multiplication is denoted by K, and the field of moduli of X by k. It is known that the string theory with $X(\mathbb{C})$ as the target space corresponds to a rational conformal field theory, when the Kähler parameter is chosen appropriately. Within this set-up, Kondo and Watari found that the L-function $L(X/k, s)$ can be expressed by using the Mellin transform of the following class of chiral correlation functions of the rational conformal field theory:

$$f^{\,\mathrm{II}}_{1\Omega'}(\tau_{ws}, \beta) := \mathrm{Tr}_{R;V_\beta}\left[(-1)^F F q_{ws}^{L_0 - 3/24} (\partial X^{\mathbb{C}})\right]; \tag{1}$$

here, β labels irreducible representations of the chiral algebra of the rational conformal field theory, and τ_{ws} the complex structure of a $g = 1$ Riemann surface (worldsheet); the trace on the right side is over the Ramond sector left-mover vector space of states in β (denoted by $R; V_\beta$), F is the Fermion number operator of the $N = 2$ superconformal algebra, $q_{ws} := e^{2\pi i \tau_{ws}}$, L_0 the Virasoro generator, and $\partial X^{\mathbb{C}}$ a complex combination of the weight-1 currents of the conformal field theory corresponding to the translation symmetry of the torus $X(\mathbb{C})$. This study revealed that the modular transformation of the $g = 1$ worldsheet is the origin of the modular property of the functions that correspond to the L-function, so long as this class of geometry X and the field of moduli k are concerned. For more information, see S. Kondo and T. Watari, Commun. Math. Phys. **367** (2019) pp.89–126, "String-theory realization of modular forms for elliptic curves with complex multiplication".

5.9 An Independent Measurement of H_0 from Lensed Quasars



Kenneth Wong

The "flat ΛCDM" model of cosmology has been highly successful at explaining a variety of observations. In particular, it is remarkably consistent with observations of the cosmic microwave background (CMB) taken by the *Planck* mission [1]. Under the flat ΛCDM model, *Planck* places a tight constraint on the Hubble constant, the present-day expansion rate of the Universe, of $H_0 = 67.4$ +/– 0.5 km/s/Mpc. However, observations of type Ia supernovae calibrated by the local Cepheid distance ladder find a higher value of $H_0 = 74.0$ +/– 1.4 km/s/Mpc (SH0ES collaboration; [2]). This 4.4 σ discrepancy between the CMB and distance ladder measurements, if unresolved, may force the rejection of flat ΛCDM in favor of new physics. Additional independent measurements of H_0 are needed as an important check of systematics.

Strong gravitational lensing, in which the gravity of a massive object (the "lens") deflects light rays from a background object (the "source") to create multiple images, can be used to determine H_0 through "time-delay cosmography". The light rays arriving from different images of the source take slightly different paths through spacetime, and thus arrive at the observer with a time delay between them. The length of this time delay is directly related to H_0. If we can measure the time delay, accurately model the mass distribution of the lens, and account for perturbers along the line of sight, we can directly calculate H_0 independent of the CMB and the distance ladder.

The H_0 Lenses in COSMOGRAIL's Wellspring (H0LiCOW) project [3] has been conducting the most detailed time-delay cosmography analysis to date. We have precise time delay measurements of several lensed quasars from long-term dedicated monitoring. In addition, we use high-resolution imaging from the *Hubble Space Telescope* and ground-based adaptive optics, along with spectroscopic observations of the lens galaxies, to perform detailed lens mass modeling. Furthermore, we have obtained wide-field imaging and spectroscopy to characterize line of sight structure. With this large dataset, we have analyzed six lenses (Figure 1) in our latest milestone result [4]. Our analysis is performed blindly with respect to the cosmological parameters of interest in order to avoid confirmation bias.

From the combination of six lensed quasars, we attain a 2.4% precision measurement of $H_0 = 73.3$ (+1.7/–1.8) km/s/Mpc in a flat ΛCDM cosmology (Figure 2), which is in 3.1 σ tension with the *Planck* CMB result. We also test simple extensions to flat ΛCDM such as allowing for spatial curvature, a time-varying dark energy equation of state parameter, and variable neutrino species and masses, but none of these are able to provide a clear resolution to the tension. Since H0LiCOW and SH0ES are completely independent late-Universe probes of H_0, we combine them and find a 5.3 σ discrepancy with *Planck*. This provides further evidence of a tension between early and late-Universe determinations of H_0 [5], suggesting the possibility of new physics beyond flat ΛCDM.

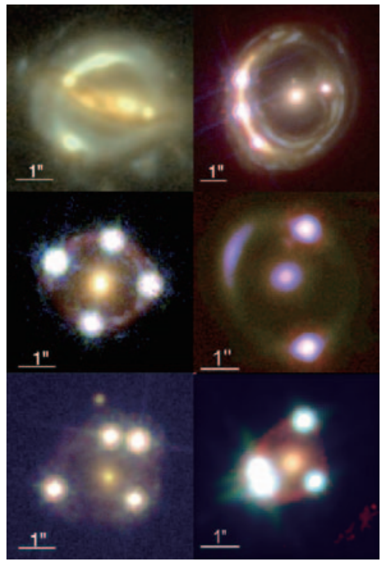


Figure 1: Multicolor images of the six gravitationally-lensed quasars analyzed in the latest H0LiCOW results.

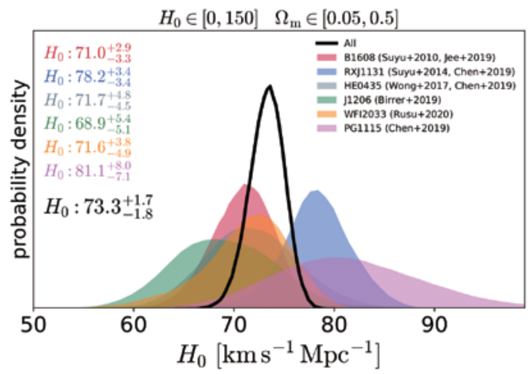


Figure 2: H_0 posterior PDFs for the individual H0LiCOW lenses (colored curves), as well as the combined constraint from all six systems (black line). The median and 16th and 8th percentiles are shown in the figure legend.

References

[1] Planck Collaboration 2018, A&A, in press (arXiv:1807.06209)
[2] Riess *et al.* 2019, ApJ, 876, 85
[3] Suyu *et al.* 2017, MNRAS, 468, 2590
[4] Wong *et al.* 2020, MNRAS, in press (arXiv:1907.04869)
[5] Verde, Treu, & Riess 2019, NatAs, 3, 891

5.10 HSC-SSP Transient Survey at COSMOS Region

Naoki Yasuda

A supernova is the name given to an exploding star that has reached the end of its life. Supernova classified as Type Ia is useful because its constant maximum brightness allows us to measure its luminosity distance. Using this characteristics, the accelerated expansion of the Universe has been discovered [1][2] and more distant supernovae are being observed to understand the nature of dark energy.

In order to discover supernova effectively and measure the light curve of them, we need to monitor wide area of the sky for a long time. High quality and wide field image of Hyper Suprime-Cam (HSC) mounted on the Subaru telescope with large aperture mirror is the best tool in the world for this kind of observation.

We have conducted a deep transient survey at COSMOS region (7.5 square degree, 5 pointings of HSC) in Sextant as a part of HSC-SSP from November 2016 to April 2017 with a cadence of 2 epochs per lunation per filter [3]. The limiting magnitudes per epoch are as follows: 26.4, 26.3, 26.0, 25.6, and 24.6 mag in the *g*-, *r*-, *i*-, *z*-, and *y*-band. The dataset obtained is one of the deepest wide-field transient surveys attempted to date. We have recorded about 65,000 transients. After excluding objects having light curves dominated by negative fluxes and objects whose host looks like stars, we have visually checked them and identified about 1,800 supernova (Figure 1 and Figure 2). For the detection of the transients, machine learning methods are also applied.

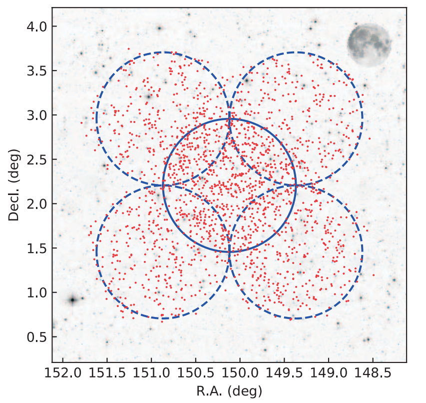


Fig 1. A map showing all of the supernovae (in red) discovered in this study. The blue circles indicate the areas HSC was able to capture in one shot. The background is an image taken by the Sloan Digital Sky Survey. An image of the moon has been added to understand the area of night sky HSC can capture.

By fitting an empirical model of SN Type Ia spectro-photometric time series to multi-color light curves, about 400 supernovae are classified as Type Ia. Among them, spectroscopic redshift or photometric redshift using 30-band photometry ranging from UV to IR are available for 129 supernovae and the median redshift of this sample is $z = 0.97$. In particular, 58 supernovae are located at $z > 1$. In comparison, Hubble Space Telescope took about 10 years to discover a total of 50 supernovae located at $z > 1$. This fact demonstrates the very high survey power of Subaru telescope and HSC. For SN Ia beyond $z > 1.2$, the peak flux of SN Ia goes into the infrared (IR) and the error of the color correction to get standardized absolute magnitude becomes large if we only use optical information. We have conducted an IR imaging follow-up observation via the HST to reduce the color-associated error for 26 SN Ia candidates.

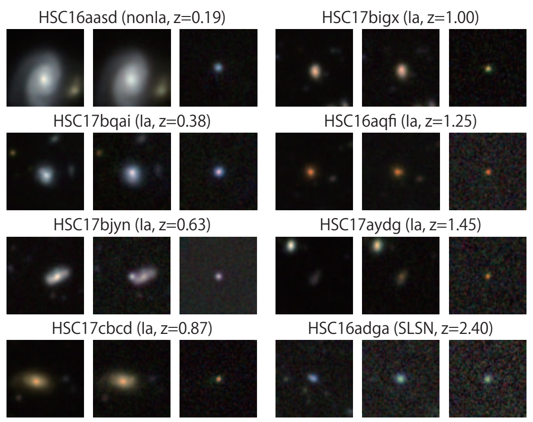


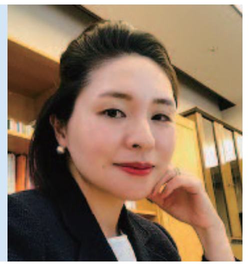
Fig 2. Some supernovae discovered in this study. There are three images for each supernova for before it exploded (left), after it exploded (middle), and supernovae itself (difference of the first two images).

The dataset obtained by our transient survey is useful for the studies of other type of supernova other than SN Ia. There has been increasing interest in using SN Type II for cosmological applications. The SN II light curves are characterized by a rapid increase to the peak value (~7 days), followed by a slow decline, frequently showing a plateau, for ~100 days. Our transient survey is also suited to SN II discovery and characterization of the entire evolution of their multi-color light curves. We used one SN II to extend the SN II Hubble diagram to $z = 0.340$ from $z = 0.190$ [4]. In addition, we have identified 5 super luminous supernovae at $z > 2$ and an event rate at these redshifts has been measured [5].

References

[1] Riess, A. G., *et al.* 1998, *AJ*, **116**, 1009.
[2] Perlmutter, S., *et al.* 1999, *ApJ*, **517**, 565.
[3] Yasuda, N. *et al.* 2019, *PASJ*, **71**, 74.
[4] de Jaeger, T. *et al. MNRAS*, **472**, 4233.
[5] Moriya, T. *et al.* 2019, *ApJS*, **241**, 16.

5.11 Parental Gender Attitudes Associated with Japanese Women's Reduced University Participation



Hiromi Yokoyama

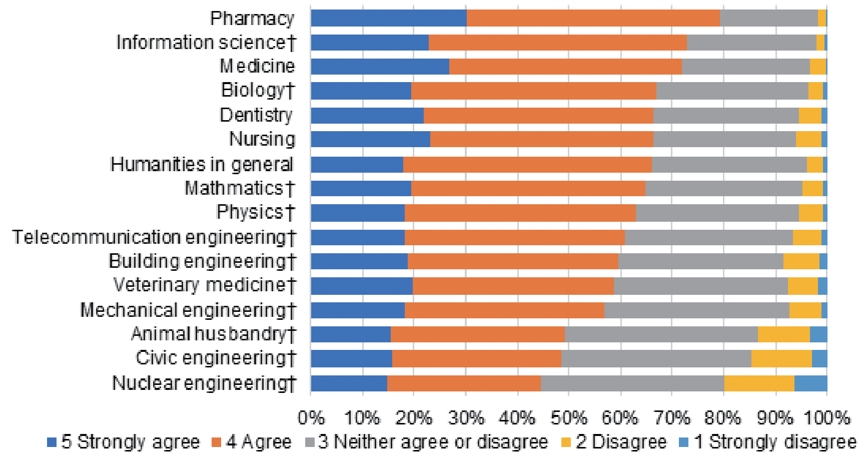
In Japan, women's participation in STEM (Science, Technology, Engineering, and Mathematics) fields remains lower than in North America and Europe. Japan ranked 110 out of 149 countries on a 2018 gender-gap survey, underscoring Japanese women's limited participation in the economy and government. However, despite multiple government and industry initiatives, encouraging greater participation across society is challenging in a country where gender role divisions are deeply entrenched. As part of a larger research project looking at why so few women in Japan choose STEM programs at university, we looked at parental influence on girls' choice of university subject and public perception of several academic fields.

We used a psychological measure of gender role attitudes called SESRA-S to measure parental attitudes. We used an online survey to canvas 618 mothers and 618 fathers across Japan with at least one daughter who had graduated from university and at least one son. We found that while parents' showing higher scores on gender equality attitudes did not mind what field of study girls chose, those with lower scores were opposed to girls choosing any field at university [1]. Over 40% of parents surveyed in this study either "strongly agreed" or "somewhat agreed" with girls' own choice of any university course. However, in the case of science courses, their main reason for agreement was because of the availability of employment opportunities after university, while they regarded the humanities as a suitable area of study for girls.

Parental agreement with girls' choosing to study in each field. Parents were asked to respond about it in general, rather than about their own daughter in particular.

While parents are sensitive to societal changes, some still maintain an image of engineering as not suitable for women, despite strong demand for female talent across engineering fields. It may be that STEM fields in Japan need to update their image. We know that parents with positive attitudes about gender equality can support girls going to university, so it is essential that we improve societal attitudes about gender equality as a whole.

We also investigated whether the public perception of several academic fields was gender- biased in Japan using SESRA-S [2]. We found that 1) the gender-bias gap in public perceptions was largest in nursing and mechanical engineering, 2) people who had a low level of egalitarian attitudes about gender roles perceived that nursing was suitable for women, and 3) people who had a low level of egalitarian attitudes perceived that many STEM fields are suitable for men. This suggests that gender-biased perceptions of academic fields can still be found in Japan.



We are promoting several other studies, and we would like to clarify why there are few women in physics and mathematics, especially in Japan.

References

[1] Ikkatai Y.,Inoue A., Kano K., Minamizaki A., McKay E., Yokoyama H.M.,(2019). Parental egalitarian attitudes towards gender roles affect agreement on girls taking STEM fields at university in Japan., *International Journal of Science Education 41(16)*, 2254-2270
[2] Ikkatai, Y., Minamizaki, A., Kano, K., Inoue, A., McKay, E., & Yokoyama, H. M. (2020). Gender-biased public perception of STEM fields, focusing on the influence of egalitarian attitudes toward gender roles. *Journal of Science Communication, 19(1)*, A08.

6 AWARDS

Hirosi Ooguri to receive Medal of Honor from the Emperor of Japan

The Emperor of Japan conferred a Medal of Honor with Purple Ribbon to Hirosi Ooguri, Director of the Kavli Institute for the Physics and Mathematics of the Universe at the University of Tokyo and the Fred Kavli Professor of Theoretical Physics and Mathematics at the California Institute of Technology.
The awards was conferred by Emperor Naruhito on November 3, 2019, the Culture Day holiday and the birthday of Emperor Meiji, who established the awards in 1881. Medals with Purple Ribbon were added in 1955 to recognize "individuals who have contributed to academic and artistic discoveries, inventions, and innovations."

Professor Masaki Oshikawa named new American Physical Society Fellow

Kavli IPMU Senior Scientist Masaki Oshikawa was elected as a 2019 Fellow of the American Physical Society. He was nominated by the Division of Condensed Matter Physics. The APS Fellowship Program recognizes members who have made significant contributions to the advancement of physics.
Oshikawa has collaborated with Kavli IPMU researchers.

Other prestigious awards

Recipient's name	Name of Award
Shiro Ikeda (The Event Horizon Telescope Collaboration)	Einstein Medal
Takaaki Kajita	IUPAP-TIFR Homi Bhabha Medal and Prize
Young-Kee Kim	2019 Scientist of the Year jointly by the Korean Scientists and Engineers Association (US) and the Korean Federation of Science and Technology Societies (Korea)
Yuko Ikkatai	Japan Society for Science Education Best Presentation Award for Young scientist 2019
Keigo Nakamura	High Energy Physics Young Researcher's Award 2019
Keigo Nakamura	Young Scientist Award of the Physical Society of Japan, 2020

7 CONFERENCES

Conference title Date, Place	Attendees (from abroad)
Prospects of Neutrino Physics 8-12 April 2019, Lecture hall	100 (21)
Hyper-Kamiokande Coordination Meeting 8-9 May 2019, Lecture hall	58 (15)
Quantum Entanglement in Cosmology 21-22 May 2019, Lecture hall	32 (8)
43rd Johns Hopkins Workshops 3-7 June 2019, Lecture hall	53 (10)
6th Galaxy Evolution Workshop 5-7 June 2019, Lecture hall	88 (2)
Cryogenics and applied superconducting technologies to probe the physics of early universe 3 July 2019, Lecture hall	52 (2)
Toward new frontiers : Encounter and synergy of state-of-the-art 15-16 July 2019, Lecture hall	49 (0)
9th Hyper-Kamiokande Collaboration Meeting 2-6 September 2019, Kashiwa Research Complex	101 (34)
The cosmos at high energies: exploring extreme physics through novel instrumentation 16-18 October 2019, Lecture hall	93 (18)
Subaru Telescope 20th Anniversary Conference 17-22 November 2019, Waikoloa Beach Marriott Resort & Spa	240 (86)
Focus Week on Primordial Black Holes 2-6 December 2019, Lecture hall	54 (15)
The 14th Kavli Asian Winter School on Strings, Particles and Cosmology 13-22 January 2020, Tohoku University	106 (70)
East Asia Core Doctoral Forum in Mathematics 2020 14-17 January 2020, Lecture hall	60 (36)
Berkeley Week 14-17 January 2020, Seminar Room B	53 (15)
Astrophysics of Gravitational Wave Sources in LIGO/Virgo Third, Observational Run (O3) 20-24 January 2020, Lecture hall	45 (31)
Integral Geometry, Representation Theory and Complex Analysis 27-28 January 2020, Lecture hall	40 (5)
10th Hyper K Proto-collaboration Meeting 5-9 February 2020, Kashiwa Research Complex	95 (53)
Cosmic Acceleration 17-19 February 2020, Lecture hall	105 (9)

8 CONFERENCE PRESENTATIONS AND SEMINAR TALKS

Invited talks given by the Kavli IPMU researchers (Selected 10 of 186)

Date	Presenter	Presentation title	Conference name
May 20, 2019	Hirosi Ooguri	Swampland and Its Physical Implications	SUSY 2019
Jun. 14, 2019	Mikhail Kapranov	Perverse schobers and the algebra of the infrared	Resurgence in Mathematics and Physics
Jul. 1, 2019	Masahiro Takada	Challenges in large-scale structure cosmology	Dynamics of Large-scale Structure Formation
Aug. 2, 2019	Hiraku Nakajima	Bow varieties - I, II	Focus week on quiver varieties
Aug. 5, 2019	Yukinobu Toda	On categorical Donaldson-Thomas theory for local surfaces	The Conference on algebraic and arithmetic geometry
Sep. 4, 2019	Shigeki Matsumoto	Light Fermionic Thermal Dark Matter with Light Scalar Mediator	PACIFIC 2019
Sep. 9, 2019	Hitoshi Murayama	Dark matter candidates and strategies for future	TAUP 2019
Oct. 12, 2019	Misao Sasaki	Perspectives on Gravitational Wave Cosmology	International Meeting on Gravitational Wave Physics
Nov. 17, 2019	Naoyuki Tamura	PFS: The next generation Subaru's facility instrument under integration	Subaru Telescope 20th anniversary conference
Dec. 18, 2019	Mark Vagins	Supernova Neutrinos in a Gd-loaded SK	NuPhys 2019

9 OUTREACH AND PUBLIC RELATIONS

TITLE	DATE	VENUE	number of participants
20th Kavli IPMU/ICRR joint public lecture "Think about the beginning of the universe"	Apr. 13, 2019	Amuser Kashiwa, Chiba	372
Science Cafe 2019 "Universe"	Jun. 22, 2019	Tamarokuto Science Center, Tokyo	52
Learning and Creating Physics– From High Schools to the Forefront Research of the Universe	Aug. 5, 2019	Institute of Industrial Science, The University of Tokyo, Tokyo	50
Booth at the 2019 Super Science High School Student Fair	Aug. 7-8, 2019	Kobe International Exhibition Hall, Hyogo	523
15th exhibition at Kashiwa Library "Beautiful Mathematics"	Sep. 13-Oct. 10, 2019	Kashiwa Library, The Univ. of Tokyo, Chiba	uncounted
Science Cafe 2019 "Universe"	Sep. 21, 2019	Tamarokuto Science Center, Tokyo	36
Open Campus Kashiwa 2019	Oct. 25-26, 2019	Kashiwa Campus, The Univ. of Tokyo, Chiba	2,167
Actually I Really Love Physics! –Career Paths of Female Physics Graduates	Nov. 30, 2019	Kavli IPMU, Kashiwa Campus, The Univ. of Tokyo, Chiba	17
21st Kavli IPMU/ICRR joint public lecture "The Forefront of Universe Exploration"	Dec. 8, 2019	Yasuda Auditorium, The University of Tokyo, Tokyo	420
8th WPI Science Symposium "The Power of Mathematics: Bridging Worlds Together"	Jan. 12, 2020	Yasuda Auditorium, The University of Tokyo, Tokyo	481
Kavli IPMU/ELSI/IRCN Joint Public Lecture "A Question of Origins"	Feb. 16, 2020	Miraikan, Tokyo	158

Kavli IPMU
Annual Report 2019 April 2019–March 2020

Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU)
The University of Tokyo Institutes for Advanced Study
The University of Tokyo

5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8583, Japan TEL: +81-4-7136-4940 FAX: +81-4-7136-4941 http://www.ipmu.jp/

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

ISSN 2187-7386 Printed in Japan