April 2022–March 2023

Kavli IPMU

ANNUAL REPORT 2022

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

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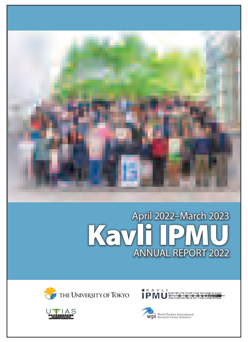


On the cover:
Group photo at the ceremony for the Kavli IPMU 15th anniversary.

FOREWORD

Hirosi Ooguri
Director

I write this with gratitude as my term as the Director will end on October 14, 2023. It has been an honor to serve as the Director of this amazing institute for the past five years.

When I became the Director, I set myself two missions.

One was to make the institute permanent. This requires a sustainable business model, both financially and in terms of long-term strategic planning. In terms of finances, thanks to the efforts of our administrative staff members and the support of the Board of Director of the University, we have secured one billion yen per year in the core funding category of the University of Tokyo budget. We also increased the Kavli IPMU endowment from $7.5 million to $17.5 million. The Kavli Foundation continues to support us; for example, this year they announced new funding for ELSI ethics research led by Hiromi Yokoyama and two inaugural Kavli Fellows, including our own Kateryna Vovk.

The long-term strategic planning exercise we undertook in my first year has guided us for the past five years. The launch of the Center for Data-Driven Discovery this year was part of that plan. I look forward to the development of the Center and its impact on our science under the leadership of Jia Liu.

Another mission has been to improve our Institute's Equity, Diversity, and Inclusion (EDI). In my inaugural address, I reaffirmed my commitment to EDI, stating, “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.” The Kavli IPMU Diversity Initiative, which we launched two years ago, is producing tangible results. For example, nearly 40 percent of the new postdoctoral fellows joining us this year and supported by our operating budget are women. We still have a long way to go to reach our EDI goals, and I look forward to further improvements under the leadership of the next Director.

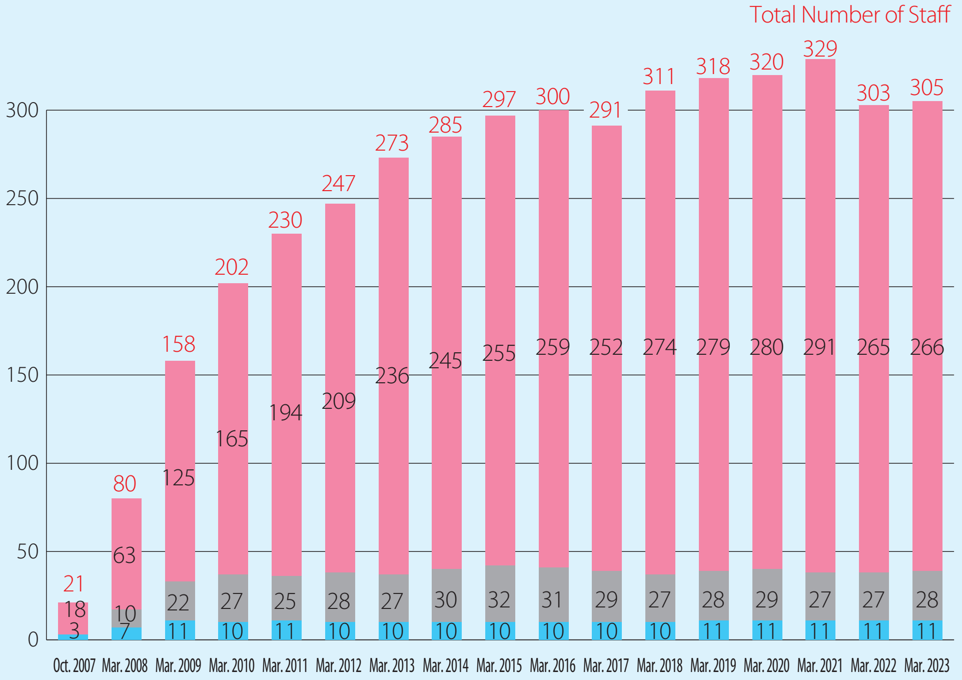
This report showcases the remarkably broad range of research activities at the Kavli IPMU, filled with creativity and great insight. I hope you enjoy reading it as much as I have.

Thank you for your support during my tenure. I am pleased with the improvements we have made over the past five years and am grateful for the support I have received. Our research in the Physics and Mathematics of the Universe is thriving, and I am delighted to be able to hand over the leadership to my successor, with the Kavli IPMU in such a good shape.

Hirosi Ooguri

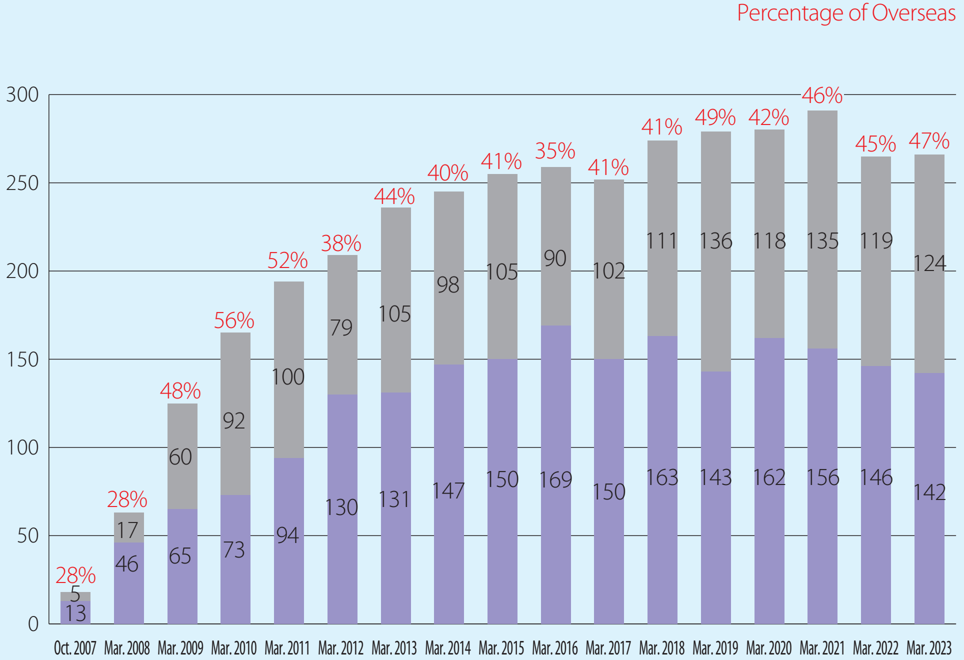
1 STATISTICS

STAFF



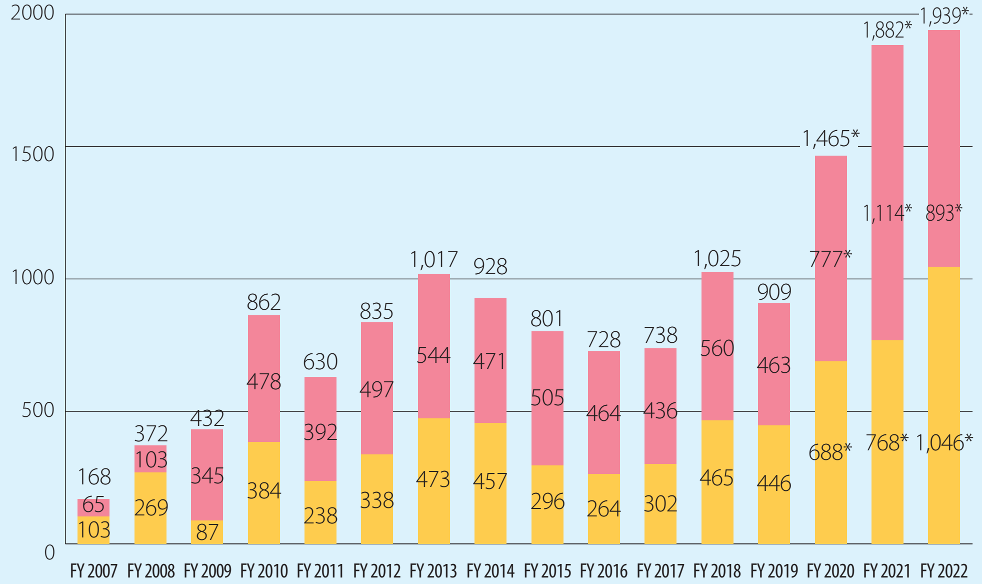
	Oct. 2007	Mar. 2008	Mar. 2009	Mar. 2010	Mar. 2011	Mar. 2012	Mar. 2013	Mar. 2014	Mar. 2015	Mar. 2016	Mar. 2017	Mar. 2018	Mar. 2019	Mar. 2020	Mar. 2021	Mar. 2022	Mar. 2023
🟥 Researchers	18	63	125	165	194	209	236	245	255	259	252	274	279	280	291	265	266
■ Research Support Staffs	0	10	22	27	25	28	27	30	32	31	29	27	28	29	27	27	28
🟦 Administrative staffs	3	7	11	10	11	10	10	10	10	10	10	10	11	11	11	11	11
Total	21	80	158	202	230	247	273	285	297	300	291	311	318	320	329	303	305

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	Mar. 2021	Mar. 2022	Mar. 2023
■ Overseas	5	17	60	92	100	79	105	98	105	90	102	111	136	118	135	119	124
■ Domestic	13	46	65	73	94	130	131	147	150	169	150	163	143	162	156	146	142
% of Overseas	28%	28%	48%	56%	52%	38%	44%	40%	41%	35%	41%	41%	49%	42%	46%	45%	47%
% of Female	0%	2%	5%	6%	5%	2%	5%	5%	6%	4%	6%	8%	9%	10%	9%	12%	12%

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	FY 2020	FY 2021	FY 2022
🟥 Visitors (Overseas)	65	103	345	478	392	497	544	471	505	464	436	560	463	777*	1,114*	893*
🟨 Visitors (Domestic)	103	269	87	384	238	338	473	457	296	264	302	465	446	688*	768*	1,046*
Visitors (Total)	168	372	432	862	630	835	1,017	928	801	728	738	1,025	909	1,465*	1,882*	1,939*

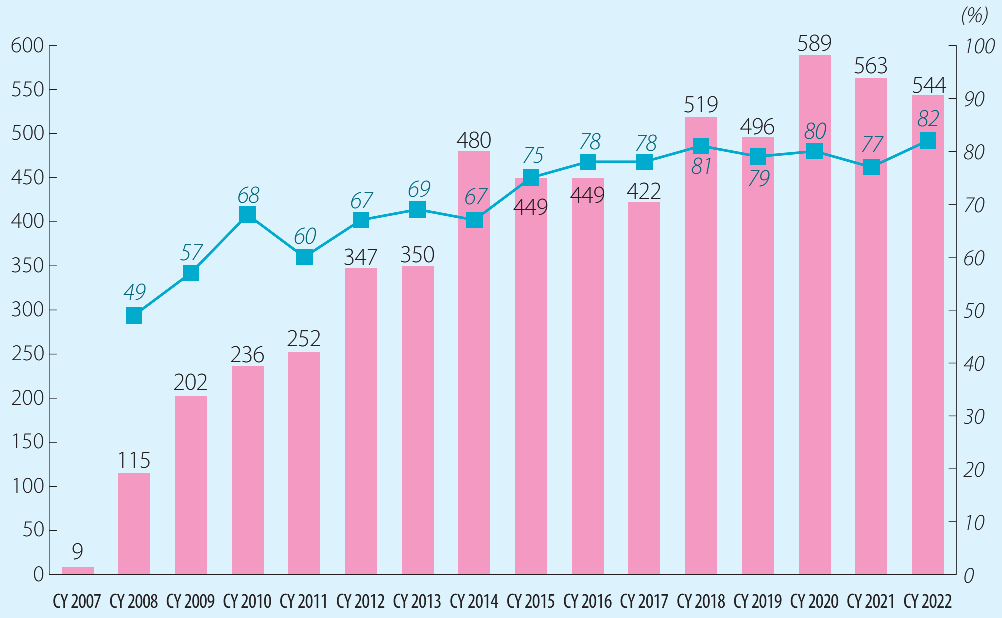
Multiple visits in a given year are counted as one.

* Number of participants for online conferences are included from FY2020 onward.

SEMINARS & CONFERENCES

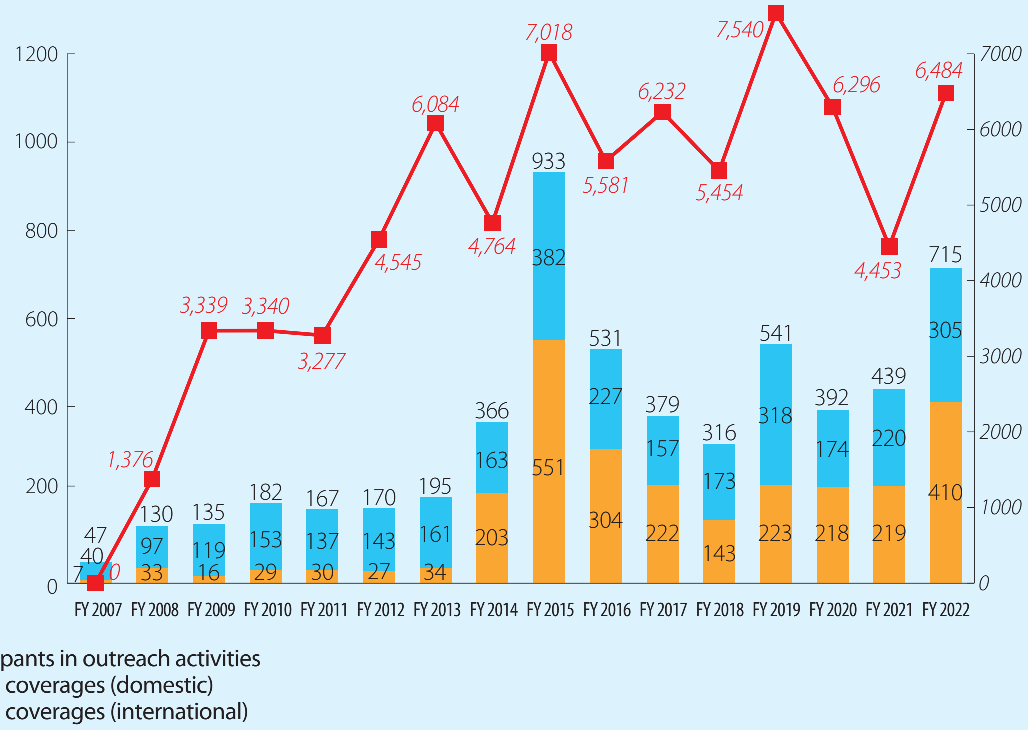
	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
🟩 Seminars	24	156	140	186	196	232	249	246	222	184	192	216	207	116	117	143
🟦 Conferences	4	7	11	16	12	11	14	13	17	14	11	21	18	8	12	12

PUBLICATIONS

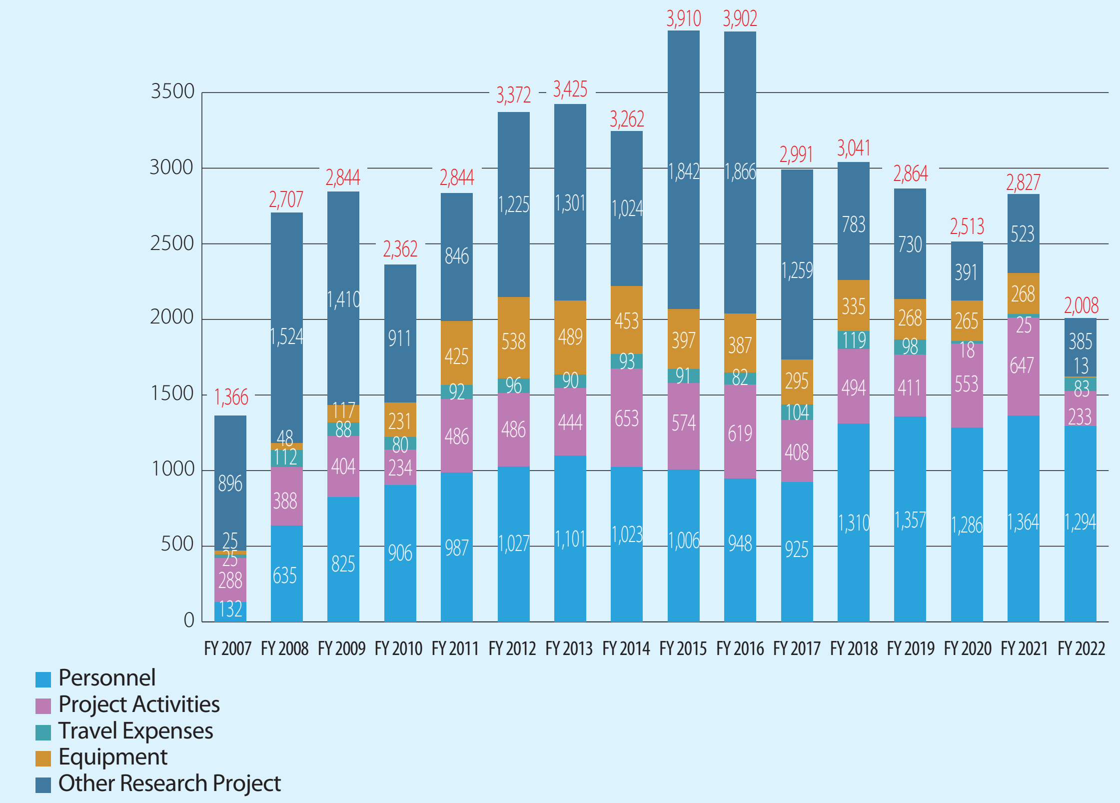


	CY 2007	CY 2008	CY 2009	CY 2010	CY 2011	CY 2012	CY 2013	CY 2014	CY 2015	CY 2016	CY 2017	CY 2018	CY 2019	CY 2020	CY 2021	CY 2022
🟪 Publications	9	115	202	236	252	347	350	480	449	449	422	519	496	589	563	544
🟦 % of int'l collaboration		49%	57%	68%	60%	67%	69%	67%	75%	78%	78%	81%	79%	80%	77%	82%

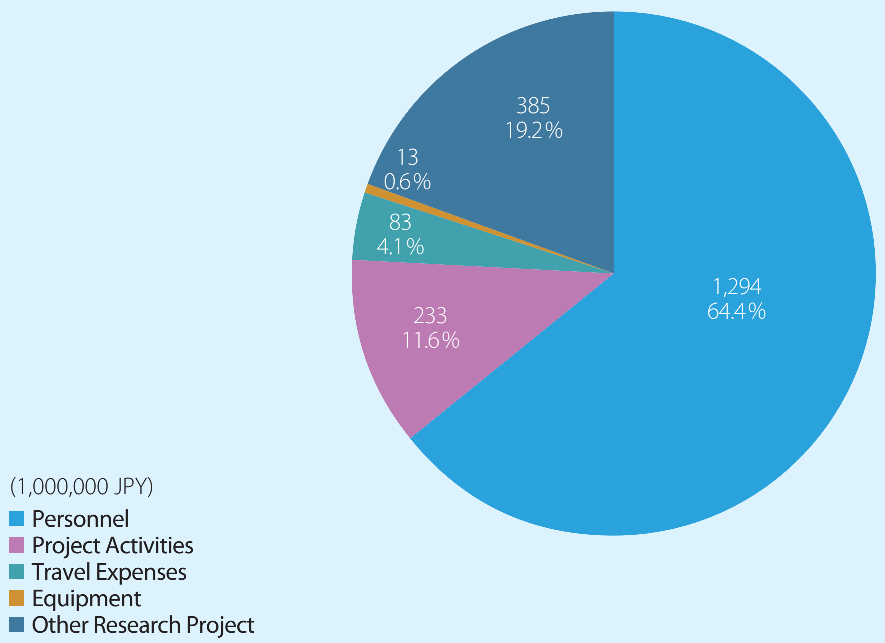
MEDIA COVERAGES AND OUTREACH ACTIVITIES



TOTAL EXPENDITURE



BREAKDOWN OF FY 2022 TOTAL EXPENDITURE



2 NEWS & EVENTS April 2022 - March 2023

APRIL

- >> Researchers use muonic X-rays to find elemental makeup of samples without damaging them
- >> Hiromi Yokoyama appointed new Deputy Director of Kavli IPMU
- >> Yukari Ito selected as new member of The Association of Academies and Societies of Sciences in Asia's Women in Science and Engineering Committee
- >> Researchers adapt technology made for astronomical observations to biomedical imaging
- >> Kyiv Formula and Related Aspects (Online)
- >> Extensive training on virtual universes from supercomputer simulations produces AI-assisted analysis of three-dimensional galaxy distribution in our Universe
- >> Millisecond Pulsars can explain the Gamma-ray Excess in the Milky Way center

MAY

- >> National Academy of Sciences elects Takaaki Kajita as new international member
- >> Researchers hunt for one-pole magnets by combining cosmic rays and particle accelerators

JUNE

- >> Researchers create 'time machine' simulations studying the lifecycle of ancestor galaxy cities
- >> Hiromi Yokoyama awarded the Tokyo Academy of Physics Award
- >> Hyper-Kamiokande Collaboration Meeting (Online)
- >> Geometric Representation Theory (Online)

JULY

- >> Informal Open House for the University of Tokyo Physics Major PhD Program
- >> Hiraku Nakajima elected President of the International Mathematical Union
- >> Researchers capture the first example of an extremely bright, and fast-evolving astronomical event in the distant universe
- >> Non-linear Aspects of Cosmological Gravitational Waves
- >> Director Hirosi Ooguri gives closing talk at Strings 2022
- >> First results from a Search for New Physics in Electronic Recoils from XENONnT

AUGUST

- >> Yukari Ito selected as executive committee member of the Asia-Oceania Women in Mathematics

SEPTEMBER

- >> Researchers develop a new way to see how people feel about Artificial Intelligence
- >> Researchers use gamma rays to detect small neighboring galaxy filled with Dark Matter
- >> State Minister of MEXT Yosei Ide visits Kavli IPMU

OCTOBER

- >> Alexander Kusenko appointed Associate Editor of Reviews of Modern Physics
- >> Hirosi Ooguri receives Science Lectureship Award
- >> Researchers measure size-luminosity relation of galaxies less than a billion years after Big Bang
- >> HirosiFest @ Kavli IPMU

NOVEMBER

- >> Kavli IPMU Senior Fellow Eiichiro Komatsu Receives Nishina Memorial Prize
- >> Prime Focus Spectrograph passes significant testing milestone to capture light from many stars at once
- >> Hitoshi Murayama named Chair of P5 Committee
- >> Kavli IPMU Annual Report 2021 released
- >> COVID-19 has had positive effect on astronomy research, but negative effect on new and female researchers

DECEMBER

- >> What the Heck Happens When the Universe Boils?
- >> Filaments of the cosmic web shine in the X-rays in the early eROSITA survey data
- >> Researchers say space atomic clocks could help uncover the nature of dark matter
- >> Masahito Yamazaki awarded the 19th JSPS Prize

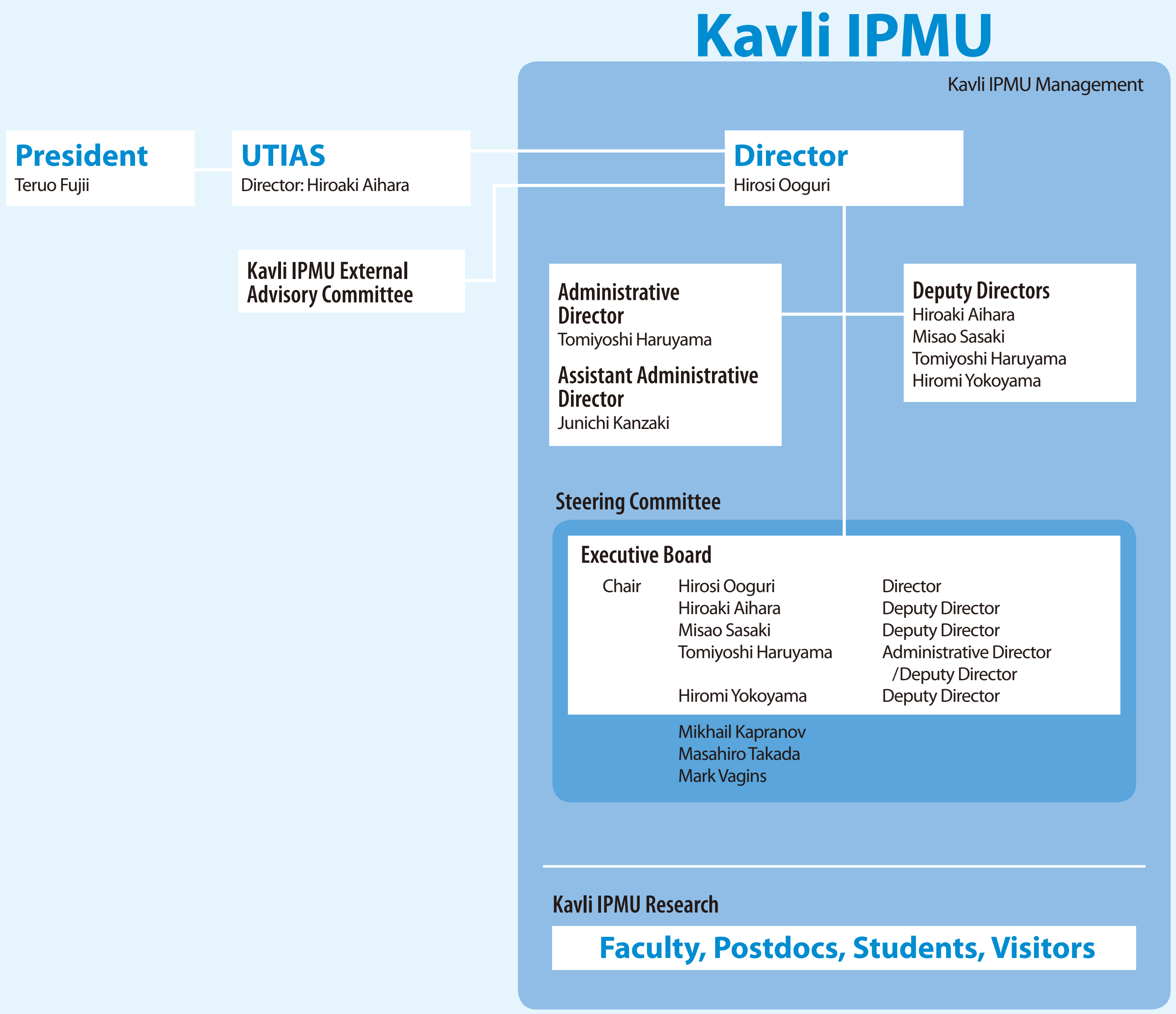
FEBRUARY

- >> Current Trends in Categorically Approach to Algebraic and Symplectic Geometry
- >> Geometry and Automorphicity of Supersymmetric Partitions (GASP)
- >> ISAS/JAXA Director General Hitoshi Kuninaka visits Kavli IPMU
- >> Gauge Theory, Moduli Spaces and Representation Theory -In Honor of the 60th Birthday of Hiraku Nakajima-
- >> Interdisciplinary Science Conference in Okinawa (ISCO 2023) -Physics and Mathematics Meet Medical Science-

MARCH

- >> PFS Collaboration Meeting
- >> FY2022 "What Is Dark Matter? - Comprehensive Study of the Huge Discovery Space in Dark Matter"
- >> Researchers uncover the first bubble in an intergalactic stew
- >> Instrument adapted from astronomy observation helps capture singular quantum interference effects
- >> Artificial intelligence finds the first stars were not alone
- >> First WIMP Search Results from the XENONnT
- >> Center of Data-Driven Discovery launched in the Kavli IPMU

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 Director of the University of Tokyo Institutes for Advanced Studies (UTIAS). The Director has complete authority to hire research staff and administrative staff. He is also solely responsible for making all other decisions. He is assisted by the four Deputy Directors and the Administrative Director. They constitute the Executive Board (EB) and regularly meet to ensure the 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 faculty members to the Director of UTIAS. Also, to clear the university's formality in faculty hiring, the decisions of the Institute have to be endorsed by the Steering Committee of the Kavli IPMU.

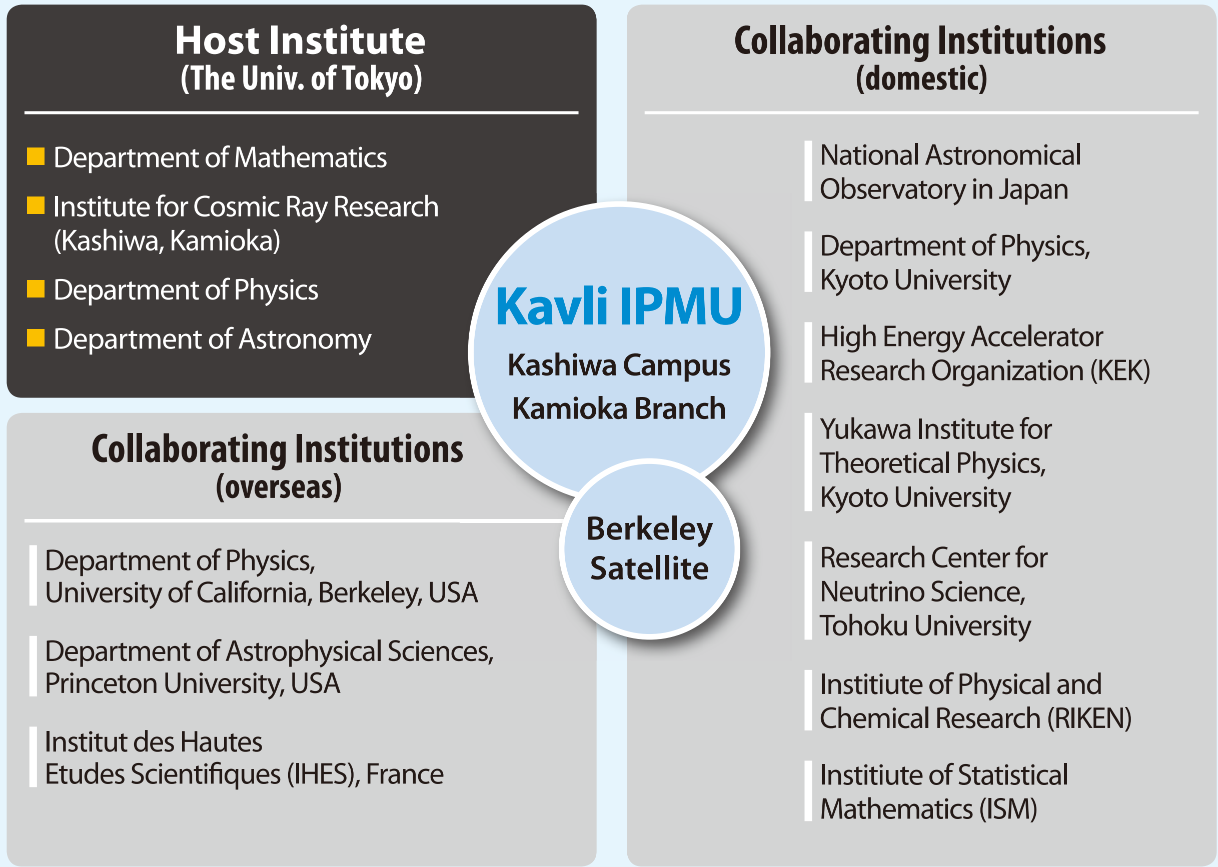
The Principal Investigator scheme is abolished, and all the Full Professors at Kavli IPMU are regarded as equivalent to PIs.

The External Advisory Committee (EAC), appointed by the Director of the Kavli IPMU, reviews annually the scientific achievement and activities of the Institute and advises the Director on scientific properties and the research activities to keep the Institute stay on the course of the objectives.

The External Advisory Committee Members (March 2021)

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
Yongbin Ruan	Zhejiang University	Mathematics
Sakura Schafer-Nameki	U Oxford	Mathematical Physics
Nigel Smith	TRIUMF	Astroparticle Physics

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.



Host Institute
(The Univ. of Tokyo)

- Department of Mathematics
- Institute for Cosmic Ray Research (Kashiwa, Kamioka)
- Department of Physics
- Department of Astronomy

Kavli IPMU
Kashiwa Campus
Kamioka Branch

Berkeley Satellite

Collaborating Institutions
(overseas)

- Department of Physics, University of California, Berkeley, USA
- Department of Astrophysical Sciences, Princeton University, USA
- Institut des Hautes Etudes Scientifiques (IHES), France

Collaborating Institutions
(domestic)

- National Astronomical Observatory in Japan
- Department of Physics, Kyoto University
- High Energy Accelerator Research Organization (KEK)
- Yukawa Institute for Theoretical Physics, Kyoto University
- Research Center for Neutrino Science, Tohoku University
- Instiitute of Physical and Chemical Research (RIKEN)
- Instiitute of Statistical Mathematics (ISM)

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 (U Tokyo), High Energy Physics
Tomiyoshi Haruyama, High Energy Physics
Misao Sasaki, Cosmology
Hiromi Yokoyama, Science and Society

Senior Fellow
Alexey Bondal (Steklov Math. Inst.), Mathematics (from 2022/5/1)
Takaaki Kajita (U Tokyo, ICRR), Neutrino Physics (from 2022/5/1)
Eiichiro Komatsu (MPI for Astrophysics), Cosmology (from 2022/5/1)
Masayuki Nakahata (U Tokyo, ICRR), Astroparticle Physics (from 2022/5/1)
Mihoko Nojiri (KEK), Particle Theory (from 2022/5/1)
Andrei Okounkov (Columbia U), Mathematics (from 2022/6/1)
Naoshi Sugiyama (Nagoya U), Cosmology (from 2022/5/1)

Faculty Members
Tomoyuki Abe, Mathematics
Hiroaki Aihara (U Tokyo), High Energy Physics
Alexey Bondal (Steklov Math. Inst.), Mathematics (2022/10/4-2023/2/15)
Patrick De Perio, Neutrino Physics (from 2022/4/1)
Elisa Gouvea Mauricio Ferreira, Cosmology
Mark Patrick Hartz, Neutrino Physics
Tomiyoshi Haruyama, High Energy Physics
Simeon John Hellerman, String Theory
Takeo Higuchi, High Energy Physics
Kentaro Hori, String Theory
Shunsaku Horiuchi (Virginia Tech), Theoretical Physics (till 2022/8/9)
Yukari Ito, Mathematics
Mikhail Kapranov, Mathematics
Nobuhiko Katayama, High Energy Physics (till 2023/3/31)
Khee-Gan Lee, Astronomy
Jia Liu, Cosmology
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
Toshiya Namikawa, Cosmology
Andrei Okounkov (UC Berkeley), Mathematics (till 2022/5/31)
Hirosi Ooguri (CALTECH), Mathematical Physics
Tadashi Orita, Experimental Physics
Misao Sasaki, Cosmology
Satoshi Shirai, Particle Theory
John David Silverman, Astronomy
Yuji Tachikawa, Particle Theory
Masahiro Takada, Cosmology
Tadayuki Takahashi, Experimental Physics
Shinichiro Takeda, Experimental Physics
Naoyuki Tamura, Astronomy (till 2023/3/31)
Yukinobu Toda, Mathematics
Mark Robert Vagins, Astroparticle Physics
Taizan Watari, Theoretical Physics
Atsushi Yagishita, Experimental Physics
Masaki Yamashita, Astrophysics
Masahito Yamazaki, String Theory
Naoki Yasuda, Astronomy
Hiromi Yokoyama, Science and Society
Naoki Yoshida (U Tokyo), Astrophysics

Project Researchers
Noah Maxwell Arbesfeld, Mathematics (till 2023/3/31)
Joaquin Andres Armijo Torres, Cosmology (from 2022/10/1)
Meer Ashwinkumar, String Theory
Metin Ata, Cosmology (till 2022/9/30)
Jahmall Matteo Bersini, Theoretical Physics (from 2022/11/1)
Tobias Binder, Theoretical Physics (till 2022/4/30)
Connor Hugh Bottrell, Astrophysics
Philip Ewen Boyle Smith, Theoretical Physics
Tuan Khai Bui, Experimental Physics (till 2023/3/31)
Anqi Chen, Cosmology
Man Wai Cheung, Mathematics (from 2022/10/1)
Ioana Alexandra Coman Lohi, Theoretical Physics (from 2022/11/1)
Anton Reyes De La Fuente, String Theory (till 2022/6/30)
Xuheng Ding, Astronomy
Zhiyuan Ding, Mathematics (till 2022/8/31)
Joshua Armstrong Eby, Cosmology
Dmitrii Galakhov, String Theory (till 2022/8/31)
Naoki Genra, Mathematics (till 2023/3/31)
Tommaso Ghigna, Experimental Physics (till 2022/7/31)
Ryuichiro Hada, Cosmology (2022/4/1-8/31)
Norihiro Hanihara, Mathematics
Takashi Hasebe, High Energy Physics (till 2023/3/31)
Thuong Duc Hoang, Experimental Physics
Shunichi Horigome, Theoretical Physics
Derek Beattie Inman, Cosmology
Kazuhiro Ito, Mathematics
Cesar Jesus Valls, Neutrino Physics (from 2022/10/1)
Baptiste Jost, Cosmology (from 2023/2/1)
Boris Sindhu Kalita, Astrophysics (from 2023/1/16)
Kookhyun Kang, High Energy Physics
Dogancan Karabas, Mathematics (from 2022/10/1)
Miho Katsuragawa, Experimental Physics
Ilya Khrykin, Astrophysics
Tasuki Kinjo, Mathematics (2022/10/1-2023/3/31)
Takafumi Kokubu, Theoretical Physics
Yun-Tsung Lai, High Energy Physics (till 2022/9/30)
Clement Leloup, Cosmology (from 2022/10/1)
Kaloian Dimitrov Lozanov, Cosmology (from 2022/11/1)
Abhiram Mamandur Kidambi, Mathematical Physics
Mohammad Khaled Hashem Mardini, Astronomy
Dmytro Matvieievskyi, Mathematics (from 2022/9/1)
Katherine Alston Maxwell, Mathematics (from 2022/9/1)
Yue Nan, Cosmology (from 2022/4/1)
Emily Margaret Nardoni, Theoretical Physics
Ippei Obata, Theoretical Physics (from 2022/10/1)
Youngsoo Park, Cosmology (till 2022/9/15)
Samuel Charles Passaglia, Cosmology
Ipsita Saha, Particle Theory (2022/6/1-9/12)
Jingjing Shi, Cosmology
Myungbo Shim, Theoretical Physics (from 2022/8/29)
Tomoko Suzuki, Astronomy
Volodymyr Takhistov, Theoretical Physics (till 2022/8/31)
Hideki Tanimura, Astrophysics (from 2022/10/1)
Ka Ming Tsui, Neutrino Physics (from 2022/12/1)
Izumi Umeda, Nuclear Medicine (till 2023/3/31)
Valeri Vardanyan, Cosmology
Kateryna Vovk, Astronomy (from 2022/12/16)
Graham Albert White, Particle Theory
Junjie Xia, Neutrino Physics (from 2022/11/1)
Kiyoto Yabe, Astronomy (till 2023/3/31)
Lilan Yang, Astronomy
Hassen Yesuf, Astronomy (till 2023/2/28)
Wai Kit Yeung, Mathematics (till 2023/1/31)
Vicharit Yingcharoenrat, Cosmology
Yu Zhao, Mathematics
Yunqin Zheng, Theoretical Physics
Yehao Zhou, Mathematical Physics (from 2022/10/16)
Zijun Zhou, Mathematics

Joint Appointments

Mark Patrick Hartz (TRIUMF), Neutrino Physics
Masashi Hazumi (KEK), High Energy Physics
Hitoshi Murayama (UC Berkeley), Particle Theory
Hirosi Ooguri (CALTECH), Mathematical Physics
Naoki Yoshida (U Tokyo), Astrophysics

Affiliate Members

Ko Abe (U Tokyo, ICRR), Astroparticle Physics
Shin'ichiro Ando (U Amsterdam), Astroparticle Physics
Metin Ata (Stockholm U), Cosmology (2022/10/1-2023/3/31)
Bruce Berger (LBL, Berkeley (LBNL)), Neutrino Physics (till 2023/3/31)
Melina Bersten (IALP CONICET-UNLP), Astronomy (till 2023/3/31)
Sergey Blinnikov (ITEP), Astronomy
Agnieszka Maria Bodzenta-Skibinska (U Warsaw), Mathematics
Alexey Bondal (Steklov Math. Inst.), Mathematics
Kevin Allen Bundy (UC Santa Cruz), Astronomy
Andrew Bunker (U Oxford), Astrophysics
Scott Huai-Lei Carnahan (U Tsukuba), Mathematics
Cheng-Wei Chiang (Natl Taiwan U), Particle Theory
Yuji Chinone (KEK), Astronomy
Neal Krishnakant Dalal (Perimeter Institute), Astrophysics
Patrick Decowski (U Amsterdam/GRAPPA), Neutrino Physics
Jason Detwiler (U Washington, Seattle), Neutrino Physics
Mamoru Doi (U Tokyo, IoA), Astronomy
Christine Done (Durham U), Astrophysics
William Ross Goodchild Donovan (Tsinghua U, Beijing), Mathematics
Yuri Efremenko (U Tennessee), Neutrino Physics (till 2023/3/31)
Motoi Endo (KEK), Particle Theory
Sanshiro Enomoto (U Washington, Seattle), Neutrino Physics
Gaston Folatelli (IALP CONICET-UNLP), Astrophysics (till 2023/3/31)
Andreu Font-Ribera (IFAE), Cosmology (till 2023/3/31)
Brian Fujikawa (LBL, Berkeley), Neutrino Physics
Masataka Fukugita (U Tokyo), Astrophysics
Shao-Feng Ge (Shanghai Jiao Tong U), Theoretical Physics
Paolo Gondolo (U Utah), Cosmology (till 2023/3/31)
Lawrence J Hall (UC Berkeley), Particle Theory
Koichi Hamaguchi (U Tokyo), Particle Theory
Jiaxin Han (Shanghai Jiao Tong U), Astronomy (till 2023/3/31)
Keisuke Harigaya (U Chicago), Particle Theory (from 2022/9/1)
Tilman Hartwig (U Tokyo), Astrophysics (till 2023/3/31)
Tetsuo Hatsuda (RIKEN), Nuclear Physics
Yoshinari Hayato (U Tokyo, ICRR), Neutrino Physics
Katsuki Hiraide (U Tokyo, ICRR), Astroparticle Physics
Raphael Hirschi (Keele University), Astronomy
Junji Hisano (Nagoya U), Particle Theory
Shunsaku Horiuchi (Virginia Tech), Theoretical Physics (from 2022/8/10)
Kenta Hotokezaka (U Tokyo, School of Sci), Astrophysics
Masahiro Ibe (U Tokyo, ICRR), Particle Theory
Kei Ieki (U Tokyo, ICRR), Neutrino Physics
Motoyasu Ikeda (U Tokyo, ICRR), High Energy Physics
Shiro Ikeda (ISM), Mathematics
Yuko Ikkatai (Kanazawa U), Science and Society
Yoshiyuki Inoue (Osaka U), Astrophysics
Miho N. Ishigaki (NAOJ, Hawaii), Astronomy
Ken'ichi Izawa (Tokushima U) (till 2023/3/31)
Nicholas Kaiser (ENS PSL), Cosmology (till 2023/3/31)
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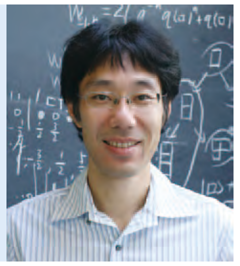
5 RESEARCH HIGHLIGHTS

5.1 Characteristic Cycle and Its Pushforward



Tomoyuki Abe

Assume we want to classify (closed compact) surface topologically. For example, let S be the surface of a sphere, and D be that of donuts. How can we distinguish these two surfaces? One of the very classical answers, going back to Euler, is to pay attention to the number of "holes" of the surface. In our example, S has no hole, contrary to D having one hole in the center. Poincare proved that in fact surfaces can be classified (topologically) by this invariant, and the number of holes is now called the *Euler-Poincaré characteristic* (*EP characteristic* for short). This invariant can also be defined for higher dimensional manifolds, and it is one of the most important invariants when we want to understand the manifold topologically.

Now, consider a smooth variety over $\mathbb{C}$, namely the geometric object given by zeros of polynomials with $\mathbb{C}$-coefficients which doesn't have singularities. In this situation, we can also consider the EP characteristic by regarding the variety as a manifold. Assume that we are a covering $f: X \to Y$. Namely, this is a locally homeomorphism such that the function which associates $\# f^{-1}(y)$ to a point y of Y is finite and constant whose value is denoted by $deg(f)$. Then it is not hard to show that

$$\chi(X) = \deg(f)\,\chi(Y). \qquad (*)$$

Motivated by Weil's conjecture, Grothendieck and his school constructed a similar theory for varieties over more exotic field, say finite field $\mathbb{F}_p$. Varieties over $\mathbb{F}_p$ is a priori a very discrete object, but his theory enables us to extract "topological invariants" like EP characteristic from such varieties. However, Grothendieck noticed that the formula $(*)$ doesn't hold anymore even in the case where Y (and consequently X as well) is a curve. He asked Serre how to understand the difference in the curve case, and Serre suggested to consider the local invariant called the Swan conductor. This is the genesis of ramification theory. Ramification theory explains the difference as contributions from the "boundary" of Y, and Grothendieck showed his famous Grothendieck-Ogg-Shafarevich (GOS) formula. We note that the appearance of ramification is not particular to number theory. Somewhere in 70's, it was observed by experts including Deligne and Laumon that the ramification behaves similarly to irregularity of linear differential equations over complex field. This observation would become important in the further development of ramification theory, which we will come back below.

A natural question is to generalize this formula to higher dimensional situation. This question turns out to be very hard. Even the formulation is not clear: in the curve case the boundary of Y consists of finitely many points, so associating a number to each point is reasonable. However, in the higher dimensional setup, the boundary does not necessarily consist of finitely many points but rather itself a higher dimensional variety. Thus, it is natural to expect that the geometry of the boundary also contributes to the difference of EP characteristics.

After numerous studies of ramifications of higher dimensional variety, notably by Deligne, Laumon, Bloch, K. Kato, etc., Takeshi Saito finally gave a definitive answer in around 2015 after the existence of "singular support" by Beilinson. The formulation was suggested by the theory of $\mathcal{D}$-modules, which is an algebraic theory of linear partial differential equations, as I alluded. Let X be a smooth variety over $\mathbb{F}_p$. For a (étale) sheaf $\mathcal{F}$ on X, Saito defines a middle dimensional cycle in the cotangent bundle T^*X called the *characteristic cycle* and denoted by $\mathrm{CC}(\mathcal{F})$. When X is a curve, this can be described in terms of Swan conductor. After suggestions of Deligne and Beilinson, Saito also showed the index formula, namely when X is projective as well, we have

$$\chi(X, \mathcal{F}) = \deg(\mathrm{CC}(\mathcal{F}), [X]).$$

In the case of curves, we can retrieve GOS formula from the index formula, and the index formula can be regarded as a generalization. Considering the philosophy of Grothendieck-Riemann-Roch theory, it is natural to expect its "relative version". In fact, this was formulated by Saito and left as a conjecture. Saito's pushforward conjecture states as follows: Let $f: X \to Y$ be a proper morphism between smooth varieties. Under this situation, we may define the pushforward of cycles $f_{\mathrm{o}}: \mathrm{CH}_{\dim(x)}(T^*X) \to CH_{\dim(Y)}(T^*Y)$. The (weak version[1] of) pushforward conjecture states that

$$f_{\mathrm{o}}: (\mathrm{CC}(\mathcal{F})) = \mathrm{CC}(\mathrm{R}f_*\mathcal{F}).$$

Saito himself verified the conjecture in specific (but important) cases. I proved[2] this conjecture up to p-torsion. One of the reasons why the proof of the identity is so hard is that it is not a coincidence of actual cycles but we need to *construct* a homotopy between them. To overcome this difficulty we need various techniques, notably the theory of ∞-categories, the theory of nearby cycle over higher dimensional bases, and the motivic homotopy theory. Another important input is an idea from p-adic cohomology theory, especially the idea of the proof of the semistable reduction theorem. To define the characteristic cycle, we need to choose nice functions. The existence of such functions is exactly where we need Beilinson's existence of singular support in the construction of characteristic cycle by Saito. To show the pushforward conjecture, we need to upgrade this to the family version, and this is where the ideas from semistable reduction theorem is required.

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[1] Original conjecture of Saito is stronger, but for simplicity of the presentation, we only state the weaker version.

[2] Abe, T.: "Ramification theory from homotopical point of view, I", arxiv.org/abs/2206.02401.

5.2 A Novel Proposal to Search for Ultralight Dark Matter Using Atomic Clocks in Space

Joshua Armstrong Eby

Our recent work investigated a novel way to potentially learn the nature of dark matter, which is a mysterious substance which makes up a large fraction of the mass in the universe. Our proposal involves an atomic clock search on-board a spacecraft in the inner reaches of the solar system, inside the orbit of Mercury and very near to the Sun. An important advantage in this search is that in this region of the solar system, the density of dark matter may be exceedingly large, leading to exceptional sensitivity to dark matter signals. Our work was published in the journal *Nature Astronomy* on December 5, 2022 [1].

Recent advances in the study of atomic and nuclear systems have opened the door to many novel searches for dark matter with extremely high sensitivity [2]. These systems are capable of probing dark matter particles which have very small masses, because large collections of such particles naturally oscillate with wavelengths that are intrinsically macroscopic. As a result, their interactions with ordinary matter (including photons and electrons) can induce apparent oscillations of the fundamental constants of nature, including the interaction strength of the electromagnetic force or the mass of the electron. These oscillations therefore induce changes in the energies observed in atomic or nuclear transitions, allowing us to search for effects from dark matter in these systems.

Any search for dark matter relies on a key assumption about the so-called *local density of dark matter*, which determines the number of dark matter particles passing through the detector at any given time and therefore the experimental sensitivity. The density can be much higher than is usually assumed if the dark matter can be captured into stable bound configurations, which is a topic of vibrant recent discussion in recent literature. There is good reason to believe that the strong gravitational field of the Sun provides an effective trap for these dark particles, leading to a large overdensity very near the Sun. In a separate work (still in preprint) with other collaborators, I have established a novel mechanism to capture ultralight particles around the Sun using dark matter self-interactions, providing a concrete target for the searches proposed in this work [3].

While the precise density of the dark matter near the Sun depends on the details of the model, we show in our work how even a relatively low-sensitivity search can provide important information. The current strongest constraints on the dark matter density in the solar system comes from observations of the orbits of planets, and therefore in the region between Mercury and the Sun, the constraints are extremely weak. Our proposal combines the two above insights: We seek to utilize the high precision of modern atomic and nuclear clocks in a very novel environment (near the Sun), where the dark matter density may be much higher than normal. Such a probe could therefore provide world-leading limits on accumulation of ultralight particles near the Sun, or even lead to a dark matter discovery.

The proposed space mission is partly motivated by several ongoing missions from organizations around the world. For example, the NASA Parker Solar Probe has been in operation since 2018 has travelled closer to the Sun than any human-made craft in history, with the help of cutting-edge heat-shield technology. At present, the Parker Solar Probe is operating inside the orbit of Mercury, and will approach its target distance, deep inside the solar coronal radius, within the year. Another mission, the NASA Deep Space Atomic Clock, has demonstrated that atomic clocks can be operated in space with very little loss in precision, providing additional indirect support for our proposal.

In addition, there are strong reasons for sending atomic clocks in space beyond searches for dark matter; a few such reasons include spacecraft navigation, improved GPS technology, and highly-precise tests of General Relativity. Along these lines, the atomic physics and particle physics community have recently worked together to understand how the study of atomic systems in space could benefit fundamental science more broadly [4].
We propose that in the future, a network of atomic or nuclear clocks around the solar system could provide all of these benefits while simultaneously providing novel ways to discover dark matter.

References

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[2] M. S. Safronova, D. Budker, D. DeMille, D. F. Jackson Kimball, A. Derevianko, and C. W. Clark, *Search for New Physics with Atoms and Molecules*. Rev. Mod. Phys. 90 (2018) 2, 025008. [arXiv: 1710.01833 [physics.atom-ph]]
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5.3 Tensions in Cosmology and How We Infer Them

Elisa Gouvea Mauricio Ferreira

With the increase of our theoretical knowledge but mostly with the improvement of the observations of our universe, most notably those of the afterglow of the hot early Universe called the cosmic microwave background (CMB), our understanding of cosmology has gone through a revolution in the past decades. We have nowadays the standard cosmological model (a.k.a ΛCDM - Λ cold dark matter), a parametrization capable of explaining a large part of the evolution of our universe, its composition, and the structures we see today. This model is extremely successful observationally, having most of its 6 parameters measured with a sub percent precision.

However, with the increase in the precision that we measure the parameters that describe our universe discrepancies have appeared. Those are discrepancies between the values of cosmological parameters directly measured or predicted from different observational techniques that have become statistically significant with the latest data analyses. We call these discrepancies *cosmological tensions*. These have been taking the attention of the cosmology community and are considered by some one of the most pressing problems in cosmology nowadays.

The most important and significant of these tensions is the "Hubble tension" (or H_0 tension). Measurements of the Hubble constant, H_0, the present-day expansion rate of the universe, obtained via indirect measurements, which depend on the assumption of a cosmological model, yield systematically lower values of H_0 than direct measurements, which do not or weakly depend on the assumption of a cosmological model. The most significant tension is seen between the (indirect) inference of H_0 from CMB data of the *Planck* mission assuming the standard cosmological model (ΛCDM) [1], $H_0 = 67.4 \pm 0.5$ km/s/Mpc, and the (direct) local inference from Cepheid-calibrated Type Ia supernovae of the SH0ES project [2], $H_0 = 73.0 \pm 1.0$ km/s/Mpc, see Fig. 1. The statistical significance of the tension is currently 5σ!

Despite the importance of this measurement, the origin of this discrepancy is still unknown. This could represent unknown systematics in the measurement and analysis of these observations. Or this tension could hint at new physics beyond the ΛCDM model.

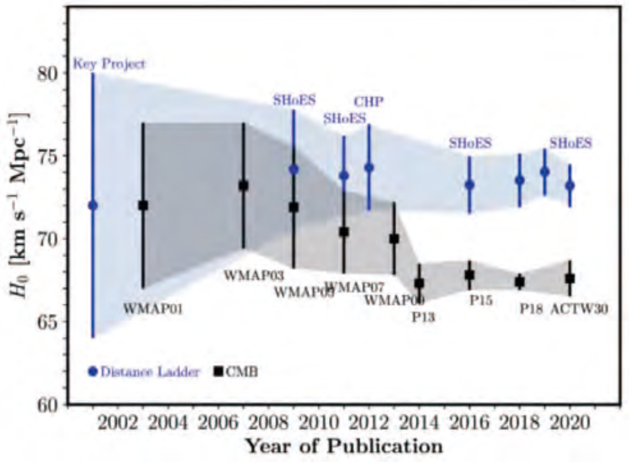

Figure 1: Value of the Hubble parameter measured over the years using direct measurements (blue) and indirect measurements from CMB experiments (black).

There are proposals for beyond ΛCDM models to solve the H_0 tension modifying either the early or the late evolution of the universe. One of the proposed models to alleviate the tension is early dark energy (EDE) (see [3] for a review). This model has been classified as one of the most promising solutions to the H_0 tension. In this model, the ΛCDM cosmology is extended to include a dark energy-like component in the pre-recombination era, before the CMB, that boosts the expansion rate of the universe before rapidly decaying. After its proposal, different authors performed separate analysis and there was not a consensus in the literature on the role of EDE in solving the Hubble tension and whether EDE was favored by both CMB and large-scale structure (LSS) data.

In order to resolve this confusion and determine the status of EDE to solve the Hubble tension, in collaboration with Laura Herold and Eiichiro Komatsu, we explored this problem in a series of papers [4, 5, 6]. Using a complementary statistical method, the profile likelihood, we showed in [4] [1](with a follow up in [6]) that the discrepancy between previous analyses came due to what is called prior volume effects or marginalization effects present in the standard statistical methods based on Markov Chain Monte Carlo (MCMC) that biases the results obtained. With that, we could obtain a consistent confidence interval for H_0, see fig. 2, using a prior-free method and conclude that EDE indeed resolves the Hubble tension, being in statistical agreement with the SH0ES direct measurement at <1.7σ for CMB (*Planck*) and LSS (BOSS) data.

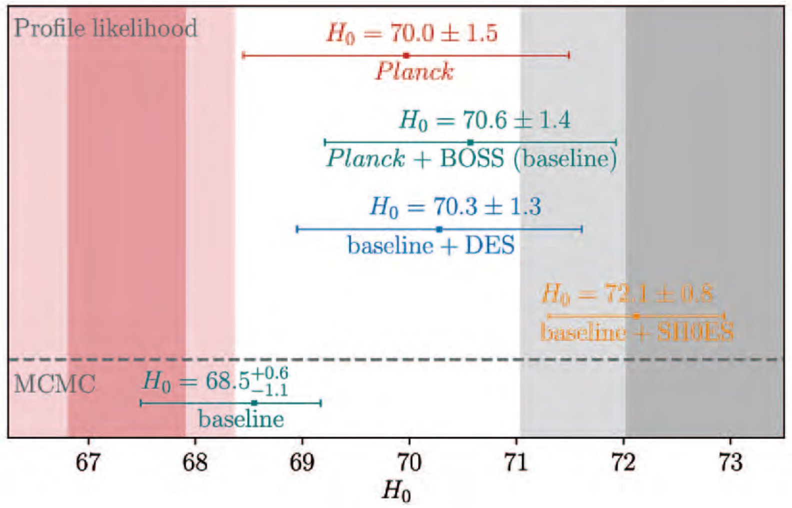

Figure 2: Values of H_0 obtained using profile likelihood and MCMC for the EDE model [6]. For comparison, the gray and red shaded areas show the 1σ and 2σ constraint for H_0 from SHOES [2] and Planck [1], respectively.

More than just for the case of EDE, our work called the attention and convinced the cosmology community that marginalization effects in MCMC are important and should be seriously taken into consideration in cosmological analysis. This can be seen in the inclusion of this type of analysis or the use of profile likelihoods by a growing number of authors and into some observational collaborations. As we are showing in some upcoming papers using different observational data and data analyses, the method shown here is a necessary tool for the statistical analyses and data sets that are subject to marginalization effects.

This discussion and expertise is especially relevant for the upcoming surveys, like the Prime Focus Spectrograph, a collaboration led by IPMU, or stage 4 projects, where these statistical analyses are going to be much more intricate. Studying these cosmological tension, but mainly applying this and other statistical tools in order to proper infer cosmological parameters is one of the goals of my group at IPMU, together with my collaborators.

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[6] Laura Herold and Elisa G. M. Ferreira, Phys. Rev. D 108, 043513 (2023).

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[1] Laura Herold won the Kippenhahn Prize 2023 for this article.

5.4 What Can We Do With Asian-Oceanian Women in Mathematics?

Yukari Ito

I am a mathematician and my research area is algebraic geometry. I meet only one or two women when I attend a conference on algebraic geometry in Japan. This situation has been the same since I was a graduate student. The percentage of women in Mathematical Society of Japan is 6 and those of female professors in the top 10 universities in Japan is almost 1. It is not the same in other countries and there may be gender bias to be a mathematician in Japan.

If you see around the world, there are several associations for women in mathematics. For example, Association for Women in Mathematics (AWM) is now more than 50 years old and it is a big power in mathematical society in the United States. Now the president of American Mathematical Society (AMS) and the director of Mathematical Science Research Institute (MSRI, will change the name to SL(Simons Laufer) Math) are women. But both of them said to me they still need AWM and they said it helps women in various situation.

There were 4 continental organizations for women in mathematics (See the map: Fig.1) and in 2022, August 1, a new association for women in mathematics in Asia and Oceania was born and I became a member of the executive committee. It is Asian-Oceanian Women in Mathematics (AOWM) with the following purpose and so on:

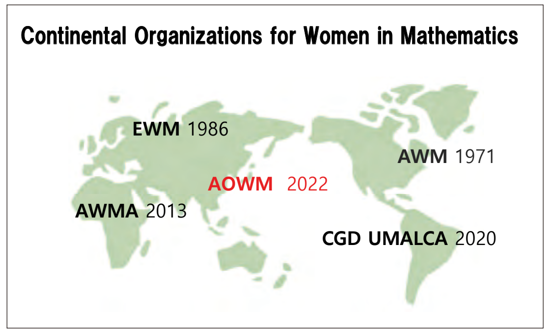

Fig. 1: Continental Organizations for Women in Mathematics.

Purpose Promote activities of all aspects of women in mathematics in Asia and Oceania, support research and career pursuit of young women in particular.
Activities Exchange information, strengthen communications and networks, provide meeting opportunities and places as a forum, workshops, schools in special topics, training opportunities, prize for young women in mathematics, Webpage, mailing list, newsletter, and data base.
Membership Any women working or studying in mathematics at universities in Asia or Oceania. And men can be a member except for a member of the executive committee.

Let's see the history before the birth. In 2020, Kyewon Koh Park and Soonyi Kang wrote an article on KWMS (Korean Women in Mathematical Sciences) for AWM 50th Anniversary publication: *Fifty Years of Women in Mathematics: Reminiscences, History, and Visions for the Future of AWM.* Around the end of the article they wrote regarding an association for women mathematicians in Asia.
Then Marie-Francoise Roy who was a chair of CWM (Committee for Women in Mathematics under International Mathematical Union) showed strong interest and encouragement in building an association in the region and helped them to find people who will be members of Working Group.

The following 8 people from Asia and Oceania started the working group from December 2020 and had several meetings; Motoko Kotani (Chair, Japan), Sanoli Gun (India), Le Thanh Nhan (Vietnam), Kyewon Koh Park (Korea), Polly Sy (Phillipines), Dongmei Xiao (China), Bakhyt Alipova (Kazakhstan) and Catherine Greenhill (Australia). And all working group members agreed to be AOWM members at the 2nd AO CWM ambassadors meeting on Feb. 25 2022.

Then AOWM Foundation Meeting was held on August 1, 2022. Total number of the members is 216 from 17 countries (contain male members). It contained 7 Australian, 6 Chinese, 54 Indian, 1 Indonesian, 2 Iranian, 34 Japanese, 2 Kazakhstan, 2 Malaysian, 4 from Nepal, 11 from New Zealand, 1 Pakistan, 12 Philippines, 60 South Korean, 6 from Sri Lanka, 9 from Thailand, 1 Uzbekistan, 1 from Vietnam.

The first members of the executive committee are as follows: (See pictures of EC: Fig. 2)
President : Sanoli Gun (India), Vice President : Melissa Tacy (New Zealand) and Polly Sy (Philippines) and Secretary: Hyang-Sook Lee (Korea). The Ordinary EC members are Budi Nurani Ruchjana (Indonesia), Yukari Ito (Japan), Dongmei Xiao (China), Bakhyt Alipova (Kazakhstan) and Zohreh Mostaghim (Iran).

It has just started and there are some rules. We will have general meetings every two years and half of the EC members will be replaced in two years. We have no funding at this moment and have to think about our activities and future of AOWM. As the situation of women in mathematics in each country is different, we have to help and encourage one another.

[Credit: Sanoli Gun, Melissa Tacy, Polly Sy, Hyang-Sook Lee, Budi Nurani Ruchjana, Yukari Ito, Dongmei Xiao, Bakhyt Alipova, Zohreh Mostaghim]

Fig. 2: Executive Committee Members of AOWM.

We had the first Inaugural Meeting of AOWM, on April 24-28, 2023, at ICTS, Bengaluru, India. ICTS is International Center for Theoretical Sciences and has several actions and events for women in Mathematics and Physics and we can learn many things from them as a similar institute. (Fig. 3)

[Credit: ICTS-TIFR]

Fig. 3: Inaugural Meeting of the Asian-Oceanian Women in Mathematics.

There are similar organization for women in mathematics in some countries in Asia and Oceania. Though there are some Japanese members in AOWM, we don't have our own organization in Japan. To make some network between female mathematician and also students are very important to continue their studies and become researchers. Then I organized a conference "Women in Mathematics" at RIMS, Kyoto University in September 2022 [1] and we heard reports on the activities of Association of Women in Mathematics (AWM), European Women in Mathematics (EWM) and Korean Women in Mathematical Sciences (KWMS) and I made a report as RIMS Kokyuroku[2]. Moreover, we will have a conference "The world of Mathematical Sciences" at Kavli IPMU in August 2023 [3] and make new network with individual webpages. It will also help young scientists to get a new job in academia.

[Credit: Emily Nakajima]

Fig. 4: Poster of "Women in Mathematics" at RIMS.

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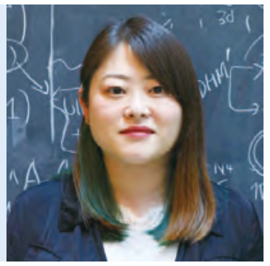
5.5 From Space to Ground Applications



Miho Katsuragawa

In observational high-energy astrophysics, the physical mechanisms of high-energy objects are being studied by analyzing energy spectra and images obtained from observations of X-rays and gamma rays emitted from the objects. Observational instruments are required to have high performance in terms of energy resolution, spatial resolution, and sensitivity, and they must also meet stringent environmental conditions, such as being small and light enough to be installed on satellites. However, it is not only in space that X-rays and gamma rays hold the key to solving problems. Hard X-ray and gamma-ray imaging are increasingly recognized as valuable techniques in various fields of accelerator experiments and medical research. In the study of developing X-ray/gamma-ray semiconductor detectors for astronomical observation, our group learned that the superior capabilities of our instruments could also be used in these various fields on the ground.

For ground-based experiments, we have developed various imaging systems using cadmium telluride double-sided strip detectors (CdTe-DSDs). The CdTe-DSD, which was developed for the Hitomi satellite (ASTRO-H) launched in 2016 [3], has a high energy resolution by using technique of Schottky diode electrodes [1,2]. In accelerator experiments, we detected muon X-rays from light elements, which had been difficult to image, by introducing CdTe-DSD, and succeeded in the world's first two-dimensional imaging [4]. In addition, we have been working on establishing a three-dimensional imaging technique for muon X-rays [5].

In recent years, our group has focused on applications in nuclear medicine. In nuclear medicine, radiopharmaceuticals are used to diagnose and treat diseases, and the visualization of X-rays and gamma rays from inside the body using SPECT (Single Photon Emission Computed Tomography) and PET (Positron Emission Tomography) devices is also an important method of molecular imaging [6]. Our group is a team of astrophysicists and medical researchers working together to solve problems in the field of nuclear medicine by applying space observation techniques to nuclear medicine.

Our group has been developing imaging systems that combine CdTe-DSD with various collimators for different purposes. One such system is an ultra-high spatial resolution SPECT system that aims to visualize the local distribution of drugs and probes accumulated inside a tumor [7]. It is composed of CdTe-DSD and pinhole optics to achieve sub-mm spatial resolution and can identify structures of about 250 μm. In addition, we have established a new analytical method and succeeded in multi-probe imaging by applying the analysis technique of astronomical observation data (Fig. 1) [8]. In molecular imaging, images are obtained by selecting a specified energy range (energy window) for each nuclide. Since X-rays in the energy range of several tens to several hundred keV are scattered in the body and by the collimator, the scattered X-rays become background components and cause image degradation. In the case of simultaneous imaging of multiple nuclides, the signal from other non-targeted nuclides cannot be separated only by specifying the energy window, and the distribution of the drug may be detected in places where the drug is not originally present. We have solved these problems by quantification by spectral fitting and image correction.

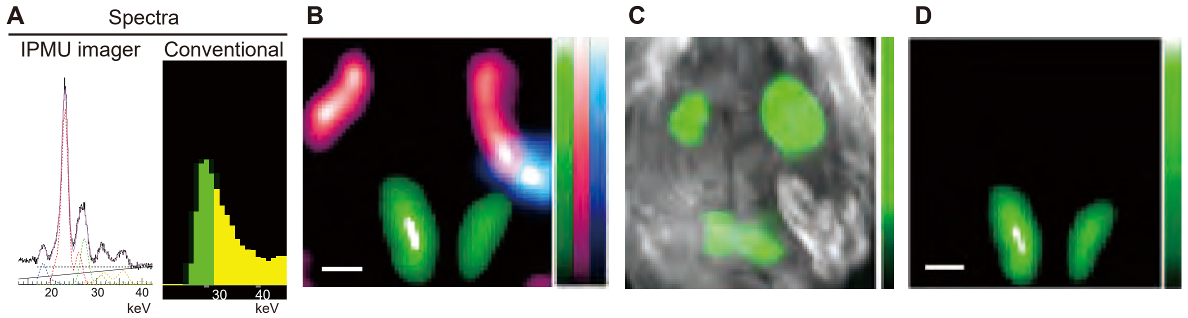


Fig. 1 (**A**) Energy spectra obtained by our imaging system and a conventional system. Dotted lines shown with the spectrum of our imager mean fitting models. (**B**) A three-color coronal image obtained with our imaging system using three radionuclides. (green: I-125 in thyroid, red: In-111 in lymph node, blue: Tc-99m in lymph node) (**C**) A coronal image in the I-125 energy band taken with conventional system. (**D**) Reconstructed coronal image in the I-125 energy band (26-29 keV) obtained with our imaging system. Figures were extracted from [8].

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5.6 The Case of the Missing Protocluster Shadow

Khee-Gan Lee

Galaxy protoclusters, the precursors to modern-day galaxy clusters, are moderately dense agglomerations of young galaxies from the universe's early epochs, spanning up to tens of megaparsecs. As they evolve, these protoclusters merge to form the colossal gravitationally bound entities known as galaxy clusters, which we observe in the present-day Universe. Mature clusters house a rich mix of galaxies, dark matter, and baryonic hot gas. The cluster gas, which encompasses up to 10% of the cosmic baryon budget, is known as intra-cluster medium (ICM) and emits X-rays due to its temperatures exceeding $T>10^7$ K. The hot ICM, which emits X-rays and, has been shaped by gas shock heating from gravitational collapse and various feedback processes from its resident galaxies.

However, at redshifts of $z>2$ (more than 10 billion years ago), the gas within galaxy protoclusters has not yet collapsed and is believed to be largely similar to other regions of the Universe, existing in a relatively cool state ($T\sim10^4$ K) in photo-ionization equilibrium with the ambient ultraviolet (UV) radiation. While the expansive intergalactic medium (IGM) is almost entirely ionized at this epoch, trace amounts of hydrogen remain neutral, revealing their presence through Lyman-alpha absorption in the restframe UV radiation. Historically, this Lyman-alpha 'forest' has been studied using the bright background light from quasars along isolated 1-dimensional lines-of-sight. Over the past decade, I have pioneered the technique of "Intergalactic medium (IGM) tomography," employing the world's most powerful telescopes to study the Lyman-alpha Forest in dense groupings of faint background galaxies. IGM tomography enables us to map the large-scale 3D gas distribution during the era of galaxy protoclusters. As galaxy protoclusters are overdense structures, they often exhibit pronounced Lyman-alpha forest absorption, reminiscent of a dense grove of trees casting a solid shadow against the sun. Multiple research groups, including mine, have detected this absorption signal from several galaxy protoclusters at $z\sim2$.

Last year, Kavli IPMU postdoctoral researcher Metin Ata (now at Stockholm University) employed a novel method known as constrained simulations on galaxy spectroscopic data, unearthing several new $2.0<z<2.5$ galaxy protoclusters within the well-examined COSMOS field. Many of these protoclusters coincide with the IGM gas map from my CLAMATO tomographic survey. Notably, one of the protoclusters at $z=2.3$, named 'COSTCO-I,' lacks the characteristic hydrogen Lyman-alpha absorption 'shadow' seen in other protoclusters (Figure 1).

Subsequently, UTokyo graduate student Chenze Dong undertook a comprehensive analysis of COSTCO-I. Ata's methodology permitted us to trace the underlying large-scale structure. Consequently, Dong was able to calculate the expected Lyman-alpha absorption from the overdensity represented by COSTCO-I, operating under the assumption that the protocluster gas aligns with the photoionized equilibrium typical of the IGM during those times. By considering uncertainties in protocluster mass, morphology, and pixel noise, Dong determined it was highly improbable ($p<0.0026$) for the protocluster gas to behave like the global IGM. This fascinating finding was later published in the Astrophysical Journal Letters (Dong et al. 2023, 945, 2, L28).

Given that the gas around COSTCO-I is transparent in the Lyman-alpha forest, it indicates the gas has been heated to the extent that the residual neutral hydrogen within the protocluster has become collisionally ionized (Figure 2). One theory suggests this structure might have already experienced gravitational collapse, shock-heating the gas on vast scales, akin to the galaxy clusters of today. However, preliminary investigations into hydrodynamical simulations propose that such a process is highly unlikely by the early epoch ($z\sim2$) represented by COSTCO-I, when most structures are still transitioning. Thus, it appears that feedback from supermassive black holes within the protoclusters, possibly in the form of intense radiation from active quasars or large kinetic jets forming radio bubbles on megaparsec scales, is a more probable explanation.

Research into analogous structures will significantly influence our understanding of the feedback processes from active galactic nuclei (AGN). Next year, the new Prime Focus Spectrograph on the Subaru Telescope will be operational, augmenting the available samples of galaxy protoclusters at $z>2$ by a significant factor. This will enable us to make statistically robust claims about the role of AGN in heating protocluster gas and the vast IGM as the Universe progresses.

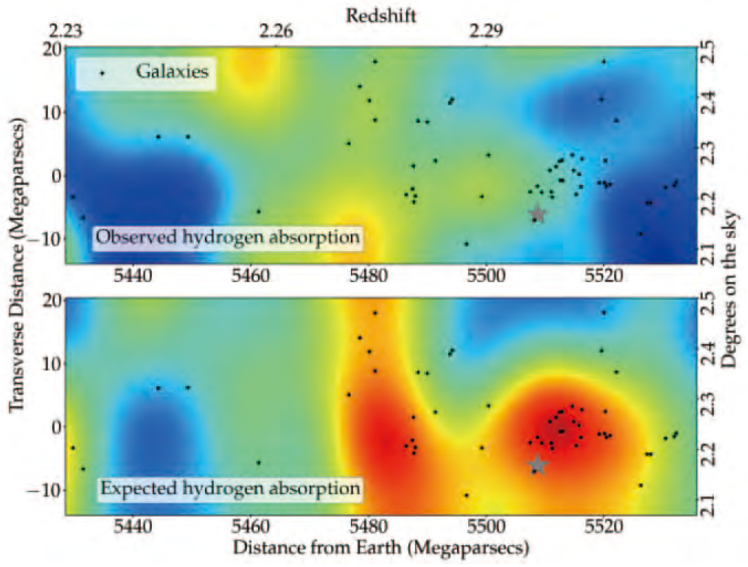

Figure 1: Color scale indicates the observed hydrogen absorption in vicinity of the COSTCO-I galaxy protocluster (top panel), compared with the expected absorption given the presence of the protocluster, assuming it behaves like the rest of the IGM at this epoch. Strong hydrogen absorption is shown in red while weak absorption is shown in blue, and intermediate absorption is denoted as green or yellow colors. The black dots indicate member galaxies through which the protocluster was first identified. At the position of COSTCO-I (with its center marked as a star in both panels), astronomers found that the observed hydrogen absorption is much lower than expected, suggesting that some large-scale heating mechanism is operating within this structure.

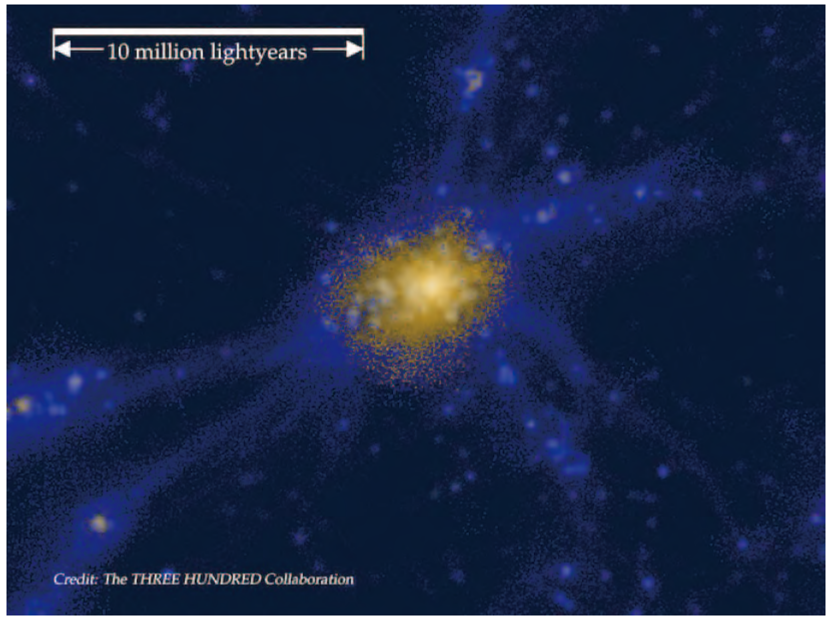

Figure 2: A hydrodynamical simulations depicts the scenario of large-scale heating around a galaxy protocluster. This is believed to be a similar scenario to that observed in the COSTCO-I protocluster. The yellow area in the center of the picture represents a huge, hot gas blob spanning several Megaparsecs. The blue color indicates cooler gas tracing the large-scale IGM, connecting the outer regions of the protocluster and filaments connecting to the cosmic web. (Simulation credit: The THREE HUNDRED Collaboration)

5.7 The Classical Equations of Motion of Quantised Gauge Theories

Tom Melia

The Maxwell and Einstein equations occupy a special place in the minds and hearts of theoretical physicists. They are the jewels in the crown of classical physics — a canon of thought that for hundreds of years formed our scientific understanding of the universe we live in.

$$\text{Maxwell: } \partial_\mu F^{\mu\nu} = J^\nu \qquad \text{Einstien: } G^{\mu\nu} = T^{\mu\nu}$$

It is interesting then that these classical theories were written down at the turn of the 20th century, right at the point in time when our classical beliefs about the universe were starting to crumble. New experiments were starting to show that the microscopic world behaved very differently. A few years after Einstein published his theory of general relativity, Schrödinger wrote down his famous equation,

$$i\frac{\partial}{\partial t}|\Psi\rangle = H|\Psi\rangle,$$

where H is the Hamiltonian of the physical system, and $|\Psi\rangle$ is the quantum mechanical wavefunction. This ushered in a new era of physics and interpretation of the universe, and the framework of quantum mechanics has provided a description of every experiment we have performed to date.

Quantum mechanics is more fundamental than classical mechanics. The latter exists only as a particular limit of the former: classical equations of motion follow from the quantum theory by taking expectation values of the corresponding operator equations (this is known as Ehrenfest's theorem).

However, for gauge theories, such as electromagnetism and general relativity, not all of the classical equations of motion can be obtained from the quantum theory in this way. This is because some of the 'equations of motion' are in fact constraint equations that do not dictate how the degrees of freedom (the photon, the graviton) evolve in time. These constraint equations are Gauss' law in electromagnetism, and are the time-time and time-space components of Einstein's equations in general relativity that give rise e.g. to the first Friedmann equation in cosmology.

So how do the classical constraint equations arise from the limit of the quantum theory? In the standard approach to quantising these theories, they come about from a choice of initial quantum state. In electromagnetism one can show that if the quantum state satisfies Gauss' law initially, it will satisfy Gauss' law at all times; similarly in cosmology regarding the first Friedmann equation.

My work with David E. Kaplan and Surjeet Rajendran has questioned this 'choice'. What if the initial quantum state of the universe was actually different to this? The quantum theory is still perfectly well-defined: the Hamiltonian of electromagnetism or general relativity can evolve these different choices of quantum state. However, the classical constraint equations — Gauss' law and the first Friedmann equation — get an effective additional contribution that captures the 'violation' produced by the chosen state. This looks like an additional fixed background charge in Gauss' law, and background dust or cold dark matter in the Friedmann equation. We called these 'shadow' contributions, because they are not real charges or masses: they are a result of the chosen configuration of initial electric and gravitational fields.

The real charges and masses in the universe would respond to these shadow charges and masses, leading to observable signatures. For the case of general relativity, it is striking that we do indeed observe a dark matter component in the classical equations of motion of the universe. This warrants further study to determine how much of the dark matter we see could just be a choice of the initial conditions of the state of gravitational field.

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5.8 A New Probe of Inflationary Gravitational Waves: Cross-Correlations of Lensed Primary CMB B-modes with Large-Scale Structure

Toshiya Namikawa

During FY2022, one of my significant achievements was to develop and propose a new method to probe cosmic inflation by measurement of cosmic microwave background (CMB) polarization, as detailed below.

Soon, measurements of the high-precision "*B-modes*," a twisting pattern in a polarization map, will become essential to explore fundamental issues in cosmology. For example, B-modes provide a unique avenue to explore the early universe, where inflation stretched quantum fluctuations and seeded cosmological structures. Inflation predicts the generation of a background of gravitational waves, which is not yet confirmed. The inflationary gravitational waves (IGWs) impart a characteristic B-mode pattern in the CMB polarization map. Thus, detecting such B-modes on large angular scales allows us to unveil the physics of the very early universe. Current and future CMB experiments seek to constrain the tensor-to-scalar ratio, r, which characterizes the IGW amplitudes more tightly, targeting specific predictions of inflation theories and restricting the parameter space to identify if and how inflation happened.

Precise B-mode data also provide a powerful means of revealing physics in the late-time universe through gravitational lensing of CMB; as the CMB photons travel through the universe, they are gravitationally deflected by the mass distribution of the large-scale structure (LSS) through which they pass. CMB lensing thus creates B-modes at small angular scales. CMB lensing probes the history of the LSS directly and is sensitive to the properties of neutrinos, which affect the growth of the LSS. Analysis of the precise B-mode data to extract lensing signals is thus a powerful probe of the unknown mass of neutrinos.

The IGW B-modes provide a new way to probe the early universe, but there are two key challenges we must overcome in ongoing and future CMB experiments. One is the lensing- induced B-modes. The B-modes from lensing must not be confused with those arising from IGWs. The lensing contaminants in B-modes already limit the detection of IGWs. Thus, to test new inflation regimes and for the full success of future experiments, we need to estimate the lensing B- mode contribution and subtract it from observed B-modes. The other, more complicated issue is the contaminants from the Galactic foregrounds. In CMB measurements, radiation from Galactic foregrounds dominates on large-angular scales of anisotropies. We must remove IGW B-modes from Galactic foregrounds, but its complete understanding is challenging. For example, in 2014, the BICEP2 team claimed detection of the IGW B-modes after careful treatment of the Galactic foregrounds based on the best knowledge of the foregrounds at that time. However, unfortunately, it turned out to be just the Galactic foreground B-modes.

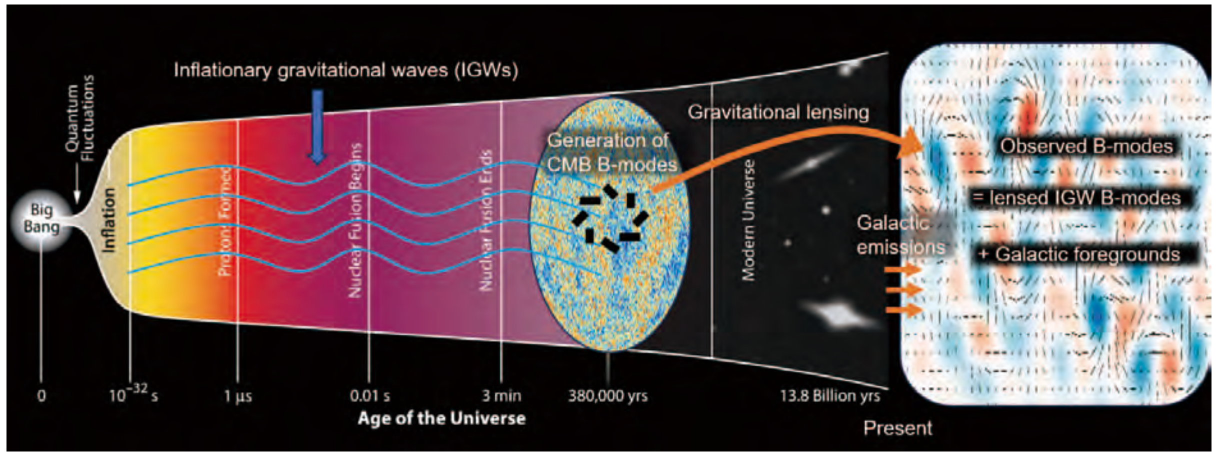


Fig.1: The important contributions to the observed B-modes. This figure is made based on the images provided by the BICEP collaboration (http :// bicepkeck.org/visuals.html) and by the ESA Planck project (https://www.cosmos.esa.int/web/planck).

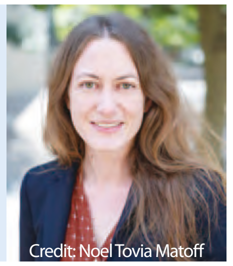
In FY2022, I developed and proposed a new IGW probe to overcome the Galactic foreground issue. The key idea to distinguish between the IGW B-modes and Galactic foregrounds is that the former is distorted by gravitational lensing of the large-scale structure, while the latter is not (see Fig.1). The former is correlated with the tracer of the mass distribution in the LSS, such as galaxy distribution. On the other hand, the latter does not correlate with the LSS tracers. The estimator is equivalent to measuring a three-point function of two CMB B-modes and an LSS tracer. With this fact, I found that the new observable, the correlation between IGW B-modes and mass distribution, will be sensitive to the IGW amplitudes.

We forecasted the expected one-sigma constraints on the tensor-to-scalar ratio, r, albeit with a simplistic foreground treatment, and found constraints of $\sigma_r \sim 0.007$ from the correlation of CMB- S4-Deep B-mode lensing and LSST galaxies, $\sigma_r \sim 0.005$ from the correlation of CMB-S4-Deep B- mode lensing and CMB-S4-Deep CMB lensing, and $\sigma_r \sim 0.01$ from the correlation of LiteBIRD B-mode lensing and CMB-S4-Wide lensing. Because this probe is inherently non-Gaussian, simple Gaussian foregrounds will not produce any biases in the measurement of r. While a detailed investigation of non-Gaussian foreground contamination for different cross-correlations will be essential, this observable has the potential to be a powerful probe of IGWs, complementary to standard methods for constraining r.

The estimate of σ_r obtained above is derived by assuming experimental configurations not optimized for the proposed method. In the experimental configurations assumed in the above analysis, CMB experiments are designed to observe polarization in multiple frequencies to mitigate the Galactic foreground biases in the B-mode auto power spectrum. In our proposed method, however, we do not need many frequencies to mitigate the Galactic foregrounds. There is, thus, room to improve the constraint on r with our method.

The results were recently published in https://arxiv.org/abs/2304.10315.

5.9 Probing the Generalized Symmetry Structure of Quantum Field Theory


Credit: Noel Tovia Matoff

Emily Margaret Nardoni

Quantum Field Theory (QFT) is the heart of modern theoretical physics, supplying the language in which we understand the interactions of fundamental particles and model the phases of matter. It is a ubiquitous feature that the degrees of freedom in a QFT reorganize in highly nontrivial ways between high and low energies under renormalization group flow, and that the most interesting physical phenomena are emergent in regimes where the constituent fields are strongly interacting. The central challenge of 21st century QFT is to learn how to extract universal features and dynamics of such emergent phenomena in strong coupling regimes where standard perturbative techniques fail.

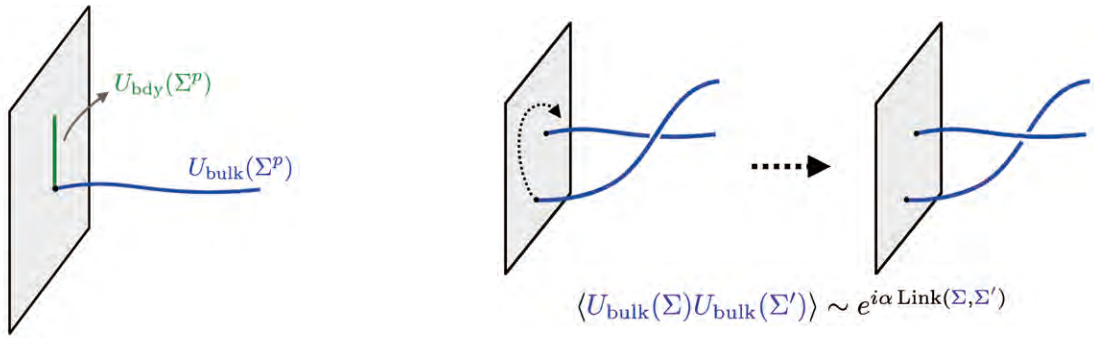
I approach this problem in my research through the lens of *symmetry*. Symmetry has deep implications for the study of Quantum Field Theory, first and foremost as an indispensable principle for distinguishing physical systems—the celebrated Landau paradigm has taught us that phases of matter are labeled by how they represent their symmetries, so that *e.g.* the eight light pseudoscalar mesons arise as Nambu-Goldstone bosons of approximate chiral symmetry breaking in QCD. Symmetries are so powerful because they furnish invariant characterizations of QFTs; they imply constraints on renormalization group flows, are fixed under dualities, and constrain observables often to the point of computability.

In the last several years the very concept of symmetry has been revolutionized, with wide reaching consequences across theoretical physics. The idea is that the familiar notion of symmetry as a set of operators that commute with the Hamiltonion can be extended; operators can form more general algebras than groups (so that they are "non-invertible"), and be defined on different-dimension submanifolds of spacetime and thus imply transformation rules for lines and other extended operators (generating "higher-form" symmetries)—see [1] for a recent review and more detailed references. The key point of view is that the symmetry operators depend topologically on these submanifolds, with fusion rules governed in general by (higher) fusion categories. These *generalized symmetries* lead to new conservation rules, new constraints on dynamics, and new ways of distinguishing phases. We are developing the vocabulary of this new language, and there is much still to learn![1]

My recent research has focused on developing modern tools for characterizing the generalized symmetry structure of QFTs. One such toolset are *'t Hooft anomalies*, renormalization group invariant quantities that characterize the detailed data of symmetries of QFTs. 't Hooft anomalies are extremely important for constraining the low-energy phases of gauge theories since they must match between high and low energies; any proposed phase must match all 't Hooft anomalies of all symmetries (whether or not we've been clever enough to uncover them all!), and so for example any nontrivial anomaly forbids a trivial vacuum.

The state of the art for capturing generalized (higher form, non-invertible) symmetries and their 't Hooft anomalies is a $d+1$ dimensional topological QFT known as the *Symmetry Topological Field Theory (SymTFT)*, on whose boundary the d-dimensional QFT of interest resides as a sort of edge mode. A generalization of anomaly inflow from the bulk SymTFT encodes the generalized symmetries of the boundary QFT, in ways that are actively being explored and understood (with many outstanding questions especially for $d>2$!) [2, 3].

In work with both fellow and former IPMU members, we have explained how the SymTFT captures key data about the 't Hooft anomalies of non-invertible symmetries for QFTs in general dimensions, and applied it to constrain the phases of 2d and 4d gauge theories [4]. The key insight is that the topological generalized symmetry operators in the boundary QFT arise from operators in the bulk SymTFT, and that the braiding of these bulk operators serves as a diagnostic of the boundary 't Hooft anomalies (see Figure 1). We showed that this perspective is powerful in probing the anomalies of non-invertible symmetries, for which a general characterization in $d>2$ is not fully developed. By identifying anomalous non-invertible symmetries in 4d gauge theories, we were then able to constrain their low-energy phases; for example, we applied this to $PSU(N)$ adjoint QCD to rule out the existence of a trivially gapped vacuum, and also to anomaly matching in $N=1$ super Yang-Mills. This is an exciting time to build on these stepping stones and attack the problem of how to fully utilize and extract information from the SymTFT.



(a) A topological operator defined on a p- dimensional submanifold (blue, depicted for $p=1$) of the $d+1$ dimensional bulk SymTFT can be attached to a p-dimensional operator (green) in the d-dimensional boundary, which generates the boundary generalized symmetry.

(b) The anomaly of the boundary symmetry is probed by link invariants of the attached bulk operators, computed by their correlation functions. The dimensions of the operators and type of correlation function depends on which anomaly coefficients a are being probed.

Figure 1: Probing 't Hooft anomalies from the SymTFT.

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[1] The starring role of symmetry in physics goes back at least to Einstein's early 20th century work on relativity, while the role of (*e.g.*) non-invertible symmetries has only recently begun to be appreciated.

5.10 Filaments of the Cosmic Web Shine in the X-rays

Hideki Tanimura

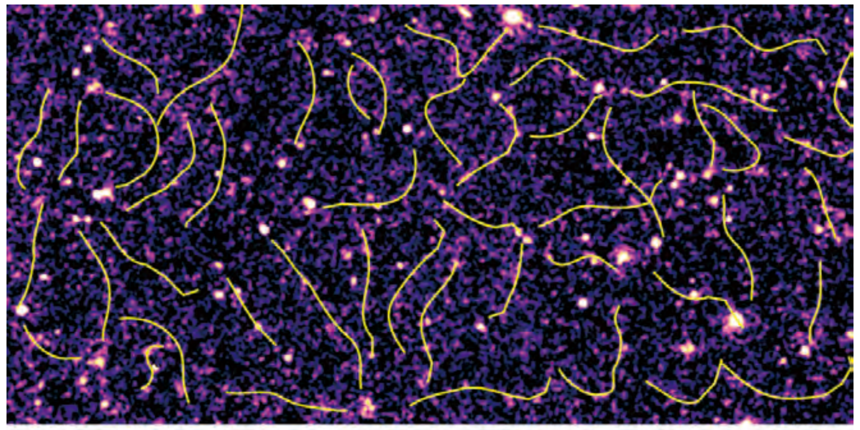
The structure formation in the Universe has been widely studied with numerical simulations. The cosmological simulations suggest that matter in the Universe is not distributed randomly, but rather distributed in the form of a complex network throughout the Universe, called the cosmic web. In the cosmic web, clusters of galaxies are located at the intersections of filamentary structures and most of the cosmic volume is occupied by low-density voids. The formation of this cosmic web can be explained by the gravitational attraction of dark matter, but because dark matter does not emit light nor interact with ordinary matter (so-called baryon), the distribution and evolution of the cosmic web cannot be directly observed and must be inferred.

To trace the large-scale structure of the Universe observationally, galaxies, formed in regions where dark matter is concentrated, are the most prominent luminous baryonic component and millions of galaxies have been observed in several galaxy surveys. However, galaxies only comprise less than 10% of baryonic matter and the rest of > 90% is in the form of baryonic gas. The baryons have been observed in stars, cold interstellar medium, residual Lyα forest gas, ionized oxygen, broad Lyα absorbers, and hot gas in clusters of galaxies, but it has been found that the observed baryons only account for ~70% of the expected; the remainder has yet to be identified and constitutes so-called missing baryons[i]. There has been extensive research to discover the missing baryons, although hydrodynamical simulations predicted that most of the missing baryons might be located in the cosmic web filaments in the form of warm hot intergalactic medium (WHIM) with temperatures ranging between 10^5 and 10^7 K and over-densities between 10 and 100. It explains that light emitted by the missing baryons is too faint to observe, and a novel technique and/or higher-quality data are required to detect the faint signature.

Therefore, I have led a research project to detect this missing baryon and identify the physical states with Nabila Aghanim, a researcher at the Institut d'Astrophysique Spatiale (CNRS/Université Paris-Saclay). In this project, I have detected, for the first time, the X-ray emission from the hot gas in filaments[ii]. This detection has been achieved by my new statistical approach with a combination of multi-wavelength data. In detail, I have studied a spatial correlation of the X-ray signals from the ROSAT survey data[iii] at the locations of approximately 15 000 large-scale cosmic filaments identified with the SDSS galaxy data[iv]. In addition, I have derived the density and temperature of the hot gas through the X-ray spectral analysis. This result has provided clear evidence of hot gas in the cosmic web and has paved the way for more detailed studies, using better quality data, to test the evolution of gas in the filamentary structure along with the structure formation in the Universe.

In my further study, I took advantage of the most recent X-ray survey data from SRG/eROSITA[v]. The X-ray data with a higher sensitivity enabled me to detect the X-ray signals with only 460 filaments within the first 140 deg^2 survey released by the SRG/eROSITA collaboration and even allowed more precise constraints on the hot plasma's physical states[vi]. In addition, its higher energy resolution allowed to confirm that the detected X-ray signal is undoubtedly associated with a thermal emission from the hot plasma in the cosmic filaments, not from stars or galaxies. Moreover, I have forecast its future improvement using the full-sky SRG/eROSTA, and it predicts that the origin of the thermal emission should be answered using the full SRG/eROSTA data released in coming years, and the future planned large X-ray observatories.

These findings confirmed my earlier analyses based on indirect detections of hot gas in the cosmic web through its effect on the cosmic microwave background (CMB), so called Sunyaev Zel'dovich effect[vii]. It provided the gas pressure inside the filaments through the distortion of the CMB spectrum. In addition, my other studies using the gravitational lensing effect on the CMB successfully derived the total matter density in the filaments, which proved that the filaments are actual gravitationally bound structures. These results will also be improved by the future CMB surveys such as Simons Observartory and CMB-S4. Because the CMB data has a better sensitivity at higher redshift than X-ray, a combination of these probes will clarify the fundamental question of how the hot gas in the cosmic web co-evolve with dark matter across time.



@Tanimura, Aghanim (CNRS) & eROSITA

Figure1: SRG/eROSITA map overlaid with the filaments identified with the SDSS galaxies.

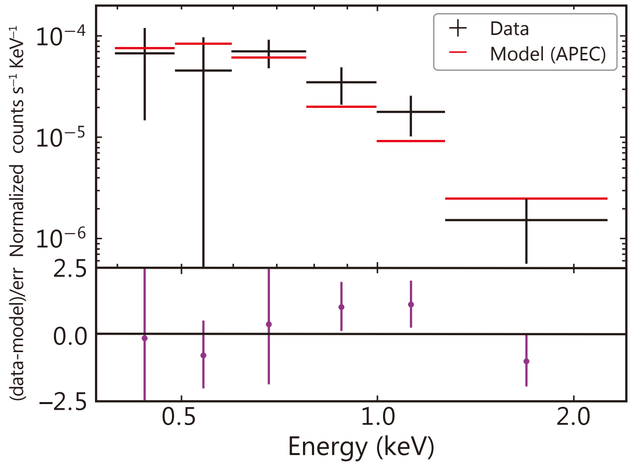


Figure2: X-ray spectrum measured with the SRG/eROSITA map at the positions of filaments.

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[i] Shull, J. M., Smith, B. D., & Danforth, C. W. 2012, ApJ, 759, 23

[ii] H Tanimura, N Aghanim, A Kolodzig, M Douspis, N Malavasi, 2020, A&A, 643, L2

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[vi] H Tanimura, N Aghanim, M Douspis, N Malavasi, 2022, A&A, 667, A161

[vii] H Tanimura, N Aghanim, V Bonjean, N Malavasi, M Douspis, 2020, A&A, 637, A41

5.11 MUSSES2020J: The Earliest Discovery of a Fast Blue Ultraluminous Transient at Redshift 1.063

Naoki Yasuda

The universe is full of energetic transient phenomena, astronomical events that occur over a short period of time. For example, most massive stars end their lives by exploding spectacularly, known as a supernova, a major type of transient. In order to understand the origin of these transient phenomena, various time-domain surveys have been carried out in the past few decades. As more and more transients have been discovered, researchers began noticing some new transient types in recent years.

The fast blue ultraluminous transient (FBUT) is a new transient type confirmed several years ago and subsequently investigated by several transient survey projects recently. The majority of FBUTs reach peak brightness of -17 to -20 mag in blue optical wavelengths which is comparable with the most luminous supernovae while their timescales are significantly shorter.

To figure out the nature of various transient phenomena, an international transient survey project called "MUltiband Subaru Survey for Early-phase Supernovae" (MUSSES), led by Ji-an Jiang, a former Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) Project Researcher (currently Project Research Staff at the University of Science and Technology of China (USTC)) attempt to catch various fast-evolving transients within one day of their occurrence, using the most powerful survey facility in the world, the Hyper Suprime-Cam (HSC) mounted on the 8.2-m Subaru telescope.

By carrying out consecutive Subaru/HSC observations in December 2020, 20 fast-evolving transients have been discovered, and one of them, MUSSES2020J (AT 2020afay), caught our attention.

MUSSES2020J was discovered with very low brightness on December 11 in 2020, and its brightness showed significant brightening during our observation. More surprisingly, the fast light curve evolution and very high redshift of the transient confirmed by follow-up observations (by the Astrophysical Research Consortium 3.5 m telescope and the 3.6 m Devasthal Optical Telescope) indicate that the brightness of MUSSES2020J was about 50 times higher than normal supernovae, while the rising phase was much shorter than those of normal supernovae, which indeed show high similarity to a recently discovered peculiar transient, AT 2018cow, which is an representative FBUT. So far only a handful of them have been discovered, and we had never seen one soon after its occurrence due to their extremely fast evolution. Thanks to the high-cadence survey mode and the excellent performance of Subaru/HSC, we were able to perfectly catch this amazing phenomenon at very early stage for the first time. The early multiband light-curve data bring some unique information to understand the origin of these amazing transients.

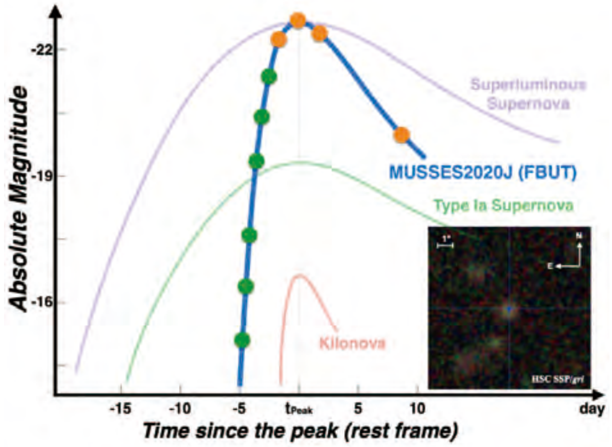

Figure 1: The schematic light curves of MUSSES2020J and other typical energetic transients (green and orange points denote the stages that MUSSES2020J was observed by the 8.2-m Subaru and follow-up telescopes, respectively). HSC g, r, and i composite multicolor thumbnail image of the host galaxy is shown in the bottom-right corner. A blue cross indicates the location of MUSSES2020J, which is almost at the nucleus of the host galaxy.

A very fast-rising lightcurve of MUSSES2020J was obtained during the Subaru/HSC survey, with a g-band brightness increase of a factor of about 23 in 5 days (observer frame). Follow-up observations show the brightness of MUSSES2020J kept increasing in the next 4 days after the last Subaru/HSC observation, indicating rise time as short as ~10 days in the observer frame.

Given the shortest projected distance and the lowest photometric redshift (also the highest brightness) among all galaxies within 10 arcseconds from MUSSES2020J, we identified the nearest galaxy as the host galaxy of MUSSES2020J. We have executed a spectroscopic observation of the host galaxy at the Gemini-North observatory, the redshift of the host galaxy has been determined as 1.063.

MUSSES2020J is located near the center of a normal low-mass galaxy at redshift 1.063. This suggests a possible connection between the energy source of MUSSES2020J and the central part of the host galaxy. The color behaivior and physical properties derived from the early multiband light curve suggest that previously proposed scenarios such as the wind-driven scenario and the SN-CSM (circumstellar material) can at least qualitatively explain the general features of MUSSES2020J. In the case of wind-driven TDE (tidal disruption event) scenario, where a star is tidally disrupted by as massive black hole, the mass of central black hole is consistent with 1 x 10^6 solar mass as expected from the M_{BH} - M_* correlation drived for nearby galaxies. More detailed theoretical work focusing on the multiband light-curve fit is required to answer the origin of this extreme transient.

For details, please refer to our paper (Ji-an Jiang et al. ApJL, 933, L36, 2022).

6 AWARDS & HONORS

Credit: Kavli IPMU

National Academy of Sciences elected Takaaki Kajita as new international member

The University of Tokyo's Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) Senior Fellow, and Institute for Cosmic Ray Research Professor, Takaaki Kajita was elected as a member of the US National Academy of Sciences.

The National Academy of Sciences is a private, non-profit society of distinguished scholars. Established in 1863, scientists are elected by their peers to membership in the NAS for outstanding contributions to research. Currently, the Academy includes 2512 members, 517 international members. Of these members, 190, including Kajita, have received a Nobel Prize.

Credit: Yukari Ito

Yukari Ito selected as new member of The Association of Academies and Societies of Sciences in Asia's Women in Science and Engineering Committee

Professor Yukari Ito of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), The University of Tokyo, was selected as a new member of the Special Committee Women in Science and Engineering (WISE), under The Association of Academies and Societies of Sciences in Asia (AASSA).

AASSA was set up in 2012 to achieve a society in Asia and Australasia in which science and technology play a major role in the development of the region, where scientists and technologists discuss and provide advice on issues related to science and technology, research and development, and the application of technology for socio-economic development. AASSA currently has members in 30 countries and regions, and 32 organizations, including the Science Council of Japan.

Yukari Ito selected as executive committee member of the Asia-Oceania Women in Mathematics

Professor Yukari Ito of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), The University of Tokyo, was selected as a member of the newly established Asia-Oceania Women in Mathematics, under the International Mathematics Union (IMU).

The AOWM was established after the Committee for Women in Mathematics (CWM) under the IMU had received a call for its development this year. The CWM has established similar groups in the past, including the European Women in Mathematics in 1971, the Association for Women in Mathematics in 1983, the African Women in Mathematics in 2013, and the Comisión de Género -Unión Matemática de América Latina y el Caribe in 2020, but this will be the first group to be active in the Asia-Oceania region.

Credit: Tokyo University of Science

Hiromi Yokoyama awarded the Tokyo Academy of Physics Award

Hiromi Yokoyama, Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) Professor and Deputy Director, was awarded the 5th Tokyo Academy of Physics Award (Tokyo University of Science).

The Tokyo Academy of Physics Award (Tokyo University of Science) was established in 2018, and recognizes past graduates or past employees of Tokyo University of Science who have made significant contributions to science, and raised awareness about the university.

Credit: Yukari Ito

Hiraku Nakajima elected President of the International Mathematical Union

Hiraku Nakajima, Professor at the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), was elected the President of the International Mathematical Union (IMU), it was announced at the IMU general assembly on July 4, 2022.

The IMU was established in 1920, but was later dissolved, then re-established in 1951 when ten countries became members, including Japan. It is an international non-governmental and non-profit scientific organization, with the purpose of promoting international cooperation in mathematics. Currently, more than 80 countries are members. The IMU is famous for awarding scientific prizes deemed to be the highest distinction in mathematics, including the Fields Medals.

Nakajima has served on several IMU-related committees since 2006. He will take over as IMU President from 2023 and serve for four years.

Credit: Hirosi Ooguri

Hirosi Ooguri received Science Lectureship Award

Hirosi Ooguri, Director of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU)and the Fred Kavli Professor of Theoretical Physics and Mathematics at California Institute of Technology, was named the recipient of the 2022 Science Lectureship Award by Chiba University, Japan.

The Science Lectureship Award recognizes researchers with outstanding achievements in sciences. The award has been given every year since 2005 with the exception of 2011 due to the Great Japan Earthquake and 2020 due to the COVID-19 pandemic. Recipients are invited to give lectures at the Faculty of Sciences of Chiba University.

Credit: Thomson Reuters

Kavli IPMU Senior Fellow Eiichiro Komatsu Received Nishina Memorial Prize

Max Planck Institute for Astrophysics Director and Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) Senior Fellow Eiichiro Komatsu was awarded the 2022 Nishina Memorial Prize, it was announced on November 10 by the Nishina Memorial Foundation.

The Nishina Memorial Prize commemorates the achievements of the late Dr. Yoshio Nishina and is an honor given to relatively young researchers who have made outstanding research achievements in atomic and sub-atomic physics and their applications. It is the oldest and most prestigious physics award in Japan.

Credit: Kavli IPMU

Masahito Yamazaki awarded the 19th JSPS Prize

Masahito Yamazaki, Professor at Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), was selected to share the 19th JSPS Prize, it was announced by the Japan Society for the Promotion of Science (JSPS) on December 15.

The JSPS Prize was established in 2004 and recognizes young researchers under the age of 45 who have made significant contributions to the humanities, social sciences, or natural sciences. This year, 25 awardees were selected. Yamazaki has been recognized for his work on integrable models using supersymmetric quiver gauge theories and the 4-dimensional Chern-Simons theory.

Credit: Hitoshi Murayama

Hitoshi Murayama named Chair of P5 Committee

Hitoshi Murayama, Professor at the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) was selected as the Chair of the Particle Physics Project Prioritization Panel (P5) in the US, it was announced by the US Department of Energy and the National Science Foundation in November 2022.

The P5 recommends priorities in particle physics research projects for the next ten years, and reports to the High-Energy Physics Advisory Panel that in turn advises the High-Energy Physics of the US Department of Energy Office of Science, and the Division of Physics at the National Science Foundation.

7
CONFERENCES

Conference Title Date, Place	Attendees (from abroad)
Kyiv Formula and Related Aspects April 5-6, 2022 [Online]	85 (14)
Geometric Representation Theory June 27 - July 2, 2022 [Online]	279 (244)
Hyper-Kamiokande Collaboration Meeting June 20 - July 2, 2022 [Online]	138 (83)
Non-linear Aspects of Cosmological Gravitational Waves July 18 - 22, 2022, Lecture Hall, Kavli IPMU	32 (19)
HirosiFest @ Kavli IPMU October 20 - 21, 2022, Lecture Hall, Kavli IPMU	191 (39)
What the Heck Happens When the Universe Boils? December 5 - 9, 2022, Lecture Hall, Kavli IPMU	63 (40)
Current Trends in Categorically Approach to Algebraic and Symplectic Geometry February 4 - 6, 2023, Lecture Hall, Kavli IPMU	19 (4)
Geometry and Automorphicity of Supersymmetric Partitions (GASP) February 13 - 17, 2023, Lecture Hall, Kavli IPMU	69 (44)
Gauge Theory, Moduli Spaces and Representation Theory -In Honor of the 60th Birthday of Hiraku Nakajima- February 27 - March 3, 2023, Lecture Hall, Kavli IPMU	135 (42)
Interdisciplinary Science Conference in Okinawa (Isco 2023) -Physics and Mathematics Meet Medical Science- February 27 - March 3, 2023, OIST, Okinawa	145 (35)
PFS Collaboration Meeting March 2 - 3, 2023, Media Hall, The University of Tokyo Kashiwa Campus, Chiba	155 (67)
FY2022 "What Is Dark Matter? - Comprehensive Study of the Huge Discovery Space in Dark Matter" March 7 - 9, 2023, Media Hall, The University of Tokyo Kashiwa Campus, Chiba	158 (14)

CONFERENCE PRESENTATIONS AND SEMINAR TALKS
8

Invited talks given by the Kavli IPMU researchers (Selected 12 of 198)

Presenter	Presentation title	Conference name and date
Elisa Gouvea Mauricio Ferreira	**Ultra-light dark matter: the light and fuzzy side of dark matter**	SynCRETism 2022 June 25, 2022
Takeo Higuchi	**Recent Results from Belle and Belle II**	International Conference on Kaon Physics 2022 (KAON2022) September 15,2022
Jia Liu	**Cosmology with Massive Neutrinos**	Unsolved Problems in Astrophysics and Cosmology Workshop December 5, 2022
Shigeki Matsumoto	**Decay of the Mediator Particle at the Threshold**	IAS Program on High Energy Physics February 16, 2023
Hitoshi Murayama	**Theory vision: the questions before us**	Seattle Snowmass 2022 July 17, 2022
Hiraku Nakajima	**Coulomb branches of 3d N=4 SUSY gauge theories and bow varieties**	Workshop on Interactions between Representation Theory, Combinatorics, and Geometry December 27-29, 2022
Toshiya Namikawa	**A quick overview of delensing for large-scale B-modes**	Key Challenges in Galaxy & CMB Lensing July 8, 2022
Hirosi Ooguri	**Summary Talk:Perspectives and Prospects**	Strings 2022 July 22, 2022
Satoshi Shirai	**On Detection of Axion Dark Matter**	Asian-European-Institutes Workshop for BSM November 17, 2022
Mark Vagins	**A Gadolinium-Loaded Super-Kamiokande**	Neutrino 2022 June 2, 2022
Masahito Yamazaki	**Elliptic Hypergeometric Integrals in Mathematics and Physics**	Dynamics of SCFTs and Special Functions April 19, 2022
Hiromi Yokoyama	**Octagon and ELSI segment for AI**	HCC15 (Human Choice and Digital by Default: Autonomy vs Digital Determination: 15th IFIP International Conference on Human Choice and Computers, HCC 2022) September 9, 2022

9 OUTREACH AND PUBLIC RELATIONS

Event Title	Date	Venue	Number of Participants
26th Kavli IPMU × ICRR Joint Public Lecture "The Mystery of the Faraway Galaxy and Universe"	April 9, 2022	Amuser Kashiwa & Online	421
15th Anniversary Symposium: World Premier International Research Center Initiative (WPI) "Kavli IPMU's 15 Years of Science and Future Prospects"	April 24, 2022	Yasuda Auditorium, The University of Tokyo & Online	1,022
Kavli IPMU presents film screening "M.C. Escher: Journey to Infinity"	June 12, 2022	Online	427
Science Café in English "Universe" 2022 "The Dark Side of the Universe: How We Know It's There and How We Might Find It"	July 10, 2022	Online	45
Science Café in English "Universe" 2022 "Strange Telescopes: Universes Are Made by Machines"	September 24, 2022	Online	40
Open Campus Kashiwa 2022	October 22-23, 2022	Online	3,287
7th Of Course I Love Physics: Careers for Girls in Physics	November 19, 2022	Online	43
8th Kavli IPMU / ELSI / IRCN Joint Public Lecture: "A Question of Origins"	November 23, 2022	Online	508
11th Annual WPI Science Symposium: "The Infinite Possibilities Opened by Science"	November 23, 2022	Ito Hall, The University of Tokyo & Online	284
Kavli IPMU × ICRR Joint Online Public Lecture: "The Forefront of the Exploration for Dark Matter"	December 11, 2022	Online	407

Kavli IPMU
Annual Report 2022
April 2022–March 2023

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KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

ISSN 2187-7386

Printed in Japan