April 2023–March 2024

Kavli IPMU

ANNUAL REPORT 2023

THE UNIVERSITY OF TOKYO

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

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

wpi World Premier International Research Center Initiative

KAVLI IPMU

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

CONTENTS

On the cover:
Group photo at the ceremony for the Kavli IPMU 16th anniversary.

FOREWORD

Jun'ichi Yokoyama
Director

I am pleased to present our annual report for the year 2023. I was appointed Director of the IPMU on 1 November 2023, which means that I was directly involved in the activities of this academic year for four months.

I have been engaged in research and education at the Research Center for the Early Universe (RESCEU) and the Department of Physics at the Hongo campus (of the University of Tokyo) for many years, and I have also been an affiliate member of IPMU since 2008. From that time on, I have included the IPMU affiliation on all my papers except for the gravitational wave collaboration paper due to my KAGRA authorship agreement.

Other than that, however, my involvement with IPMU activities had been rather non-substantive. After I assumed office, I have worked to understand the current situation and problems IPMU faces. In particular, I have aimed to interview all members of the Institute and have talked with many of them. It has taken longer than expected, but I have completed interviews with all faculty members and have also spoken to staff members in the orders of the years of employment. As a result, I am once again keenly aware of the concentration of brilliant minds here, which is rare in the world, and I am honored to be able to work with such people. In particular, I have never had the pleasure of associating with mathematicians before, but the interaction with the mathematicians at IPMU has been pleasant and the level of their work has been remarkable. On the other hand, I feel that there is much more room for overall growth at Kavli IPMU, as some of the best minds in some other fields are not fully engaged.

I have also learned that one of the reasons for Kavli IPMU's high international reputation is its staff, who support researchers from overseas to quickly establish a living foundation and start their research in Japan. Therefore, unlike previous years, we decided to include not only the researchers but also the staff in the group photo of the anniversary celebration. We also hold an induction ceremony for newly appointed researchers in our office, proudly introducing the staff and taking a commemorative photo in the director's office.

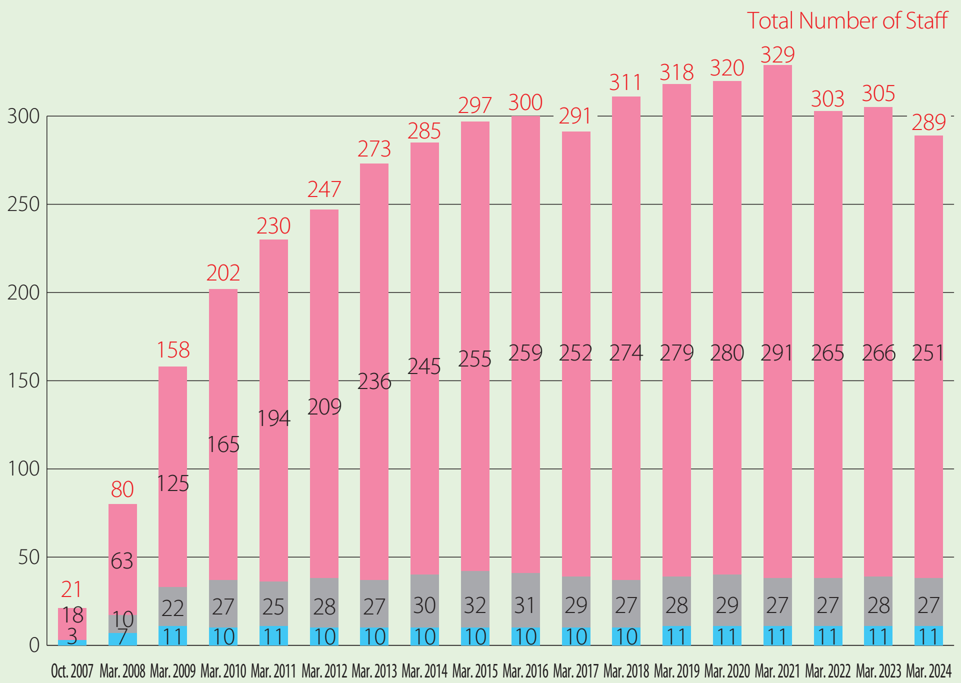
Notable activities during the past year include the CD3, led by Center Director Jia Liu, which is now fully operational and has hosted numerous workshops and educational programs. In addition, three new faculty members, Jingjing Shi, Linda Blot, and Leander Friedrich Thiele, were appointed.

In the 16 years since its establishment, thanks to the efforts of many people, including the founding Director Murayama, we have succeeded in creating an institute that attracts people from all over the world and attracts the attention of the world. However, we have yet to achieve research results that will shine brilliantly in the history of the world. We hope that this report will serve as a milestone toward enhancing the value of Kavli IPMU.

Jun'ichi Yokoyama

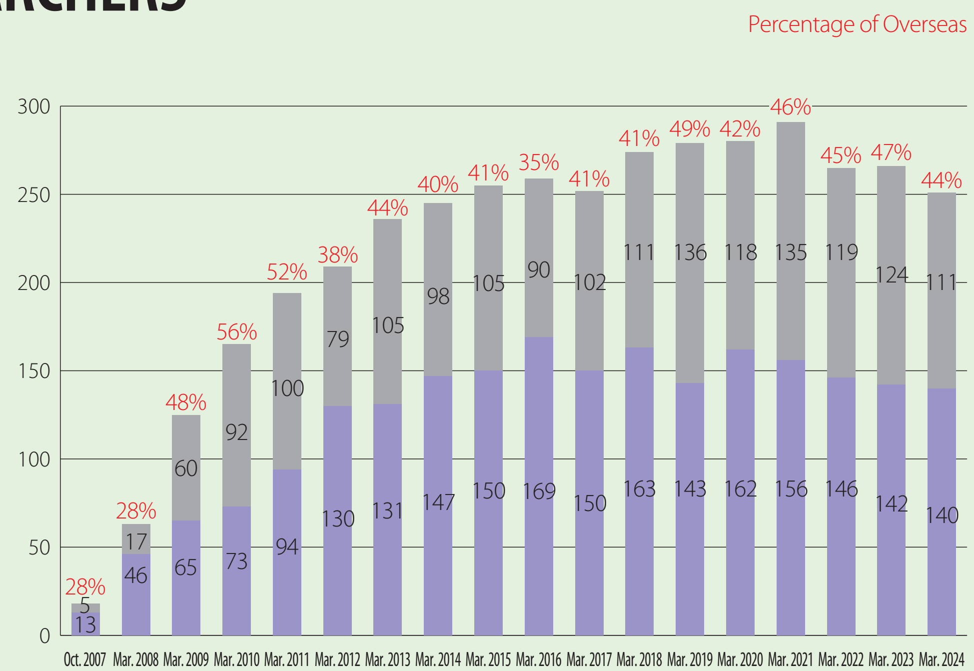
1 STATISTICS

STAFF



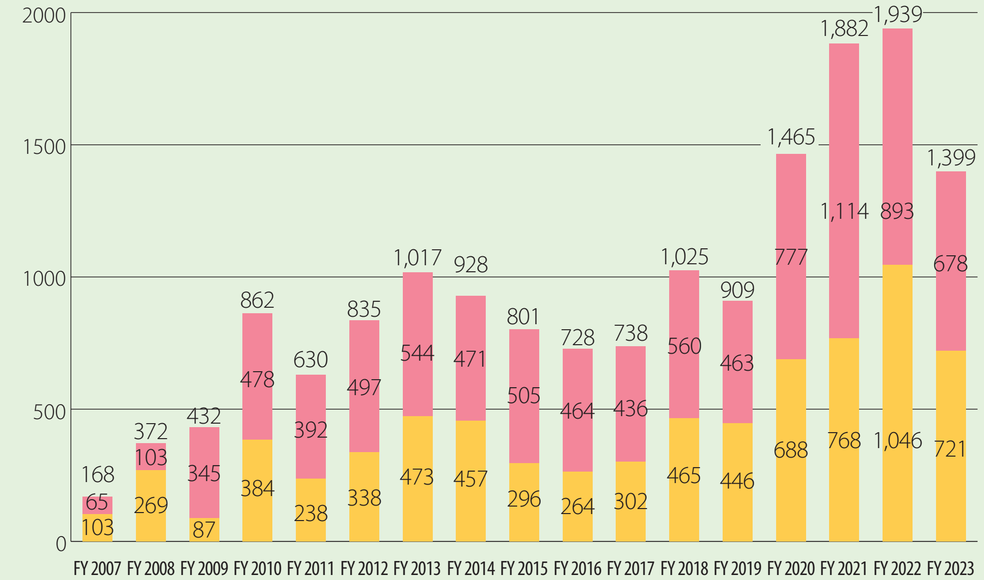
	Oct. 2007	Mar. 2008	Mar. 2009	Mar. 2010	Mar. 2011	Mar. 2012	Mar. 2013	Mar. 2014	Mar. 2015	Mar. 2016	Mar. 2017	Mar. 2018	Mar. 2019	Mar. 2020	Mar. 2021	Mar. 2022	Mar. 2023	Mar. 2024
Researchers	18	63	125	165	194	209	236	245	255	259	252	274	279	280	291	265	266	251
Research Support Staffs	0	10	22	27	25	28	27	30	32	31	29	27	28	29	27	27	28	27
Administrative staffs	3	7	11	10	11	10	10	10	10	10	10	10	11	11	11	11	11	11
Total	21	80	158	202	230	247	273	285	297	300	291	311	318	320	329	303	305	289

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	Mar. 2024
Overseas	5	17	60	92	100	79	105	98	105	90	102	111	136	118	135	119	124	111
Domestic	13	46	65	73	94	130	131	147	150	169	150	163	143	162	156	146	142	140
% of Overseas	28%	28%	48%	56%	52%	38%	44%	40%	41%	35%	41%	41%	49%	42%	46%	45%	47%	44%
% of Female	0%	2%	5%	6%	5%	2%	5%	5%	6%	4%	6%	8%	9%	10%	9%	12%	12%	14.7%

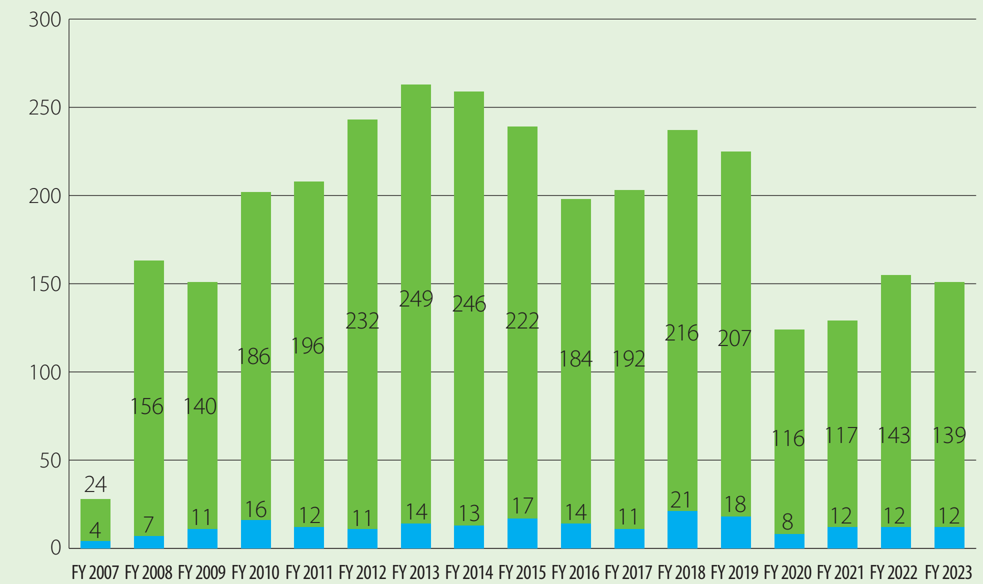
RESEARCH ACTIVITIES



	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	FY 2023
Visitors (Overseas)	65	103	345	478	392	497	544	471	505	464	436	560	463	777	1,114	893	678
Visitors (Domestic)	103	269	87	384	238	338	473	457	296	264	302	465	446	688	768	1,046	721
Visitors (Total)	168	372	432	862	630	835	1,017	928	801	728	738	1,025	909	1,465	1,882	1,939	1,399

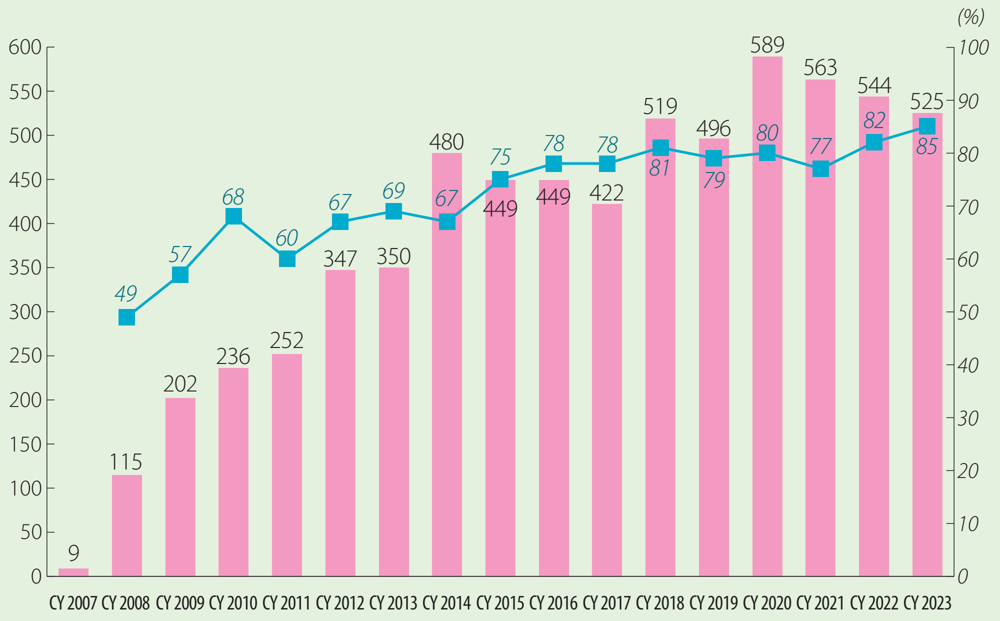
The total number of visitors is listed from FY2023 onward.
Number of participants for online conferences are included from FY2020 onward.

SEMINARS & CONFERENCES



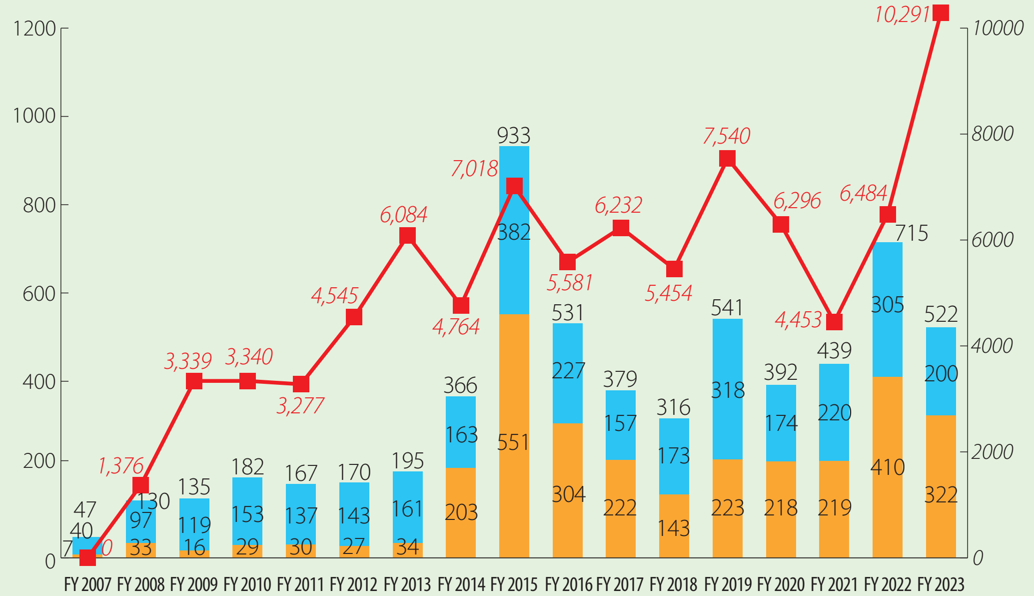
	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Seminars	24	156	140	186	196	232	249	246	222	184	192	216	207	116	117	143	139
Conferences	4	7	11	16	12	11	14	13	17	14	11	21	18	8	12	12	12

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	CY 2023
Publications	9	115	202	236	252	347	350	480	449	449	422	519	496	589	563	544	525
% of int'l collaboration		49%	57%	68%	60%	67%	69%	67%	75%	78%	78%	81%	79%	80%	77%	82%	85%

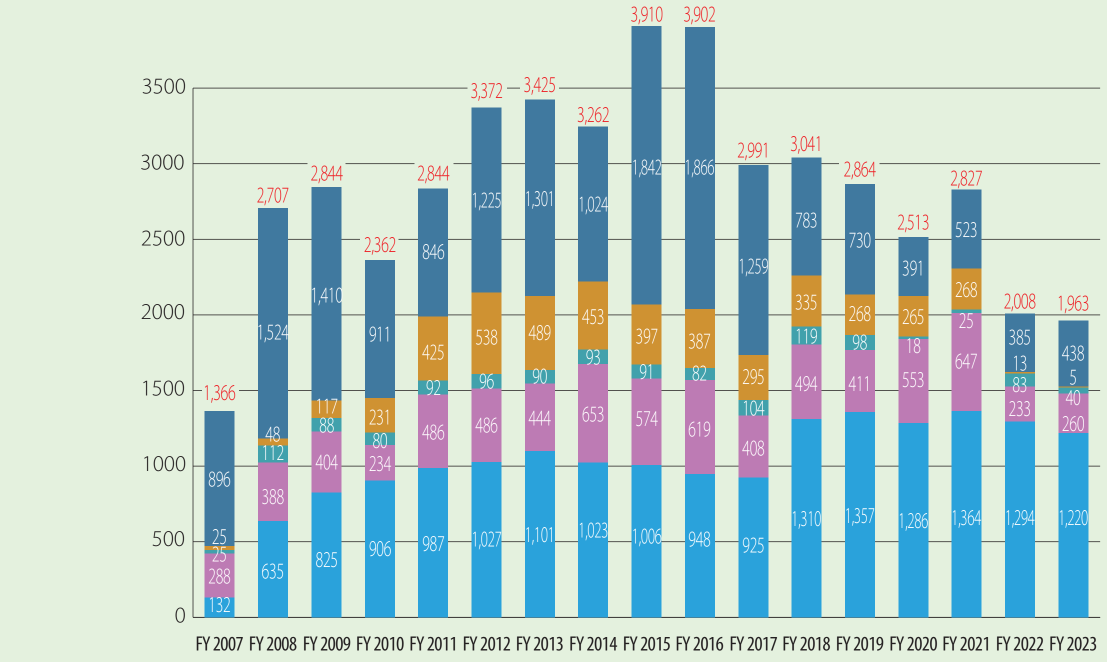
MEDIA COVERAGES & OUTREACH ACTIVITIES



- participants in outreach activities
- media coverages (domestic)
- media coverages (international)

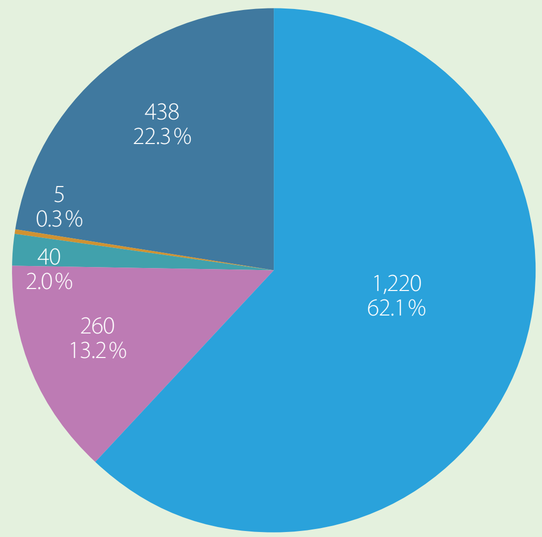
TOTAL EXPENDITURE

(1,000,000 JPY)



- Personnel
- Project Activities
- Travel Expenses
- Equipment
- Other Research Project

BREAKDOWN OF FY 2023 TOTAL EXPENDITURE



(1,000,000 JPY)

- Personnel
- Project Activities
- Travel Expenses
- Equipment
- Other Research Project

2 News & Events

April 2023 - March 2024

APRIL

- How to see the invisible: Using dark matter distribution to test our cosmological model
- Director Ooguri named an expert advisor for the universities for international research excellence program
- Director Hirosi Ooguri named 2023 Guggenheim Fellow
- YITP Workshop: Future Science with CMB x LSS
- New findings that map the universe's cosmic growth support Einstein's theory of gravity
- CD3 Opening Symposium
- Kavli IPMU x ICRR Hybrid Joint Public Lecture: "How Gamma Rays are Seen in Astronomy and Medicine"
- Quantum Electrodynamics Verified with Exotic Atoms

MAY

- Researchers find new approach to explore earliest universe dynamics with gravitational waves

JUNE

- Current Trends in Categorically Approach to Algebraic and Symplectic Geometry 2
- Hiraku Nakajima receives two Frontier of Science Awards
- LiteBIRD Simulation Hands-on Collaboration Meeting
- Starlight and the first black holes: researchers detect the host galaxies of quasars in the early universe

JULY

- Kavli IPMU receives funding for AI Ethical, Legal and Social Issues project
- Graduate open house (Online) – Department of Physics, the University of Tokyo
- Science Cafe "Universe"

AUGUST

- Hirosi Ooguri elected honorary trustee for life of the Aspen Center for Physics
- The World of Mathematical Sciences

SEPTEMBER

- Science Cafe "Universe"
- The Strongest Tag Team of the James Webb Space Telescope and ALMA Captures the Core of the Most Distant Galaxy Protocluster
- Researchers find gravitational lensing has significant effect on cosmic birefringence

OCTOBER

- Researchers develop new method that precisely targets cancer lesions while protecting healthy tissues
- Baton changes hands at Kavli IPMU, Jun'ichi Yokoyama becomes the new director
- Kashiwa Open Campus 2023
- Researchers study a million galaxies to find out how the universe began

NOVEMBER

- 9th Kavli IPMU/ELSI/IRCN Joint Public Lecture: "A Question of Origins"
- Development of tissue molecular imaging technique using multiple probes at hundreds of microns
- Focus Week on Primordial Black Holes
- 12th Annual WPI Science Symposium: Frontiers of Informatics-Based Research - Working with Information to Achieve Top-Level Research

DECEMBER

- Kavli IPMU Annual Report 2022 released
- CD3 Mini-Workshop "Time-Domain Astronomy and Cosmology in the LSST Era"
- Particle physicists' panel in US chaired by Hitoshi Murayama announce their priorities for the coming decade
- Kavli IPMU x ICRR Joint Public Lecture: "Gravitational Waves x Computational Cosmology"
- McKay Correspondence, Tilting Theory and Related Topics

JANUARY

- Tsinghua-Tokyo Workshop on Calabi-Yau
- Kavli IPMU alumni Christian Schnell elected fellow of the American Mathematical Society
- AI-Driven Discovery in Physics and Astrophysics

FEBRUARY

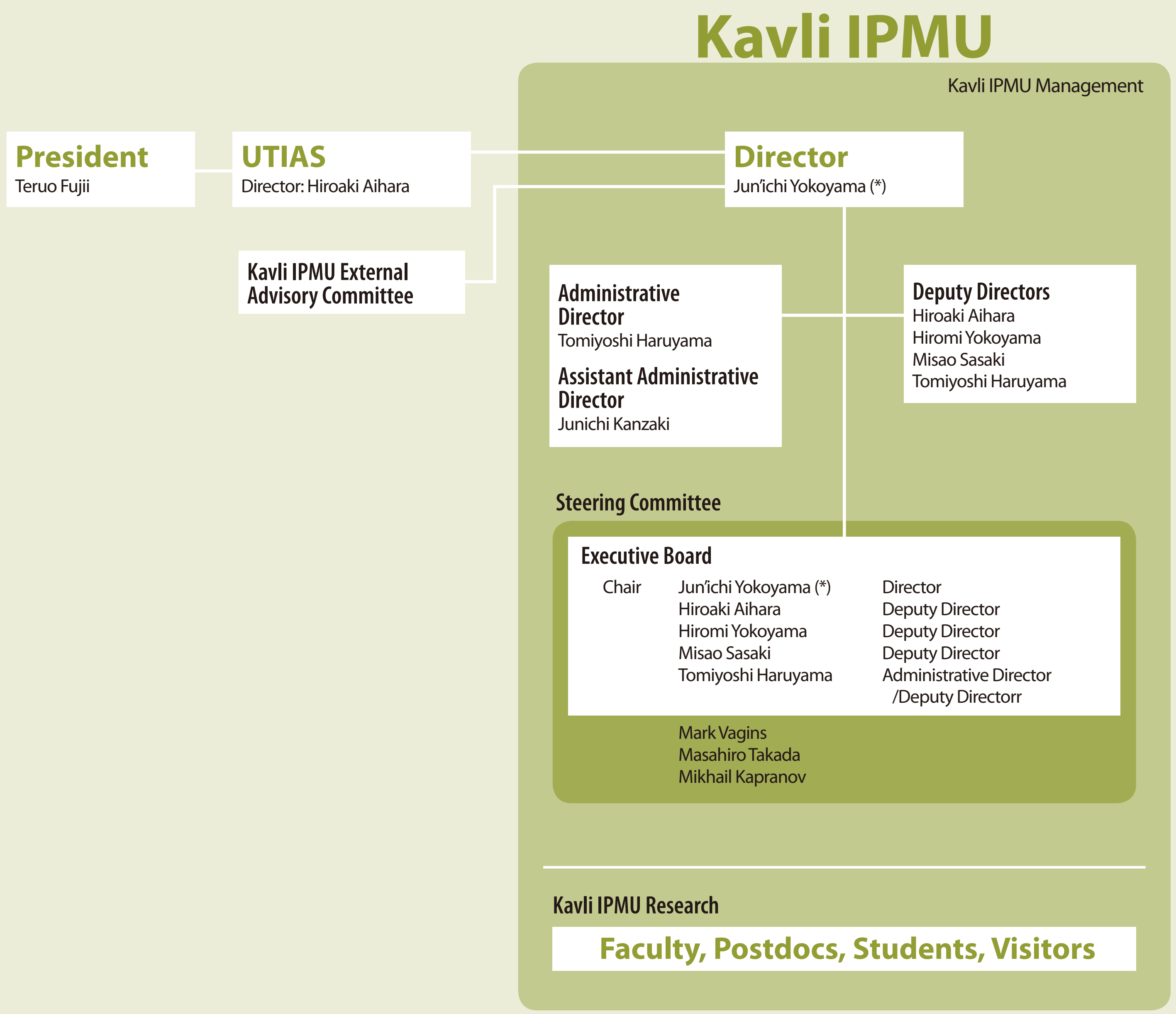
- Astronomy observation instrument used to uncover internal structure of atomic nuclei

MARCH

- What Is Dark Matter? — Comprehensive Study of the Huge Discovery Space in Dark Matter
- Envisaging Future Trajectories in Effective Field Theory (EFT in EFT)
- Masahiro Takada receives Hayashi Chushiro Prize
- Masamune Oguri awarded the 2024 Japan Academy Prize

News & Events

3 ORGANIZATION



*Hirosi Ooguri (until October 31, 2023)

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 (April 2023)

Joshua Frieman	FNAL/U Chicago, USA; Chair	Astrophysics
John Ellis	King's College London, UK	Particle Theory
Giovanni Felder	ETH Zürich, Switzerland	Mathematics
Masahiko Hayashi	JSPS Bonn Office, Germany	Astronomy
Tatsuya Nakada	EPFL, Switzerland	High Energy Experiment
Sakura Schafer-Nameki	U Oxford, UK	Mathematical Physics
Nigel Smith	TRIUMF, Canada	Astroparticle Physics
Yongbin Ruan	Zhejiang University, China	Mathematics

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 Études Scientifiques (IHES), France

Collaborating Institutions
(domestic)

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

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

4 STAFF

Director
Hirosi Ooguri, Mathematical Physics (till 2023/10/14)
Jun'ichi Yokoyama, Cosmology (from 2023/11/1)

Deputy Directors
Hiroaki Aihara, High Energy Physics
Tomiyoshi Haruyama, High Energy Physics
Misao Sasaki, Cosmology (till 2024/3/31)
Hiromi Yokoyama, Science and Society

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

Faculty Members
Tomoyuki Abe, Mathematics
Hiroaki Aihara (U Tokyo, School of Sci.), High Energy Physics
Linda Blot, Astrophysics (from 2023/12/1)
Alexey Bondal (Steklov Math. Inst.), Mathematics
(from 2023/8/3 - till 2024/2/15)
Patrick De Perio, Neutrino Physics
Elisa Gouvea Mauricio Ferreira, Cosmology
Mark Patrick Hartz (U Victoria), Neutrino Physics
(till 2023/7/31)
Tomiyoshi Haruyama, High Energy Physics
Simeon John Hellerman, String Theory
Takeo Higuchi, High Energy Physics
Kentaro Hori, String Theory
Yukari Ito, Mathematics
Mikhail Kapranov, Mathematics
Khee-Gan Lee, Astronomy
Jia Liu, Cosmology
Kai Uwe Martens, Experimental Physics
Shigeki Matsumoto, Cosmology
Tomotake Matsumura, Experimental Physics
Thomas (Tom) Edward Melia, Particle Theory
Todor Eliseev Milanov, Mathematics
Hitoshi Murayama (UC Berkeley), Particle Theory
Hiraku Nakajima, Mathematics
Toshiya Namikawa, Cosmology
Hirosi Ooguri (CALTECH), Mathematical Physics
Tadashi Orita, Experimental Physics
Misao Sasaki, Cosmology
Jingjing Shi, Cosmology (from 2023/10/1)
Satoshi Shirai, Particle Theory
John David Silverman, Astronomy
Yuji Tachikawa, Particle Theory
Masahiro Takada, Cosmology
Tadayuki Takahashi, Experimental Physics
Shinichiro Takeda, Experimental Physics
Leander Friedrich Thiele, Astrophysics (from 2024/3/1)
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
Jun'ichi Yokoyama, Cosmology (from 2023/11/1)
Naoki Yoshida (U Tokyo, School of Sci.), Astrophysics

Project Researchers
Joaquin Andres Armijo Torres, Cosmology
Meer Ashwinkumar, String Theory (till 2023/9/30)
Sebastian Bahamonde, Cosmology (from 2023/10/1)
Jiakang Bao, Mathematics (from 2023/4/30)
Rahool Kumar Barman, Particle Theory (from 2023/12/1)
Jahmall Matteo Bersini, Theoretical Physics
Connor Hugh Bottrell, Astrophysics (till 2023/6/14)
Philip Ewen Boyle Smith, Theoretical Physics
Anqi (Angela) Chen, Cosmology
Man Wai Cheung, Mathematics (till 2023/7/31)
Ioana Alexandra Coman Lohi, Theoretical Physics
Xuheng Ding, Astronomy (till 2024/1/31)
Andrew Thomas Eberhardt, Cosmology (from 2023/8/16)
Joshua Armstrong Eby, Cosmology (till 2023/9/10)
Norihiro Hanihara, Mathematics (till 2024/3/31)
Wahei Hara, Mathematics (from 2023/10/1)
Anamaria Hell, Cosmology (from 2023/10/1)
Thuong Duc Hoang, Experimental Physics (till 2023/10/31)
Shunichi Horigome, Theoretical Physics
Benjamin Aaron Horowitz, Theoretical Physics
(from 2024/1/16)
Sagharsadat Hosseinisemnani, Theoretical Physics
(from 2023/10/1)
Derek Beattie Inman, Cosmology (till 2023/5/31)
Kazuhiro Ito, Mathematics (till 2023/9/30)
Cesar Jesus Valls, Neutrino Physics
Baptiste Jost, Cosmology
Boris Sindhu Kalita, Astrophysics
Kookhyun Kang, High Energy Physics
Dogancan Karabas, Mathematics
Miho Katsuragawa, Experimental Physics (till 2024/3/31)
Ilya Khrykin, Astrophysics (till 2023/6/15)
Takafumi Kokubu, Theoretical Physics (till 2023/9/30)
Toshiki Kurita, Cosmology (from 2023/4/1 - till 2023/9/30)
Clement Leloup, Cosmology
Qiuyue Liang, Theoretical Physics (from 2023/9/1)
Huaxin (Henry) Liu, Mathematics (from 2023/9/16)
Kaloian Dimitrov Lozanov, Cosmology
Abhiram Mamandur Kidambi, Mathematical Physics
(till 2023/10/31)
Mohammad Khaled Hashem Mardini, Astronomy
(till 2024/2/6)
Dmytro Matvieievskyi, Mathematics
Katherine Alston Maxwell, Mathematics
Yuan Miao, Theoretical Physics (from 2023/5/22)
Hayato Morimura, Mathematics (from 2023/10/1)
Maria Mylova, Theoretical Physics (from 2023/11/1)
Yue Nan, Cosmology
Emily Margaret Nardoni, Theoretical Physics
Ippei Obata, Theoretical Physics
Masafusa Onoue, Astronomy (from 2023/11/1)
Samuel Charles Passaglia, Cosmology (till 2023/11/30)
Tian Qiu, Astronomy (from 2023/10/1 - till 2024/3/31)
Jingjing Shi, Cosmology (till 2023/9/30)
Myungbo Shim, Theoretical Physics (till 2023/8/31)
Sunao Sugiyama, Cosmology (from 2023/4/1 - till 2023/8/31)
Tomoko Suzuki, Astronomy
Ryota Takaku, Experimental Physics
(from 2023/4/1 - till 2024/3/31)
Hideki Tanimura, Astrophysics (till 2024/3/31)
Ka Ming Tsui, Neutrino Physics
Valeri Vardanyan, Cosmology (till 2023/7/31)
Kateryna Vovk, Astronomy
Graham Albert White, Particle Theory (till 2023/4/30)
Junjie Xia, Neutrino Physics
Lilan Yang, Astronomy (till 2023/9/4)
Mengxue Yang, Mathematics (from 2023/9/16)
Vicharit Yingcharoenrat, Cosmology
Si-Yue Yu, Astrophysics (from 2024/3/1)
Hao Zhang, Theoretical Physics (from 2023/10/16)
Yu Zhao, Mathematics
Yunqin Zheng, Theoretical Physics (till 2023/8/31)
Yehao Zhou, Mathematical Physics
Zijun Zhou, Mathematics (till 2023/8/31)

Cross Appointments

Mark Patrick Hartz (U Victoria), Neutrino Physics (till 2023/7/31)
Masashi Hazumi (KEK), High Energy Physics
Hitoshi Murayama (UC Berkeley), Particle Theory
Hirosi Ooguri (CALTECH), Mathematical Physics
Naoki Yoshida (U Tokyo, School of Sci.), Astrophysics

Affiliate Members

Ko Abe (U Tokyo, ICRR), Astroparticle Physics
Shin'ichiro Ando (U Amsterdam), Astroparticle Physics
Susumu Ariki (Osaka U), Mathematics (from 2023/4/1)
Metin Ata (Stockholm U), Cosmology (till 2024/3/31)
Melina Bersten (IALP CONICET-UNLP), Astronomy
Sergey Blinnikov (ITEP), Astronomy
Agnieszka Maria Bodzenta-Skibinska (U Warsaw), Mathematics
Alexey Bondal (Steklov Math. Inst.), Mathematics
Kevin Allen Bundy (UC Santa Cruz), Astronomy (till 2024/3/31)
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), Neutrino Physics
Jason Detwiler (U Washington, Seattle), Neutrino Physics
JMamoru Doi (U Tokyo, IoA), Astronomy (till 2024/3/31)
Christine Done (Durham U), Astrophysics
William Ross Goodchild Donovan (Tsinghua U, Beijing), Mathematics
Motoi Endo (KEK), Particle Theory
Sanshiro Enomoto (U Washington, Seattle), Neutrino Physics
Gaston Folatelli (IALP CONICET-UNLP), Astrophysics
Brian Fujikawa (LBL, Berkeley), Neutrino Physics
Masataka Fukugita (U Tokyo), Astrophysics
Shao-Feng Ge (Shanghai Jiao Tong U), Theoretical Physics
Lawrence J Hall (UC Berkeley), Particle Theory
Koichi Hamaguchi (U Tokyo, School of Sci.), Particle Theory
Keisuke Harigaya (U Chicago), Particle Theory
Mark Patrick Hartz (U Victoria), Neutrino Physics (from 2023/10/1)
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
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
Jun Kameda (U Tokyo, ICRR), Neutrino Physics
Amanda Irene Karakas (Monash U), Astronomy
Kazumi Kashiyama (Tohoku U), Astronomy
Yosuke Kataoka (U Tokyo, ICRR), Neutrino Physics
Akishi Kato (U Tokyo, Math Sci), Mathematical Physics
Yasuyuki Kawahigashi (U Tokyo, Math Sci), Mathematics
Masahiro Kawasaki (U Tokyo, ICRR), Cosmology
Edward T. Kearns (Boston U), Neutrino Physics
Sergey Ketov (Tokyo Metropolitan U), Theoretical Physics
Yasuhiro Kishimoto (Tohoku U), Neutrino Physics
Ryuichiro Kitano (KEK), Particle Theory
Chiaki Kobayashi (U Hertfordshire), Astronomy
Toshiyuki Kobayashi (U Tokyo, Math Sci), Mathematics
Masayuki Koga (Tohoku U), Neutrino Physics
Toshitake Kohno (Meiji U), Mathematics
Kazunori Kohri (KEK), Cosmology
Eiichiro Komatsu (MPI for Astrophysics), Cosmology
Satoshi Kondo (Middle East Tech. U), Mathematics
Yusuke Koshio (Okayama U), Neutrino Physics
Akito Kusaka (U Tokyo, School of Sci.), Experimental Physics
Alexander Kusenko (UCLA), Particle Theory
Tatsuki Kuwagaki (Kyoto U), Mathematics
Alexie Solange Leauthaud Harnett (UC Santa Cruz), Astrophysics (till 2024/3/31)
Shiuhang (Shiu-Hang) Lee (Kyoto U), Astrophysics
Marco Limongi (INAF), Astrophysics
Kazuo Makishima (U Tokyo, School of Sci.), High Energy Physics
Makoto Miura (U Tokyo, ICRR), High Energy Physics
Hironao Miyatake (Nagoya U), High Energy Physics
Hiroshi Mizuma (QST), Experimental Physics
Anupreeta Sadashiv More (IUCAA), Astronomy
Surhud Shrikant More (IUCAA), Astronomy
Yuki Moritani (NAOJ, Hawaii), Astronomy
Shigetaka Moriyama (U Tokyo, ICRR), Neutrino Physics
Takeo Moroi (U Tokyo, School of Sci.), Particle Theory
David Robert Morrison (UC Santa Barbara), Mathematics
Shinji Mukohyama (Kyoto U), Cosmology
Motohico Mulase (UC Davis), Mathematics
Dinakar Muthiah (U Glasgow), Mathematics
Kentaro Nagamine (Osaka U), Astrophysics
Yasuhiro Nakajima (U Tokyo, School of Sci.), Neutrino Physics
Yusuke Nakajima (Kyoto Sangyo U), Mathematics
Kenzo Nakamura (KEK), Neutrino Physics
Tsuyoshi Nakaya (Kyoto U), High Energy Physics
Kazunori Nakayama (Tohoku U), Cosmology
Shoei Nakayama (U Tokyo, ICRR), Neutrino Physics
Takahiro Nishimichi (Kyoto U), Cosmology
Samaya Michiko Nissanke (U Amsterdam), Astrophysics
Ken'ichi Nomoto (U Tokyo), Astronomy
Yasunori Nomura (UC Berkeley), Particle Theory
Hirokazu Odaka (Osaka U), High Energy Astrophysics
Masamune Oguri (Chiba U), Cosmology
Shinnosuke Okawa (Osaka U), Mathematics
Kimihiro Okumura (U Tokyo, ICRR), Neutrino Physics
Teppei Okumura (Academia Sinica), Cosmology
Domenico Orlando (INFN), String Theory
Ken Osato (Chiba U), Astrophysics (from 2023/5/1)
Masaki Oshikawa (U Tokyo, ISSP), Theoretical Physics
Atsuhisa Ota (Chongqing U), Theoretical Physics (from 2023/12/22)
Masami Ouchi (U Tokyo, ICRR), Astronomy
Guillaume Patanchon (APC), High Energy Physics (from 2023/4/1)
Serguey Todorov Petcov (SISSA), Particle Theory
Shi Pi (Chinese Academy of Sci.), Astrophysics
Jason Xavier Prochaska (UC Santa Cruz), Astronomy
Anna Puskas (U Queensland), Mathematics
Robert Michael Quimby (San Diego State U), Astronomy
Susanne Reffert (U Bern), String Theory
Jason Rhodes (NASA JPL/Caltech), Cosmology
Joshua Thomas Ruderman (New York U), Particle Theory
Kyoji Saito (Kyoto U), Mathematics
Ryo Saito (Yamaguchi U), Astrophysics
Shun Saito (Missouri U of Sci. and Tech.), Cosmology
Yoshihisa Saito (Rikkyo U.), Mathematics
Yuki Sakurai (Okayama U), Experimental Physics (from 2023/4/1)
Francesco Sala (U Pisa), Mathematics
Katsuhiko Sato (U Tokyo), Astroparticle Physics
Vadim Schechtman (U Toulouse III-Paul Sabatier), Mathematics
Christian Schnell (SUNY, Stony Brook), Mathematics
Kate Scholberg (Duke U), Neutrino Physics
Hiroyuki Sekiya (U Tokyo, ICRR), Neutrino Physics
Masato Shiozawa (U Tokyo, ICRR), High Energy Physics
Gary Shiu (U Wisconsin, Madison), String Theory
Aurora Simionescu (SRON, Netherlands Inst. for Space Research), Astrophysics
Michael Smy (UC Irvine), Neutrino Physics
Yevgeny Stadnik (U Sydney), Theoretical Physics
Samantha Lynn Stever (Okayama U), Astrophysics
Shigeki Sugimoto (Kyoto U), Theoretical Physics
Nao Suzuki (Florida State U), Astrophysics
Atsushi Takahashi (Osaka U), Mathematics
Fuminobu Takahashi (Tohoku U), Particle Theory
Tadashi Takayanagi (Kyoto U), String Theory
Atsushi Takeda (U Tokyo, ICRR), Astroparticle Physics
Yasuhiro Takemoto (U Tokyo, ICRR), Experimental Physics
Yasuo Takeuchi (Kobe U), Astroparticle Physics
Volodymyr Takhistov (KEK), Theoretical Physics (till 2024/3/31)
Naoyuki Tamura (NAOJ, Hawaii), Astronomy (from 2023/5/1)
Hidekazu Tanaka (U Tokyo, ICRR), Neutrino Physics
Masaomi Tanaka (Tohoku U), Astronomy
Atsushi Taruya (Kyoto U), Astrophysics
Meral Tosun (Galatasaray U), Mathematics (from 2024/1/26)
Sachiko Tsuruta (Montana State U), Astrophysics
Edwin L Turner (Princeton U), Astrophysics
Kazushi Ueda (U Tokyo, Math Sci), Mathematics
Hokuto Uehara (Tokyo Metropolitan U), Mathematics
Alexander Voronov (U Minnesota), Mathematics
Christopher W. Walter (Duke U), Neutrino Physics
Shin Watanabe (JAXA), Experimental Physics
Marcus Christian Werner (Duke Kunshan U), Mathematical Physics
Benda Xu (Tsinghua U, Beijing), Experimental Physics
Kiyoto Yabe (NAOJ, Hawaii), Astronomy (from 2023/5/1)
Tsutomu Yanagida (U Tokyo, School of Sci.), Particle Theory
Jun'ichi Yokoyama (U Tokyo), Cosmology (till 2023/10/31)
Masashi Yokoyama (U Tokyo, School of Sci.), High Energy Physics
Shuichiro Yokoyama (Nagoya U), Cosmology
Ying-li (Yingli) Zhang (Tongji U), Cosmology

Graduate Students

Kosuke Aizawa, Experimental Physics (from 2023/4/1)
Ryosuke Akizawa, Experimental Physics (from 2023/4/1)
Tatsuya Aonashi, Cosmology (from 2023/4/1)
Yuto Arai, Mathematics
Andres Nahuel Briones, Theoretical Physics (from 2024/3/1)
Weiguang Cao, Theoretical Physics
Jessica Alice Cowell, Astrophysics (from 2023/10/1)
Bruna Lorrany De Castro Araujo, Astronomy (from 2023/4/1)
Chenze Dong, Astronomy
Linghu Fan, Mathematics
Saki Fujita, Experimental Physics
Akira Harada, Mathematics (from 2023/4/1)
Kota Hayashi, Cosmology
Tatsuya Hayashi, Cosmology
Kyosuke Higashida, Mathematics
Yuxin Huang, Astronomy
Tomohiro Karube, Mathematics
Kotaro Kawasumi, String Theory
Shotaro Kinoshita, Science and Society
Dan Kondo, Particle Theory
Kouki Kumagai, Mathematics (from 2023/4/1)
Peijang Liu, Mathematics
Zhaoxuan Liu, Astronomy
Tianle Mao, Mathematics
Takahiro Minami, Experimental Physics
Yutaka Nagai, Mathematics (from 2023/4/1)
Shunsaku Nagasawa, Experimental Physics (till 2024/3/31)
Shintaro Nakano, Cosmology (from 2023/4/1)
Kanade Nishikawa, Particle Theory
Kanmi Nose, Cosmology
Caio Takanori Oba Ishikawa, Experimental Physics (from 2023/4/1)
Risshin Okabe, Particle Theory
Masaki Okada, Theoretical Physics

Fumiaki Otani, Experimental Physics
Tian Qiu, Astronomy (till 2023/9/30)
Shota Saito, Particle Theory (from 2023/4/1)
Renji Sakamoto, Mathematics
Yotaro Sato, Theoretical Physics (till 2024/3/31)
Tomoyuki Shimasaki, Experimental Physics
Yanming Su, Theoretical Physics (from 2023/10/1)
Yusuke Suetake, String Theory
Takumi Tanaka, Astronomy (from 2023/4/1)
Shenli Tang, Astronomy (till 2023/9/30)
Takanori Taniguchi, Cosmology
Ryo Terasawa, Cosmology
Taisei Terawaki, Cosmology (from 2023/4/1)
Akira Tokiwa, Cosmology
Soichiro Uemura, Mathematics (from 2023/4/1)
Akihiro Watanabe, String Theory (till 2024/3/31)
Yu Watanabe, Particle Theory (till 2024/3/31)
Yuki Watanabe, Cosmology
Xiaokun Xia, Mathematics
Fanli Zeng, High Energy Physics
Dongao Zhou, Theoretical Physics (from 2023/10/1)

Administration
Tomiyoshi Haruyama, Administrative Director, Project Professor
Junichi Kanzaki, Deputy Administrative Director, Project Lecturer (till 2024/3/31)
Kouji Yoshiizumi, General Manager
Akiko Yamasue, Deputy General Manager (from 2023/4/1)

Accounting
Masataka Tanaka*
Takako Okawa
Hiromi Yoshida
Yukiko Yoshikawa

Budget Control
Takuya Tanigaichi*
Rie Kohama
Madoka Okamoto
Kaori Watanabe

Contract & General Purchasing
Noboru Abe* (till 2024/3/31)
Naoko Ishida
Yuri Kazama
Sachiko Shimada
Tomoko Yamanaka

General Management
Manabu Hirano*
Yuuko Enomoto
Mika Miura
Ayako Nakada
Mana Shindo
Rieko Tamura

International Relations and Researchers Support
Yuko Fukuda* (till 2024/3/31)
Masami Nishikawa
Yuhi Ota
Tomoko Shiga
Eri Shinoda
Saki Suzuki (from 2023/5/15)

Network & Web Service
Kazuyuki Fukushima (from 2023/4/1)
Satoko Inoshita
Masahiro Kawada (till 2023/4/30)

Planning & Assessment
Shoko Ichikawa

Public Relations
Motoko Kakubayashi
Marina Komori
Aya Tsuboi

Kamioka Branch
Hideaki Abe*
Masako Ishikura
Yoshimi Kakioka
Hitoshi Nakagawa

(*section head)

5 Research Highlights

5.1 Finding New Branes in String Theory

Yuji Tachikawa

String theory originated from an attempt in the 1970s to treat string-like objects quantum mechanically in a manner respecting special relativity. The original motivation was to study the dynamics of "the strong force" which underlies the nuclear force. It soon turned out, however, that string theory was not quite suitable for this original purpose, but instead was found to contain a quantized version of general relativity. Since then, string theory continues to be a rare example where quantum mechanics and general relativity can be treated consistently at the same time. Another interesting fact is that the structure of string theory is quite constrained. Its consistency requires that the spacetime is ten dimensional, and there are only a handful of such consistent ten-dimensional string theories, known as Type IIA string theory, Type IIB string theory, Type I string theory, and a number of heterotic string theories. Furthermore, a consistent ten-dimensional string theory almost automatically exhibits supersymmetry, a symmetry exchanging bosons and fermions. Finally, if we hope to describe our four-dimensional world using string theory, we need to assume that the ten-dimensional spacetime has the form of the large four-dimensional spacetime times a very small six-dimensional space. This much was uncovered in the 1980s.

By construction, the ten-dimensional spacetime described by string theory contains degrees of freedom which are string-like, that is, excitations which extend along one space-like dimension. A big development in the middle 1990s was that string theory was found to automatically contain membrane-like excitations, that is, those extending along two dimensions, and other more general extensions extending along many more dimensions. These general excitations are now known as "branes", a word coined by removing "mem-" from "membranes". More precisely, a brane extending along p dimensions is called a p-brane. Therefore, a string is a 1-brane and a membrane is a 2-brane. The discovery of branes made string theory much more useful than it ever had been. Many of the applications of string theory to other subfields of physics (such as condensed-matter physics or hadron physics) and to mathematics were done in terms of branes. Therefore, such applications were even unthinkable without branes.

A natural question then is to find out the types and the properties of branes contained in each of the consistent ten-dimensional string theories. A complete answer was soon given, if we restrict our attention to branes which preserve some of the supersymmetry. For example, the only supersymmetric branes in a heterotic string theory are the 5-branes in addition to the 1-branes (i.e. the strings we started our story with). There was no systematic attempt to find all the non-supersymmetric branes at that time, however.

Things started to change only in the last several years, with the publication of the preprint [1] in 2019 by McNamara and Vafa, who suggested a semi-systematic method to look for such non-supersymmetric branes. My investigations since then with J. Kaidi (a regular visitor of IPMU, now an assistant professor at Kyushu Univ.), K. Ohmori (an assistant professor at Hongo, Univ. Tokyo) and K. Yonekura (a former IPMU postdoc, now an associate professor at Tohoku Univ.) culminated in a paper [2] published in Physical Review Letters in 2023, where we gave a uniform description of non-supersymmetric 7-, 6-, 4- and 0-branes in heterotic string theory. The 4-branes and the 0-branes were known previously, while the 7-branes and 6-branes are new. Even the known 4- and 0-branes were not known to be in a single uniform family either.

Not only did this discovery show the existence of a new, uniform family of branes in heterotic string theory, but it also opened up a novel connection with mathematics. Heterotic string theory has been suspected to be closely related to a mathematical object known as topological modular forms, which plays an important role in algebraic topology. It is fairly straightforward to show that a p-brane in heterotic string theory should correspond to a topological modular form of degree p–24. The detailed data of topological modular forms were first concretely tabulated in a mathematical monograph [3] from 2021. Now, I would like to ask the reader to have a look at Figure 1 below, which I adapted from [3]. We can easily see in it that there are special elements (marked in red) at degrees −31, −30 and −28, together with a named element D_7 at degree −24, nicely corresponding with our 7-, 6-, 4- and 0-branes. In fact, this figure from [3] was one of the motivations for me to look for the new heterotic p-branes for exactly these values of p. These points and more details are discussed in my preprint [4] with a mathematician Mayuko Yamashita (an associate professor at Kyoto Univ.), which is currently under review. Hopefully, what we have found is only a tip of a large iceberg connecting branes in string theory and algebraic topology, and I intend to look into these matters in the near future. I also hope that the new branes we found would turn out to be useful in various applications of string theory in general.

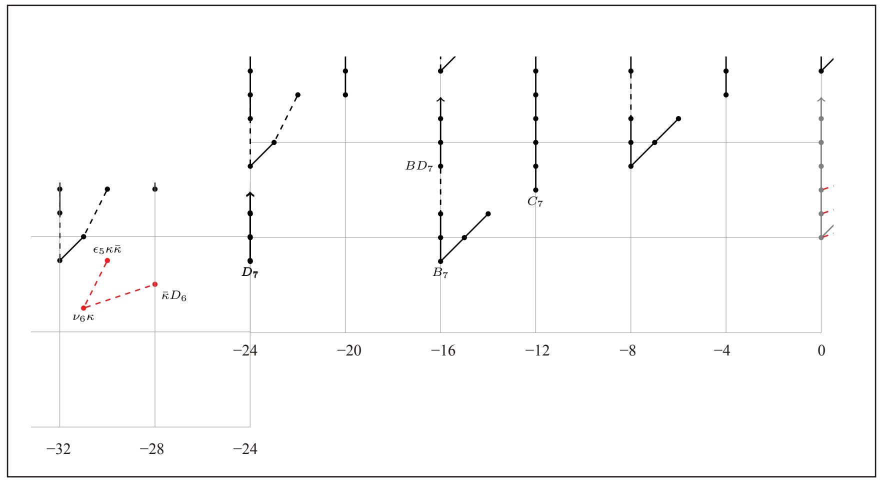


Figure 1: Table of elements of topological modular forms, adapted and modified from Fig. 9.12 and Fig. 9.13 of [3]. Horizontal and vertical axes are for the degree and the Adams filtration of the topological modular forms, respectively.

References
[1] J. McNamara and C. Vafa, "Cobordism classes and Swampland", arXiv:1909.10355 [hep-th]
[2] J. Kaidi, K. Ohmori, Y. Tachikawa and K. Yonekura, "Non-supersymmetric heterotic branes", Physical Review Letters **131** (2023) 121601, arXiv:2023.17623 [hep-th]
[3] R. Bruner and J. Rognes, "The Adams Spectral Sequence for Topological Modular Forms", Mathematical Surveys and Monographs 253, AMS, 2021
[4] M. Yamashita and Y. Tachikawa, "Anderson self-duality of topological modular forms, its differential-geometric manifestations, and vertex operator algebras", arXiv:2305.06196 [math.AG]

Research Highlights

5.2 Enumerative Geometry and Category Theory

Yukinobu Toda

Enumerative geometry is a branch of mathematics, in which we count geometric objects in a given space. For example, the number of lines in the plane passing through given two points is just one, the number of lines on cubic surfaces is 27, the number of lines on quintic 3-folds is 2875, and so on. Since the question is primitive, enumerative geometry has long history in mathematics.

The situation of enumerative geometry drastically changed around 1990, when string theorists discovered that the number of curves on quintic 3-folds may be calculated by solving some differential equations. A quintic 3-fold is one of the special types of manifolds, called Calabi-Yau 3-fold, and the above phenomenon was found through a curious symmetry among Calabi-Yau 3-folds, called mirror symmetry. Since then, enumerative geometry of curves on Calabi-Yau 3-folds has developed involving both of mathematics and string theory. In particular, several enumerative invariants which virtually count curves on algebraic varieties have been defined in mathematically rigorous way, which are expected to be equivalent in highly non-trivial ways. The Donaldson-Thomas (DT) invariant, which was introduced by Thomas around 1998, is one of such invariants.

Around 2008, I started the study of applying the theory of derived categories of coherent sheaves to enumerative geometry, in particular DT theory. Here, the category is an abstract mathematical concept, with the notion of objects and morphisms between them. One can roughly say that a category is a 'community' of mathematical objects. The derived category of coherent sheaves was introduced in 1960s by Grothendieck and Verdier. It was first regarded as a technical mathematical concept, but is now itself regarded as a kind of nice 'non-commutative space'. Using non-trivial symmetries of derived categories, I proved several important properties of DT invariants.

My recent research is in the opposite direction. I am trying to upgrade the enumerative invariants, which are integers, to some categories which recover these invariants. There are several motivations of categorifying the DT invariants; they not only reveal categorical origin of several important properties of DT invariants but also give applications, new insight, to other research areas of mathematics, e.g., birational geometry, representation theory, McKay correspondence, classical moduli problem in algebraic geometry, geometric Langlands problem, and so on.

In my research monograph [1] published in 2024, I established such categorical DT theory in the case of special type of Calabi-Yau 3-folds called local surfaces, and explained my motivation of pursuing categorical DT theory. I have also collaborated with Tudor Pădurariu and written several joint papers [2, 3, 4] in this research direction. For example, in [2], we proved the following theorem which gives a categorification of the formula for DT invariants counting points in the 3-dimensional affine space, the simplest Calabi-Yau 3-fold.

Theorem ([2])
Let *DT*(*d*) be the DT category for d-points on the 3-dimensional affine space. Then there is a semiorthogonal decomposition

$$\mathcal{DT}(d) = \left\langle \otimes_{i=1}^{k} S(d_i)_{v_i} : d_1 + \cdots + d_k = d, 0 \leq \frac{v_1}{d_1} < \cdots < \frac{v_k}{d_k} < 1 \right\rangle.$$

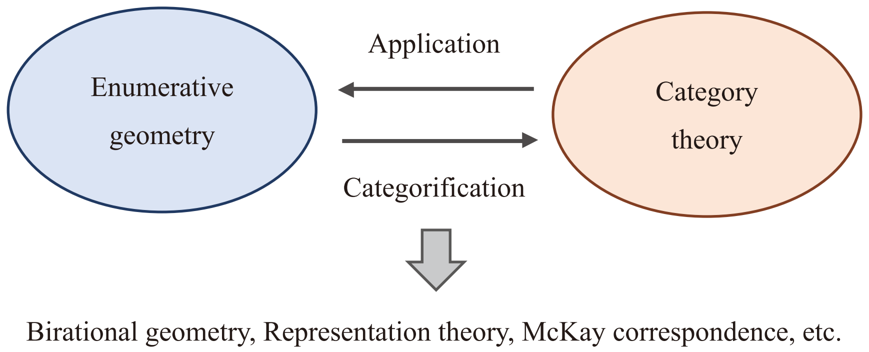
Here the category $S(d)_v$ is called `quasi-BPS category' of weight v, whose torus equivariant K-theory has dimension n = gcd(*d*, *v*) over $Q(q_1^{\pm 1}, q_2^{\pm 1})$.

Here the `semiorthogonal decomposition' roughly means a decomposition of the category into smaller pieces in some sense. The above theorem gives a categorification of the formula of the generating series of numerical DT invariants, which was known to be the series of numbers of plane partitions (called MacMahon function)

$$\prod_{k\geq 1} \frac{1}{(1-q^k)^k} = 1 + q + 3q^2 + 6q^3 + \cdots$$

We also conjectured that $S(d)_v$ is equivalent to the Z/2-periodic derived category of coherent sheaves on the quotient stack $(C^3)^{\times n}/S_n$. The above conjecture is related to McKay correspondence, which is an interesting phenomenon which relates representation theory of finite groups and resolution of singularities of the quotient space, and also geometric Langlands program.

I will continue this research of categorical DT theory and develop a new fascinating research area which relates enumerative geometry with other research fields through categorification of enumerative invariants.



References
[1] Yukinobu Toda, Categorical Donaldson-Thomas theory for local surfaces, Springer Lecture Notes in Mathematics (2350), 2024, 309 pages.
[2] Tudor Pădurariu and Yukinobu Toda, Categorical and K-theoretic Donaldson-Thomas theory of C^3 (part I), Duke Mathematical Journal 173 (10), 1973-2038, 2024.
[3] Tudor Pădurariu and Yukinobu Toda, Categorical and K-theoretic Donaldson-Thomas theory of C^3 (part II), Forum of Mathematics, Sigma 11, Paper No. e108, 47, 2023.
[4] Tudor Pădurariu and Yukinobu Toda, The local categorical DT/PT correspondence, Advances in Mathematics 442, Paper No. 109590, 2024.

5.3 Metastable Cosmic Strings and Gravitational Waves

Satoshi Shirai

The Standard Model of particle physics is defined by its gauge symmetries, which describe three of the fundamental forces of nature: electromagnetic, weak, and strong interactions, represented by the group structure $SU(3) \times SU(2) \times U(1)$. However, the Standard Model is not regarded as the ultimate theory of nature, as it does not adequately explain several critical phenomena, such as the origin of dark matter in the early universe and the integration of quantum gravity. To bridge these gaps, physicists often extend the Standard Model by introducing additional gauge symmetries. These extended symmetries can spontaneously break at different epochs in the universe's history, potentially giving rise to macroscopic entities known as topological defects. For example, the spontaneous breaking of a $U(1)$ gauge symmetry can lead to the formation of cosmic strings—large, stable structures characterized by a strong flux of the $U(1)$ magnetic field.

The stability of a cosmic string arises from the topological properties of the gauge symmetry. This stability can also be interpreted in terms of the persistence of the magnetic field within the cosmic string. As commonly taught in electromagnetism, the divergence of a magnetic field is zero, which implies that magnetic field lines are continuous and cannot terminate. This inherent continuity of magnetic field lines is a key factor contributing to the stability of cosmic strings.

If cosmic strings were generated in the early universe, they would evolve dynamically over time, bending, oscillating, and forming loops. This continuous evolution can lead to the emission of gravitational waves (GWs), which could manifest as a stochastic gravitational wave background detectable by observational instruments.

Recently, several pulsar timing array (PTA) collaborations have reported the detection of a stochastic gravitational wave (GW) signal exhibiting a Hellings–Downs angular correlation in the nanohertz (nHz) range [1,2,3,4]. However, it is crucial to recognize that these GW signals require further validation, and the exact origin of these signals remains uncertain. Notably, the features of the observed spectrum appear to favor the presence of metastable cosmic strings over stable ones [5]. The metastability of these strings results in a suppression of the low-frequency components of the GW signal within the PTA band. These initial observations have sparked considerable interest in the theoretical investigation of metastable cosmic strings, as researchers aim to elucidate their possible role in the early universe.

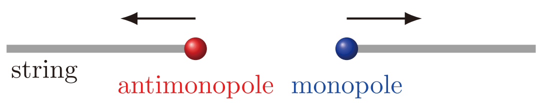


Figure 1: String breaking via monopole-antimonopole pair creation.

How can we understand metastable cosmic strings? Traditionally, the stability of cosmic strings is attributed to the fact that $\nabla \cdot B = 0$, indicating that magnetic field lines are continuous and cannot terminate. However, if magnetic monopoles exist, this condition changes to $\nabla \cdot B \neq 0$, implying that magnetic field lines could, in principle, become disconnected. The influence of a magnetic monopole on a cosmic string can be explained as follows: A strong magnetic field within a cosmic string can induce the formation of monopole-antimonopole pairs, a process analogous to the Schwinger effect, in which particle-antiparticle pairs are created in a strong electric field. When these monopole-antimonopole pairs form, they can cause the cosmic string to sever. This severing process may occur repeatedly, ultimately leading to the complete destruction of the cosmic string through the successive annihilation of monopole-antimonopole pairs (see Fig. 1).

Magnetic monopoles are sometimes predicted by Grand Unified Theories (GUTs). In certain $SO(10)$ GUTs, both magnetic monopoles and cosmic strings are anticipated, making cosmic strings potentially metastable. Thus, the recently detected stochastic gravitational wave background could suggest the existence of such GUTs, which has attracted substantial interest.

To better understand this phenomenon, we can examine the decay rate of cosmic strings mediated by monopoles. The decay rate per unit length of a cosmic string is approximately given by:

$$\mu \exp\left(-\frac{\pi m_M^2}{\mu}\right) ,$$

where μ is the tension of the cosmic string, and m_M is the mass of the monopole. This expression, commonly used in conventional analyses, assumes that the mass of the monopole is much larger than the energy scale of the cosmic string ($m_M^2 \gg \mu$). However, to explain the recently observed gravitational wave signals, shorter-lived cosmic strings are needed, which implies a parameter regime where $m_M^2 \sim \mu$. This contradicts the initial assumption of a significantly larger monopole mass, suggesting that the conventional estimate for the cosmic string decay rate may be unreliable.

To address this issue, we calculated the stability and decay rate of cosmic strings using field theory techniques, avoiding reliance on monopole pair creation [6]. We considered a simple gauge symmetry breaking pattern, $SU(2) \to U(1) \to$ nothing, realized by introducing two types of Higgs fields. We numerically determined the field configurations of the Higgs and gauge fields during the tunneling process and employed quantum tunneling techniques to calculate the decay of metastable cosmic strings. Our analysis revealed monopole-like configurations emerging during this process, as seen in Fig. 2.

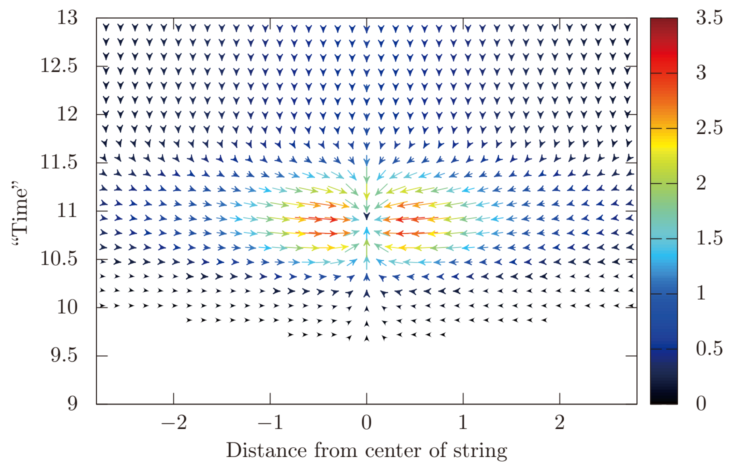


Figure 2: The configuration of magnetic fields during the string-breaking process. An emerging large magnetic field indicates the appearance of a monopole-like configuration.

Our findings indicate that, within the parameter space consistent with the recent observations, the conventional decay rate calculation is indeed unreliable. We identified a decay channel that leads to faster string decay than would be expected from a simple monopole pair creation process. However, our current calculations only consider a subset of possible tunneling configurations. Future work will focus on conducting a more comprehensive analysis and applying our findings to more realistic GUT scenarios.

References

[1] G. Agazie *et al*. [NANOGrav], "The NANOGrav 15 yr Data Set: Evidence for a Gravitational-wave Background," Astrophys. J. Lett. **951**, no.1, L8 (2023)
[2] J. Antoniadis *et al*. [EPTA and InPTA:], "The second data release from the European Pulsar Timing Array - III. Search for gravitational wave signals," Astron. Astrophys. **678,** A50 (2023)
[3] D. J. Reardon *et al*. "Search for an Isotropic Gravitational- wave Background with the Parkes Pulsar Timing Array," Astrophys. J. Lett. **951**, no.1, L6 (2023)
[4] H. Xu *et al*. "Searching for the Nano-Hertz Stochastic Gravitational Wave Background with the Chinese Pulsar Timing Array Data Release I," Res. Astron. Astrophys. **23**, no.7, 075024 (2023)
[5] A. Afzal *et al*. [NANOGrav], "The NANOGrav 15 yr Data Set: Search for Signals from New Physics," Astrophys. J. Lett. **951**, no.1, L11 (2023)
[6] A. Chitose, M. Ibe, Y. Nakayama, S. Shirai and K. Watanabe, "Revisiting metastable cosmic string breaking," JHEP **04**, 068 (2024) [arXiv:2312.15662 [hep-ph]].

5.4 Test gravity in the upcoming pulsar timing array observations

Qiuyue Liang

Pulsars, discovered in 1967, are highly magnetized rotating compact stars that emit beams of electromagnetic radiation from their magnetic poles, arriving at Earth as pulses when the poles point to our direction. The period of these pulses is extremely stable, and therefore, if, for example, a gravitational wave — a distortion in space and time that is a consequence of theories of gravity — passes, the pulse signal is affected, and the period would change. We can measure this change in the period over time and can infer details of both properties of the sources of the gravitational waves, and of the theory of gravity in which they were produced. The default would be to expect these measurements to reflect that gravity is described by Einstein's theory of General Relativity, but any deviations from this would be one of the most important experimental results in decades.

To obtain a larger signal-to-noise ratio from these measurements, astronomers have developed the idea of a pulsar timing array (PTA) which measures many pairs of pulsars in the system and analyzes their correlated signatures. Given the typical observational time to be order of 10 years, PTA measurements are sensitive to gravitational waves in the nano-Hertz frequency band. This makes them particularly useful probes, since this band cannot be probed by other gravitational wave detectors, such as the Laser Interferometer Gravitational-Wave Observatory (LIGO)/VIRGO/KAGRA, and the proposed Laser Interferometer Space Antenna (LISA)/DECIGO. For example, the gravitational wave background produced by the supermassive black holes that are generally thought to lie at the centers of galaxies should be in the nano-Hertz band. Furthermore, important early universe processes such as the formation of exotic objects such as cosmic strings from phase transitions in the quantum field theories that describe elementary particles, or primordial gravitational waves produced during the initial dynamics of the universe after the big bang, also predict waves within this low-frequency band. Besides gravitational waves, these sensitive and precise clocks can also detect other periodic fluctuations with a different response function to explore fundamental physics, such as the nature of dark matter, which is one important missing energy component consisting of 26% of the universe and barely interacts with the standard model. It has been proposed that the PTA system is capable of detecting the substructure of dark matter, and, more interestingly, the sensitivity band of the PTA system lies within the current bounds of the ultralight dark matter scenario.

In recent data released by North American Nanohertz Observatory for Gravitational Waves (NANOGrav), the Parkes Pulsar Timing Array (PPTA), the European Pulsar Timing Array (EPTA), the Indian Pulsar Timing Array (InPTA), and the Chinese Pulsar Timing Array (CPTA), strong evidence for a power-law power spectrum, the function that describes how the energy in gravitational waves depends of their frequencies, has been claimed, as shown in left panel of Fig. 1. Moreover, for the first time, the shape of this signal as a function of the angle between the pulsar pairs has been discovered, and further convinced the gravitational wave nature of the signal from the negative correlation at 90 degrees, shown in right panel of Fig. 1.

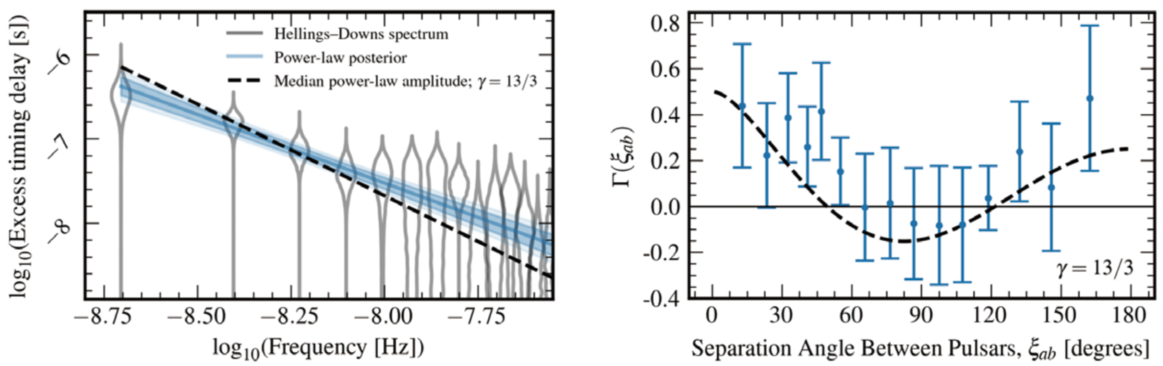


Fig.1: NANOGrav 15-year result published in *Astrophys.J.Lett* 951 (2023) 1, L8 [1]. Left panel: The power-law like power spectrum of the gravitational wave background. The blue represents the posterior median and 1/2σ posterior bands for a power-law model; the dashed black line corresponds to a γ = 13/3 (SMBHB-like) power-law. Right panel: The overlap reduction function denoting the angular dependence of the pulsar pairs response to the gravitational wave background. Measured from 2,211 distinct pairings in 67-pulsar, assuming maximum-a-posteriori pulsar noise parameters and γ = 13/3 common-process amplitude from a Bayesian inference analysis. The dashed black line shows the Hellings–Downs correlation pattern, and the binned points are normalized by the amplitude of the γ = 13/3 common process to be on the same scale.

However, within the current error bars, several questions remain to be addressed in future data releases. Firstly, it is still under investigation whether the observed stochastic gravitational wave background (SGWB) has an astrophysical origin, such as supermassive black hole binaries, or a cosmological origin, such as phase transitions or primordial gravitational waves. Additionally, the current power spectrum exhibits a frequency dependence that is shallower than all standard predictions as can be seen in the left panel of Fig. 1, a discrepancy that further PTA data in the next decade may help resolve.

Secondly, the error bars on the overlap reduction function are too large to definitively exclude or support any new physics. Whether there is a monopole/dipole contribution is crucial for dark matter physics, and the coefficients of the higher multipole moments will be important for testing gravity theories. Thirdly, it is widely believed that there are nearby, bright supermassive black hole binary candidates that could be distinguishable on top of the SGWB in PTA observations. Searching for such signals is an ongoing effort within PTA collaborations, and it is important for us to provide theoretical predictions in modified gravity theory to guide these searches. Finally, if a gravitational wave background exists within our galaxy and can be detected by pulsars, it should also affect other stars. It is important to explore the potential of using other stellar objects to detect the gravitational waves. By measuring the deflection angles of stars via astrometry, such as with Gaia, we should be able to independently detect this SGWB. These systems are also of importance to be considered as a joint analysis despite the fact that they can be sensitive other useful information of the SGWB.

These findings inspired our study of using PTA systems to test gravity. Since the overlap reduction function (ORF) is independent of specific gravity theories, the best approach to isolating the effects of modified gravity is to examine the ORF. In my recent publication [2], we found that if we assume the stochastic gravitational wave background (SGWB) behaves as plane waves, only the phase velocity of the gravitational waves affects the modification of the ORF, as shown in Fig. 2. Furthermore, the angle capturing the minimum of the ORF shifts to the left if the phase velocity is less than 1, and to the right if it is greater than 1. This finding corrects the misleading terminology in the literature, where group velocity has been used as a parameter to describe deviations in the ORF, implicitly assuming a massive gravity-like dispersion relation that relates group velocity to phase velocity. This result highlights that in modified gravity theories, the ORF is typically frequency-dependent, as the phase velocity often varies with frequency.

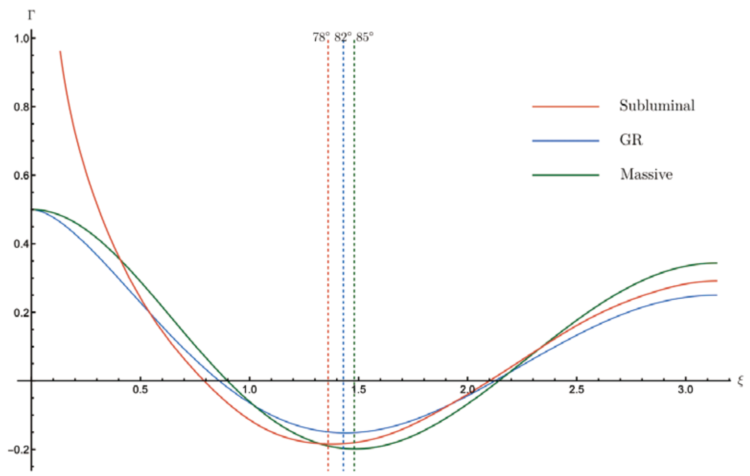


Fig.2: the overlap reduction function in modified gravity theories with phase velocity (vp) not equal to speed of light. Blue: prediction in GR; Green: vp>1; Red: vp<1.

References

[1] Gabriella Agazie et al. "The NANOGrav 15 yr Data Set: Evidence for a Gravitational-wave Background". In: Astrophys. J. Lett. 951.1 (2023), p. L8. arXiv: 2306.16213 [astro-ph.HE].
[2] Qiuyue Liang, Meng-Xiang Lin, and Mark Trodden. "A test of gravity with Pulsar Timing Arrays". In: JCAP 11 (2023), p. 042. arXiv: 2304.02640 [astro-ph.CO].

5.5 Quantum Electrodynamics Verified with Exotic Atoms

Tadayuki Takahashi

Using the newly introduced superconducting Transition Edge Sensor (TES) calorimeter, we successfully performed precision spectroscopy of muonic characteristic X-rays emitted from isolated muonic atoms in a vacuum. This allowed us, for the first time in the world, to experimentally reveal Quantum Electrodynamics (QED) effects in muonic atoms of heavy elements—a system that has long been of interest but challenging to realize.

Negative muons can be extracted as beams from large accelerators. In muonic atoms, the negative muon orbits the nucleus at a radius approximately 1/200th that of a bound electron. Consequently, the electric field experienced by the muon is about 40,000 times stronger than that experienced by a bound electron in a highly charged ion at the same quantum level, resulting in significant QED effects (Figure 1). Additionally, using negative muons that occupy high angular momentum quantum levels with minimal overlap with the nucleus allows experiments to largely suppress the influence of the nucleus's finite size. By precisely measuring the energy of muonic characteristic X-rays emitted during the de-excitation of muonic atoms, QED can be verified under strong electric fields.

Thus, muonic atoms present a promising experimental opportunity for verifying strong-field QED. However, several challenges must be overcome. The most significant is the need to prepare a number of muonic atoms in an isolated environment. The presence of nearby atoms or molecules can cause rapid electron transfer, altering the energy of the muonic characteristic X-rays. The solution is to use dilute gas targets with low density (low pressure), but this reduces the number of muonic atoms produced and, consequently, the intensity of the muonic characteristic X-rays. We conducted experiments at the Japan Proton Accelerator Research Complex (J-PARC) in Tokai-mura, Ibaraki, where the world's most intense low-velocity muon beam is available. To achieve sufficient energy resolution with the low intensity muonic characteristic X-rays, the experiment was conducted using a TES microcalorimeter, a highly efficient and high-resolution X-ray detector.

By employing neon (Ne: atomic number 10) atoms as the target under dilute conditions of 0.1 atm, we achieved an energy resolution more than ten times higher than that of conventional semiconductor detectors (with an FWHM of 5.2 eV). This enabled us to measure the muonic characteristic X-rays near 6.3 keV, corresponding to the 5g-4f and 5f-4d transitions in muonic Ne atoms. Although the resulting peak primarily comprised overlapping muonic X-rays from six different transitions, we analyzed each contribution and determined the energy of the muonic characteristic X-rays with an extremely high accuracy of 0.002 % (Figure 2). The absolute energy of the muonic characteristic X-rays associated with the 5g→4f transition in muonic neon (μNe) was measured to be 6298.8 eV, with a statistical error of 0.04 eV and a systematic error of 0.26 eV [1,2,3].

Furthermore, we repeated similar measurements while varying the pressure of the Ne gas target. We observed that the energy of the muonic characteristic X-rays remained constant within experimental error, regardless of the pressure. This result led us to conclude that the muonic Ne atoms used in our experiment were in an isolated environment, free from electron capture from surrounding atoms. A comparison between the latest theoretical calculations and our experimental results confirmed agreement within the experimental uncertainties. Notably, our study succeeded in verifying the effect of vacuum polarization under a strong electric field with a remarkably high accuracy of 5.8 %, comparable to the verification accuracy achieved using highly charged uranium ions (U91+) with an atomic number of 92.

In this study, the energy of muonic characteristic X-rays emitted from muonic neon atoms was precisely measured by combining the high-intensity muon beam at J-PARC with the state-of-the-art TES detector. This demonstrated a proof-of-principle strong-field QED verification experiment using muonic atoms. Our demonstration of the experimental technique using muonic atoms is expected to lead to significant advancements in the study of QED verification under strong electric fields.

The experiment was carried out under the Grant-in-Aid for Scientific Research on Innovative Area, entitled "Toward new frontiers: Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams."

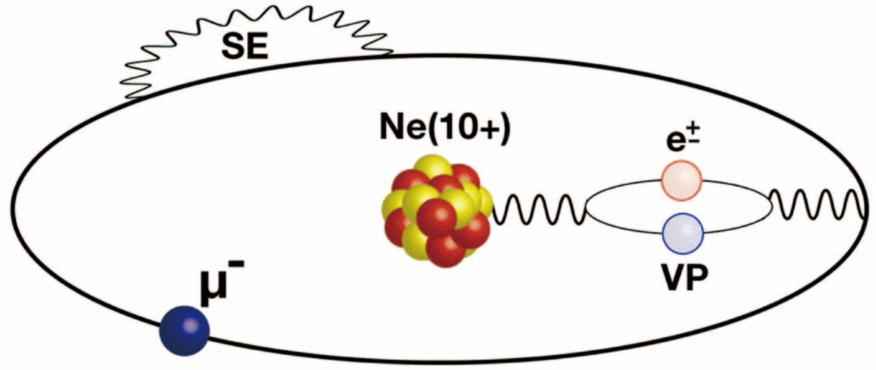


Figure 1 Conceptual diagram showing muonic atoms and quantum electrodynamic (QED) effects. In a muonic atom, the negative muon (μ^-) is bound to the nucleus and orbits around it. According to quantum electrodynamics, the bound negative muon continues its orbital motion while repeatedly emitting and absorbing virtual photons (self-energy: SE). In addition, there is an electrostatic attraction between the neon nucleus (Ne^{10+}) and the negative muon, and the photons propagating through this interaction continuously repeat the creation and annihilation of virtual electron-positron ($e^{\pm}$) pairs (vacuum polarization: VP). (Credit: Okumura et al.)[2]

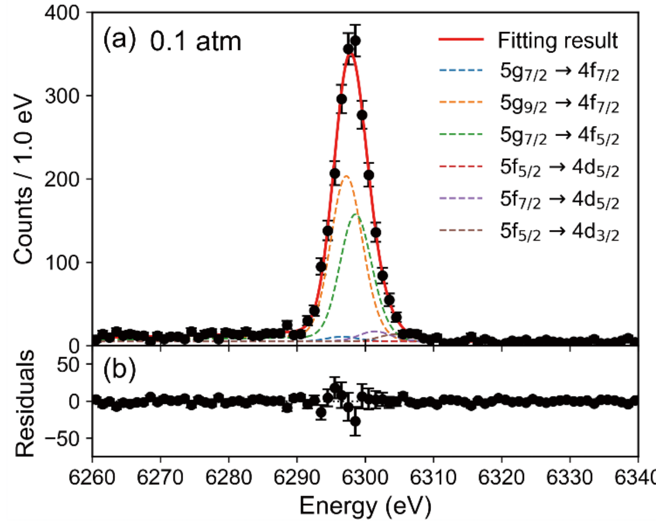


Figure 2 Spectrum of emitted muonic characteristic X-rays emitted from muonic neon atoms. (a) Muonic characteristic X-rays emitted from muonic neon atoms appearing around 6300 eV at a neon gas target pressure of 0.1 atm. This peak is formed by the superposition of six different transitions. The peak energy was determined to an accuracy of 0.002% by fitting with respect to each contribution. (b) The residuals (difference between theoretical and measured values) from the fitting. (Credit: Okumura et al.)[1]

References

[1] T. Okumura et al., "Proof-of-Principle Experiment for Testing Strong-Field Quantum Electrodynamics with Exotic Atoms: High Precision X-ray Spectroscopy of Muonic Neon," *Physical Review Letters*, 130, 173001, 2023.
[2] https://www.riken.jp/press/2023/20230510_1/index.html
[3] https://www.ipmu.jp/en/20230510-QED

5.6 Superstring measure

Katherine A. Maxwell

Superstring theory was developed by physicists to fix certain unphysical predictions of bosonic string theory. In particular, the physical theory should include fermions in addition to bosons. From a mathematical point of view then superstring theory needs to be based on super Riemann surfaces (SRSs), which incorporate fermionic geometry based on anticommutative algebras of functions, in addition to the familiar bosonic geometry of usual commutative algebras of functions. We refer to the study of spaces which have both fermionic and bosonic geometry as supergeometry.

One of the main goals in supergeometry is to better understand SRSs and their supermoduli space. The classical counterpart, the moduli space of Riemann surfaces (or algebraic curves), is already the source of an enormous amount of interesting mathematics and ongoing research. In gaining an understanding of basic supergeometry, we hope that many of the results on the classical moduli space can be extended to the supermoduli space, such as construction of the supermoduli space in algebraic geometry, calculation of various enumerative invariants, and finding good coordinates and cellular decompositions. The supermoduli space of SRSs is topologically given by the moduli space of spin curves, however, much of the difficulty in working with the supermoduli space of SRSs comes from its fermionic geometry, which is non-topological.

Despite the difficulties in supergeometry, some results are in fact simpler than the classical counterpart. This should not be a total surprise given that superstring theory is a more physical theory. It is known that the scattering amplitudes in bosonic string theory are infinite, while the superstring scattering amplitudes are expected to be finite. Unfortunately, actually calculating these superstring scattering amplitudes has proven quite difficult, with results only in genus 0, 1, and 2 currently. The latest results are in [1]. The difficulty lies in the supergeometry of the supermoduli space of SRSs, while the superstring measure is relatively simple. One of the motivations in my research has been to try to exploit properties of the superstring measure in order to more easily set up the scattering amplitude integrals over the supermoduli space.

The superstring measure may be derived from the super Mumford isomorphism [2,7], which states that the line bundles $\lambda_{j/2} := Ber\,(R\pi_*((Ber\Omega)^{\otimes j}))$, the superdeterminant of the derived pushforward of the $j/2$-differentials on a SRS, are in fact isomorphic to a tensor power of the super Hodge line bundle:

$$\lambda_{j/2} = \lambda_{1/2}^{\otimes -(-1)^j(2j-1)}.$$

The superstring measure, called the super Mumford form, is then the image of $1 \in \mathcal{O}$ in $\lambda_{j/2} \otimes \lambda_{1/2}^{\otimes (-1)^j(2j-1)}$. The analogous statement for the moduli space of Riemann surfaces exists (the Mumford isomorphism), but with the tensor power as quadratic as $6j^2 - 6j + 1$ and the isomorphism as non-canonical. The relatively simple properties of the super Mumford isomorphism should lead to many interesting results. The most well-known consequence is the critical dimension of superstring theory is 10 (real) spacetime dimensions, which results from setting $j = 3$ in the super Mumford isomorphism giving the tensor power of 5 (complex dimensions).

The simplicity of the super Mumford isomorphism is related to the fact that the Deligne pairing between line bundles on the supermoduli space of SRSs is actually trivial. Because of this fact, there exists an interesting rewriting of the super Mumford form discovered by A. Schwarz in 1987 [5]:

$$\mu \cong \frac{\tau_L(g^3)}{\tau_L^3(g)}.$$

The left hand side consists of tau functions on the super Sato grassmannian. It is not obvious that such a rewriting is equivalent to the original definition of the super Mumford form. I have worked to show that this expression is equivalent to the original, and that is gives a good definition the extend the super Mumford form into the super Sato grassmannian [4]. The Sato grassmannian, also known as the semi-infinite grassmannian, is the geometrical space underlying KP and KdV integrable systems. The super counterparts, super KP and super KdV, based on the super Sato grassmannian, are much less studied.

Here I'll describe 3 interesting directions for research.

- There exist tau functions of the KP and KdV hierarchies which contain remarkable properties, for instance as generating functions of intersection classes on the moduli space of curves or of Hurwitz numbers, or as partition functions of random matrix models. Of particular interest is Witten's conjecture [8] and proof by Kontsevich [3] which showed the equivalence of a known tau function to a seemingly unrelated model for 2-dimensional quantum gravity. Most of the analogous super tau functions to the interesting constructions in the classical case are not known.

  The perhaps surprising relationship of the Sato grassmannian to the intersection theory of the moduli space of curves provides a large motivation to study the super case. Unfortunately, a rigorous intersection theory in supergeometry is not known. However, we may attempt to study the super Sato grassmannian and predict results on what the intersection theory of the supermoduli space should be. The existence and simplicity of Schwarz's formula for the super Mumford measure using super tau functions is perhaps a prediction that other super tau functions and their relationship to physical theories also have remarkable properties.

- Another large motivation to study the super Sato grassmannian is closer to the topic introduced at the beginning of this text. It was suggested in the 1980s that the (super) Sato grassmannian could be the geometry behind a non-perturbative (super)string theory. This idea originates from the fact that for every genus the classical moduli space of curves with decorations embeds into the same connected component of the Sato grassmannian. This all-genus locus within the grassmannian seems to be a "universal moduli space". This suggests that we wish to find an expression for the Mumford form over this locus in order to calculate non-perturbative string theory scattering amplitudes. But, fulfilling this lofty goal for classical string theory has not been possible, as no appropriate extension of the Mumford measure has been known.

  The supermoduli space of SRSs cannot be embedded into a single connected component of the super Sato grassmannian. While this may seem like a deal breaker, given the simple expression of Schwarz's extended super Mumford form and the fact that supergrassmannians seem to provide the best ambient space in supergeometry, the idea of a "universal supermoduli space" is still worth pursuing.

- Combining the other two motivations, significant recent progress in working with enumerative tau functions has been done using the methods of topological recursion and resurgence. In particular, Stanford and Witten recently [6] related JT (super)gravity to the volumes of the (super)moduli space of (super)curves. The success of this result in calculating the volumes of the supermoduli space of SRSs via a recursion is interesting, since the super Weil-Peterson measure has not been rigorously defined. The super Mumford measure, while more complicated than a super Weil-Peterson measure, is related in a manageable way, in which methods such as a recursion might apply. Applying modern methods to scattering amplitudes in superstring theory may be surprisingly productive!

References

[1] E. D'Hoker and D. H. Phong. Two-loop superstrings I: Main formulas. *Phys. Lett. B* 529.4, 2002, pp. 241–255. doi: 10.1016/s0370-2693(02)01255-8.
[2] P. Deligne. Lettre à Manin. 1988.
[3] M. Kontsevich. Intersection theory on the moduli space of curves and the matrix Airy function. *Comm. Math. Phys.* 147.1, 1992, pp. 1–23. url: projecteuclid.org/euclid.cmp/1104250524.
[4] K. A. Maxwell and A. A. Voronov. The Mumford form on Sato grassmannians. 2024.
[5] A. S. Schwarz. The fermion string and a universal modulus space. *JETP Letters* 46.9, 1988, pp. 428–431. url: jetpletters.ru/ps/1232/article_18604.shtml. Trans. of Фермионная струна и универсальное пространство модулей. *Письма в ЖЭТФ* 46.9, 1987, pp. 340–342. url: jetpletters.ru/ps/164/article_2805.shtml.
[6] D. Stanford and E. Witten. JT gravity and the ensembles of random matrix theory. *Adv. Theor. Math. Phys.* 24.6, 2020, pp. 1475–1680. doi: 10.4310/ATMP.2020.v24.n6.a4.
[7] A. A. Voronov. A formula for the Mumford measure in superstring theory. *Funct. Anal. Appl.* 22.2, 1988, pp. 139–140. doi: 10.1007/bf01077608.
[8] E. Witten. Two-dimensional gravity and intersection theory on moduli space. *Surveys in differential geometry.* Proceedings of the Conference on Geometry and Topology (Harvard University, 1990). Lehigh Univ., 1991, pp. 243–310. doi: 10.1142/9789814365802_0061.

5.7 The First Year of JWST Observations for Distant Supermassive Black Holes

Masafusa Onoue

I joined Kavli IPMU in November 2023 as part of the second half of my Kavli Astrophysics Fellowship, shared between the Kavli Institute for Astronomy and Astrophysics (KIAA) at Peking University and Kavli IPMU. The past two years at KIAA were centered around the James Webb Space Telescope (JWST), which was launched in December 2021 and released its first science data in July 2022. The exceptional quality of JWST's infrared data inspired me to search for high-redshift Active Galactic Nuclei (AGN), which are the accreting supermassive black holes (SMBHs) located at the centers of galaxies. Leveraging the deep survey data from the 6.5-meter space telescope, I was fortunate to discover an AGN at z=5.2 [1, 2], which is 1-2 dex fainter than the luminous AGN identified by ground-based surveys such as SDSS and Subaru HSC. At KIAA, I also collaborated with theorists to predict the observability of high-redshift quasars with JWST [3] and next-generation wide-field survey facilities such as Euclid mission and Nancy Grace Roman Space Telescope [4].

One of my major research focuses is the study of z=6 galaxies hosting luminous quasars. These studies have been made possible by JWST beyond z=2, as the dim starlight of host galaxies, often outshone by the quasar radiation, needs to be carefully decomposed. In JWST's Cycle 1 observations, we were allocated 50 hours of observing time to follow up on 12 of the lowest-luminosity z=6 quasars that our team discovered through the Hyper Suprime-Cam Subaru Strategic Program, an international collaboration in which Kavli IPMU plays a significant role. Figure 1 shows the JWST/NIRCam image of one of our first targets, where we clearly detected spatially resolved host galaxy emission, for the first time in the cosmic reionization epoch [5]. We also observed this target with JWST/NIRSpec to detect broad Balmer emission lines from the nuclear region of the accretion disk, allowing us to measure the central black hole mass. By combining these two observations, we have placed the first targets on the stellar mass vs. SMBH mass plane (Figure 2), finding that the observed distribution is consistent with the local scaling relation. The analysis is ongoing as we work to complete the full sample.

Another exciting finding is that we detected the host galaxy signature in the NIRSpec data as well for some targets, through the detection of stellar absorption lines. These absorption lines directly indicate that the host galaxy has experienced little star formation since a starburst event that occurred a few million years before the time of observation. This work will be reported in a forthcoming paper that we are preparing.

Fig 1: JWST/NIRCam F356W image of HSC J2236+0032 at z=6.4 [5]. The zoom-out image, the quasar image, and the host galaxy image after subtracting the quasar light (from left to right).

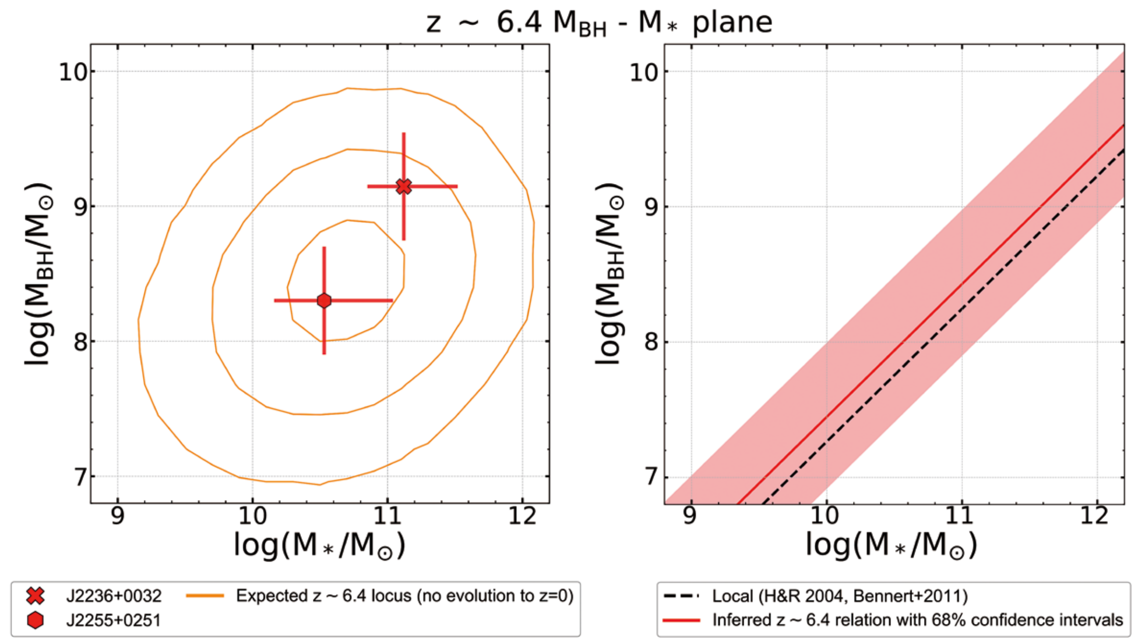


Fig2: Stellar mass vs. black hole mass distribution of the two quasars in Ding, Onoue, Silverman et al. (2023) [5]. The orange contour represents the mock observations of z=6 quasars, assuming the local scaling relation, with the sample selection and measurement uncertainties taken into account. The right panel shows the estimated underlying relation.

References

[1] Kocevski, D. D., Onoue, M., Inayoshi, K., et al. 2023, The Astrophysical Journal Letters, 954, L4.
[2] Onoue, M., Inayoshi, K., Ding, X., et al. 2023, The Astrophysical Journal Letters, 942, L17.
[3] Inayoshi, K., Onoue, M., Sugahara, Y., et al. 2022, The Astrophysical Journal Letters, 931, L25.
[4] Li, W., Inayoshi, K., Onoue, M., et al. 2023, The Astrophysical Journal, 950, 85.
[5] Ding, X., Onoue, M., Silverman, J. D., et al. 2023, Nature, 621, 51.

5.8 Enhanced gravitational waves from inflaton oscillons: a novel way to probe the early Universe

Kaloian Dimitrov Lozanov

The Universe is about 13.7 billion years old. Our knowledge of its history is incomplete. An impressive combination of cosmological observations and theoretical modeling has allowed us to infer the evolution of the Universe from astoundingly early times – when it was approximately 1 second old – until today.

The 1 second-old cosmos was hot and dense. Matter was in the form of plasma. As time went on, the Universe expanded, the temperature and density of the plasma decreased, and the first light chemical elements formed – a process known as Big Bang Nucleosynthesis (BBN). At some point later on, the temperature became sufficiently low for the first stable atoms to exist. At that moment, photons began to stream freely and today we observe this afterglow from the Big Bang as the Cosmic Microwave Background (CMB). The CMB is nearly completely uniform. Importantly, it has minute variations in its temperature. They reflect tiny variations in the matter density at the time of the emission of the CMB. Over time, and under the influence of gravity, these matter density variations grew. Dense regions were becoming denser, and eventually the first galaxies, stars and planets formed.

While this scenario for the evolution of the Universe – from 1 second after the Big Bang until today – has the status of a scientific fact, we do not know what the Universe looked like at earlier times. Nevertheless, there is mounting evidence for an earlier stage of cosmic inflation during which the Universe underwent swift, accelerated expansion. It appears increasingly likely that the tiny density variations imprinted on the CMB originated as microscopic quantum fluctuations, which got stretched to cosmic sizes during inflation.

Despite all these great successes of modern cosmology, we still do not know what exactly the Universe looked like at early times. We do not know what gave rise to inflation – was it a new form of matter, called the inflaton field, and if yes, what are its characteristics? What was the evolution of the Universe between inflation and BBN – did the inflaton decay into the hot plasma in a process known as reheating? Did reheating feature other non-trivial states of matter such as solitons?

So far, the best experimental probe of the early Universe has been the CMB. Thanks to precise measurements of the temperature variations of the CMB we have managed to rule out the simplest and, according to some, most natural models of inflation. However, there is still a wide range of inflationary models which are consistent with the experimental constraints. Many of these models are the main target of upcoming CMB experiments like LiteBIRD [1]. However, there are numerous models which cannot be tested with the CMB, namely models of inflation which do not generate a sizeable B-mode CMB polarization.

A natural question to ask is: can we test the models of inflation which cannot be tested with the CMB? We believe that the answer is yes – we can do it using Gravitational Waves (GWs) from reheating. As we showed in our work [2], the GWs are of special type, called induced GWs. The reheating model is also special – it involves the formation of a certain type of inflaton solitons, known as oscillons. Provided that at some point after formation, the inflaton oscillons decay abruptly into radiation (e.g., into hot plasma), they can induce GWs which can fall in the detection ranges of currently operational (as well as upcoming) GW interferometer experiments like LIGO, Virgo and Kagra [3].

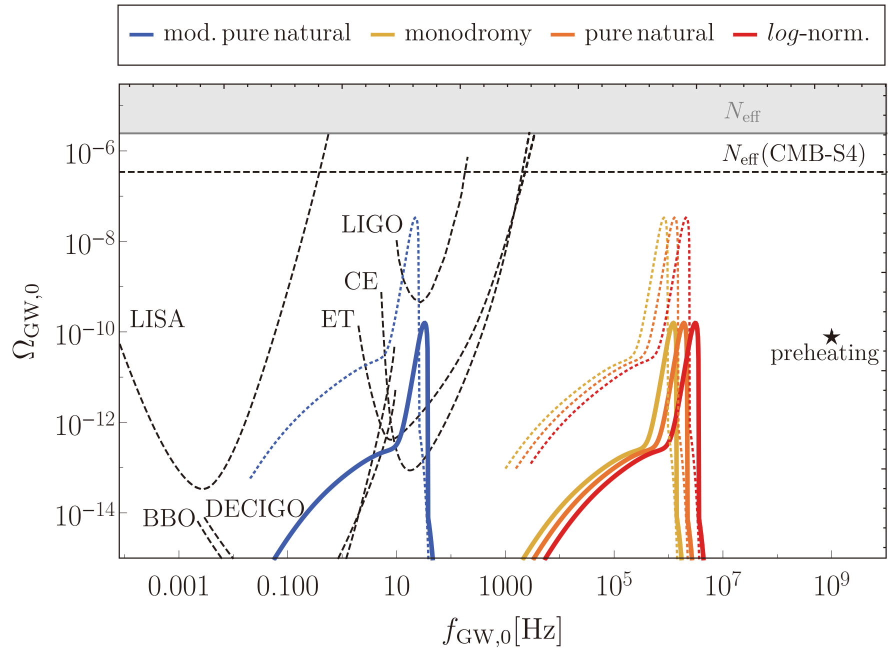


Figure from K.D. Lozanov and V. Takhistov [2]

Oscillon-induced gravitational wave signatures. The colored solid and dashed lines are the gravitational wave signals from various models of inflation. For more details see [2]. The current Neff constraints from CMB and BBN [4] and expected sensitivity for CMB-S4 [5], LISA, Einstein Telescope (ET), Cosmic Explorer (CE), Big Bang Observer (BBO), and DECIGO [6], as well as LIGO O5 [7] are also displayed. The proposed scenario in our work presents a unique opportunity for GW interferometer experiments to probe the physics of cosmic inflation in a novel, CMB independent way.

Our work showed for the first time how to probe cosmic inflation and reheating in a novel, CMB independent way, solely based on GWs. We hope it will open a new avenue for experimental and theoretical studies in the dawn of multi-messenger cosmology.

References

[1] H. Sugai et al., Journal of Low Temperature Physics 199, 1107 (2020).
[2] K.D. Lozanov and V. Takhistov, Phys.Rev.Lett. 130 (2023) 18, 181002.
[3] "Gravitational-wave detectors start next observing run to explore the secrets of the Universe", Max Planck Society, 24 May 2023: https://www.mpg.de/20357878/gravitational-wave-detectors-ligo-virgo-and-kagra-start-next-observing-run

Literatures quoted in the figure

[4] N. Aghanim et al. (Planck Collaboration), Astron. Astrophys. 641, A6 (2020); 652, C4(E) (2021).
[5] K. Abazajian et al., arXiv:1907.04473.
[6] K. Schmitz, J. High Energy Phys. 01 (2021) 097.
[7] B. P. Abbott et al. (LIGO Scientific and Virgo Collaborations), Phys. Rev. Lett. 116, 131102 (2016).

5.9 The Inaugural Year of CD3

Jia Liu (CD3 Director)

"AI-driven Discovery in Physics and Astrophysics" Conference (January 2024)

Will artificial intelligence (AI) replace humans in scientific research? — While many of us have joked about being replaced by AI one day, this thought has never felt more real than it does today. Recent rapid developments in AI have significantly affected how humans work and live. Generative AI tools such as ChatGPT, Claude, DALL-E, and Midjourney can create human-like text and generate realistic images from simple prompts. Large Language Models (LLMs) can summarize, translate, and analyze vast amounts of information. With reinforcement learning, AI can now make complex decisions at superhuman levels in strategic games like Chess, Go, Poker, Dota 2, and StarCraft II – in fact, top chess players now regularly rely on AI to train and advance their skills.

It is natural to conclude that AI will transform scientific research sooner or later. To ride this wave, the Center for Data-Driven Discovery (CD3) was established at the Kavli IPMU in April 2023, with a mission to decode our Universe through innovative AI and data science techniques. After one year of operation, CD3 now has 70 members, with an approximately 1:1:1 ratio of students, postdocs, and faculty members. We have successfully recruited three new faculty members — Jingjing Shi, Leander Thiele, and Linda Blot — to lead this new research direction. To strengthen our connections with other institutes, we have also established partnerships with Beyond AI, DLX Design Lab, the Information Technology Center, FoPM, and ILANCE, involving collaborative projects and student exchange programs.

At the core of CD3 are our 15 data-driven projects across a broad range of fields:

- **Subaru Hyper Suprime-Cam (HSC):** A cosmological imaging survey using the 8.2-meter Subaru Telescope in Hawaii.
- **Subaru Prime Focus Spectrograph (PFS):** An upcoming spectroscopic survey featuring a massively multiplexed, fiber-fed optical and near-infrared 3-arm spectrograph at the Subaru Telescope.
- **Vera Rubin Legacy Survey of Space and Time (LSST):** A cosmological survey using the 3.2-gigapixel Rubin Observatory LSST Camera and the 8.4-meter Simonyi Survey Telescope in Chile.
- **Compton Spectrometer and Imager (COSI):** A soft gamma-ray survey telescope covering the range of 0.2–5 MeV, designed to probe the origins of Galactic positrons, uncover the sites of nucleosynthesis in the Galaxy, perform pioneering studies of gamma-ray polarization, and find counterparts to multi-messenger sources.
- **Euclid:** A space telescope designed to survey the extragalactic sky with optical imaging and slitless spectroscopy in the infrared, successfully launched in the summer of 2023.
- **LiteBIRD:** A cosmic microwave background (CMB) satellite that will search for primordial gravitational waves emitted during the cosmic inflation era, around 10^{-38} seconds after the beginning of the Universe, by performing an all-sky CMB polarization survey.
- **The Simons Observatory (SO):** A ground-based CMB experiment located 5,300 meters above sea level in the Atacama Desert, Northern Chile.
- **CMB-S4:** The next-generation ground-based CMB experiment, planned to involve 21 telescopes at the South Pole and in Chile.
- **Super-Kamiokande:** The world's largest water Cherenkov detector, located 1,000 meters underground in the Kamioka mine, Hida City, Gifu, Japan. It studies neutrino properties and searches for proton decay and supernova relic neutrinos.
- **Hyper-Kamiokande:** The next generation of large-scale water Cherenkov detectors, an order of magnitude larger than Super-Kamiokande.
- **T2K (Tokai to Kamioka):** A long-baseline neutrino experiment in Japan studying neutrino oscillations.
- **XENON:** A direct dark matter search experiment using liquid xenon, located deep underground at the INFN Laboratori Nazionali del Gran Sasso in Italy.
- **Belle-II:** The first super B-Factory experiment designed to make precise measurements of weak interaction parameters and discover new physics beyond the Standard Model. It is based at the SuperKEKB accelerator complex at KEK in Tsukuba, Ibaraki Prefecture, Japan.

CD3 Lego Day (November 2023)

- **Machine Learning Theory:** Theoretical study of quantum machine-learning algorithms and quantum simulations to better understand the capabilities and limitations of quantum computers.
- **Score ELSI:** A social science project that aims to develop a simple scale to measure the Ethical, Legal, and Social Issues (ELSI) in science and technology, including areas such as artificial intelligence, genome editing, mental health instruments, and climate engineering.

One major challenge CD3 faced was bringing together the diverse fields our members represent—mathematics, string theory, phenomenology, particle physics, cosmology, astrophysics, and social science. Instead of diving directly into intensive research collaborations, we started with baby steps (literally!) by asking the members to explain their sciences with Lego blocks. In November 2023, on the day of Kavli IPMU's 16th anniversary, CD3 members created Lego artworks to explain complex concepts such as Calabi–Yau manifolds, strong gravitational lensing, neutrino oscillation, and galaxy formation. This event was held in collaboration with our neighbor, DLX Design Lab, on the Kashiwa II campus, an interdisciplinary lab with expertise in bringing ideas to reality.

To encourage our members to explore new ideas and connect with fellow researchers regularly, we created the weekly Hackathon (collaborative coding session) "Hack Friday," which takes place every Friday afternoon. Members are asked to bring one challenging task to tackle during the session, be it a new technique to learn, a tricky programming bug to solve, or a risky scientific idea to explore. By explaining to other members, experimenting with ideas over the span of an afternoon, and receiving feedback by the end of the session, participants are given the opportunity to challenge their routines and think outside the box. We consider "Hack Friday" a playground to experiment, explore, and connect.

We developed the "CD3 X" seminar series, where speakers who work at the intersection of AI/data science and other fields are invited to exchange ideas. A diverse range of topics has been presented, including a CD3 x Phenomenology seminar by Matt Buckley (Rutgers University) on the application of machine learning to dark matter physics, a CD3 x Cosmology seminar by Shirley Ho (CCA) on applying LLMs to scientific data, a CD3 x CMB seminar by Jo Dunkley (Princeton) on cracks in cosmological models with CMB and large-scale structure data, a CD3 x Astronomy seminar by Cosimo Bambi (Fudan University) on reflection models for accreting black holes, and a CD3 x Cosmology seminar by Michelle Ntampaka (Space Telescope Science Institute) on trustworthy machine learning for data-driven discovery.

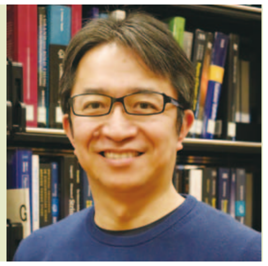
To broaden our scientific reach, we organized workshops and conferences centered on data-driven physics, such as the conference "Future Science with CMB x LSS" (April 2023, YITP, Kyoto), the "CD3 Opening Symposium" (April 2023, Kavli IPMU), the "Astro AI and Fugaku" workshop (September 2023, University of Tsukuba Tokyo Campus), the workshop "Time-Domain Astronomy and Cosmology in the LSST Era" (December 2023, Kavli IPMU), and the conference "AI-driven Discovery in Physics and Astrophysics" (January 2024, Kavli IPMU). These workshops and conferences welcomed more than 400 participants worldwide and connected CD3 to the international community. We actively promote diversity and junior researchers in these events with "Women and Diversity Lunch" and "Fire Slide" presentations for junior researchers.

Women's Lunch (February 2024)

In its inaugural year, CD3 projects achieved significant results. For example, CD3 researchers Toshiya Namikawa and Ippei Obata investigated cosmic birefringence in the late-time universe, described as the rotation of polarization angles of CMB photons, and found that the effect can be probed by the polarized Sunyaev-Zel'dovich effect (Namikawa, T., & Obata, I., 2023, *Physical Review D, 108*, 083510). To investigate why so few women choose to work in science, technology, engineering, and mathematics (STEM), Hiromi Yokoyama and her team found that a social climate of inequality affects the gendered images of STEM fields (Yokoyama, H. M. et al., 2024, *Asia Pacific Business Review, 30*(3), 543–559). In a series of five papers, using the latest Subaru HSC data, a team led by Masahiro Takada and collaborators measured the matter fluctuation of our universe to be lower than what was measured by previous CMB experiments—an intriguing result hinting at potential new physics (Sugiyama, S. et al., 2023, *Physical Review D, 108*, 123521; More, S. et al., 2023, *Physical Review D, 108*, 123520; Dalal, R. et al., 2023, *Physical Review D, 108*, 123519; Li, X. et al., 2023, *Physical Review D, 108*, 123518; Miyatake, H. et al., 2023, *Physical Review D, 108*, 123517). Discrepancies like the one cited above are called tensions in cosmology and they have been an important topic in cosmology nowadays. CD3 member Elisa Ferreira and collaborators investigated new cosmological models and their capability of solving these tensions (Pedreira et al, 2023, Physical Review D 109 , 10, 103525)

Looking ahead, the goals for year two are twofold. First, we will continue to expand our research portfolio with interdisciplinary projects and international conferences and workshops. Second, we will extend our educational efforts to teach AI in physics to young researchers in Asia through the "AstroAI Asian Network (A^3 Net)" summer school, with more than 10 Asian institutes already committed to being part of this initiative. We also have plans for an international workshop, "Future of Artificial Intelligence for Science in Japan (FAIRS-Japan)," to be held at Nagoya University. With these planned activities, CD3 strives to become the interdisciplinary hub for AI and physics. In the first year of CD3, we have laid a strong foundation for growth and impact in the coming years, and we remain committed to our mission of leveraging AI and data science to unlock new insights into the fundamental laws of the universe. We look forward to the continued support of the University, our partners, and the wider scientific community as we embark on the next phase of our journey.

5.10 Subaru Hyper Suprime-Cam Year 3 Cosmology Results



Masahiro Takada

An international team of astrophysicists and cosmologists from various institutions, including the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), reported the results of the Subaru Hyper Suprime-Cam Year 3 (HSC-Y3) cosmology analyses based on a shear catalog covering 416 square degrees of the sky with exquisite depth and seeing. The HSC-Y3 cosmology effort has been led by a group of primarily early-career scientists, who have prepared the shear catalog, developed redshift distribution inference methods, studied potential contamination from systematics, measured data vectors and carried out the cosmological analyses. Scientists, who are associated with Kavli IPMU, The University of Tokyo, and made significant contributions to the HSC-Y3 results, include, for example, Dr. Xiangchong Li (PhD at U. Tokyo in 2021, now Carnegie Mellon U., USA), Dr. Sunao Sugiyama (PhD at U. Tokyo in 2023, now University of Pennsylvania, USA), Dr. Hironao Miyatake (PhD at U. Tokyo in 2009, now Nagoya U.), Dr. Yosuke Kobayashi (PhD at U. Tokyo in 2021, now Kyoto-Sangyo U.), Prof. Surhud More (the former faculty member at Kavli IPMU, now IUCAA, India), and myself (Masahiro Takada). We published a series of papers in 2023, after many years of effort, as described below.

As predicted by Einstein's theory of gravity, the path of a light ray emitted by a distant galaxy is bent by weak gravitational lensing due to intervening large-scale structures, causing a distortion in the observed galaxy image. Although the distortion is too weak to be measured on a galaxy-by-galaxy basis, the coherent distortion effect is statistically measurable by combining images of many different galaxies. The HSC team used the exquisite Subaru HSC images of about 25 million galaxies to make precise measurements of weak gravitational lensing effects caused by cosmic large-scale structures. The team then performed the cosmological analysis by comparing the measured weak lensing signals with the predictions of the standard cosmological model, the ΛCDM model.

The team performed multiple cosmological analyses using different weak lensing observables from the Subaru HSC data. In the analyses, the team performed a "blinded analysis" to avoid confirmation bias. All of the blinded cosmology analyses were carried out in a coordinated fashion to ensure an appropriate degree of consistency on common elements such as catalog-level systematics, and common decision criteria to define model choices. However, the actual results were produced independently, and consistency of the cosmological constraints assessed only after all analysis choices were complete. In addition, the team adopted a very conservative approach to account for the effect of residual systematic errors in the photometric redshifts on the cosmological results. Our approaches to the scientific results lend robustness to the analysis results.

After performing many validation tests of the systematic effects and analysis methods, the team "unblinded" the values of the cosmological parameters measured from the HSC data, with the promise that the team would not change the results after unblinding. The HSC team accomplished the precise measurements of the cosmological parameters of the ΛCDM model; for example, the team found the so-called "S8" parameter, which describes the clumpiness seen in the today's universe, to be 0.76 to a fractional precision of a few percent. The HSC value of S8 is consistent with values found in other weak-lensing surveys - but it is not consistent with the value of 0.83 inferred from the ΛCDM model, which was derived from the *Planck* data of the anisotropies of the cosmic microwave background (CMB), which measures the early universe when the universe was about 380,000 years old. This inconsistency between the S8 values from the weak-lensing data and the CMB data, or in other words, the late-time and early-time universe data, is known as the S8 tension problem, and it has received a lot of attention from the cosmology community. If this inconsistency is not due to unknown systematic errors, or if it is of physical origin, it would imply a "new physics" beyond the standard model, the ΛCDM model. Thus, solving the S8 tension problem could lead to a revolution in cosmology.

These HSC-Y3 results are published in Miyatake et al. 2023, Sugiyama et al. 2023, Li et al. 2023 and Dalal et al. 2023. These papers were selected as the "Viewpoint" papers from Physical Review D, the peer-reviewed scientific journal of the American Physics Society (APS), where the Viewpoint picks up only papers of particular interest and attention from the APS journal. This reflects the attention and importance of the HSC-Y3 cosmology results.

Thus, the international HSC team, in which the Kavli IPMU played a major role, achieved results at the forefront of cosmology. Next is the Subaru Prime Focus Spectrograph (PFS), the forthcoming instrument capable of simultaneous spectroscopic observations of 2400 astronomical objects over the similar field of view to that of the HSC. The Kavli IPMU has also

Figure 1: An example image from HSC mounted at the 8.2 m Subaru Telescope (Credit: HSC-SSP project & NAOJ)

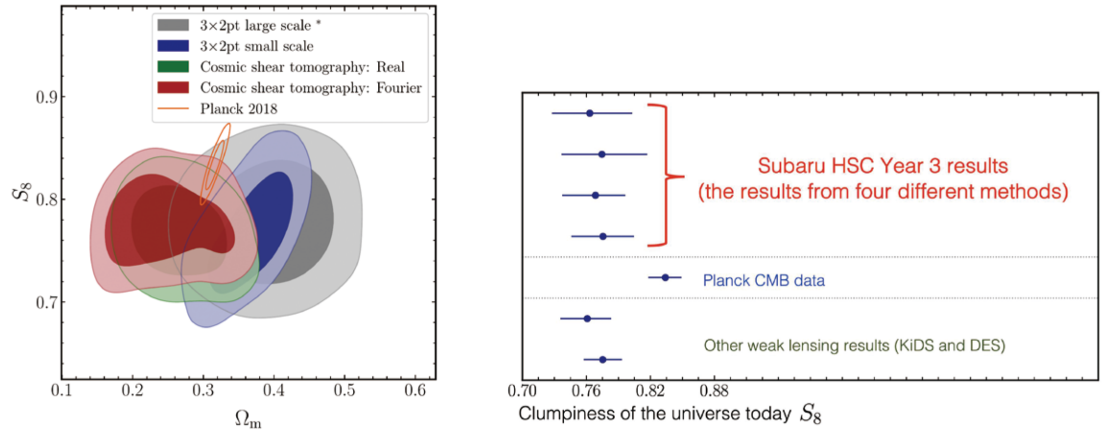


Figure 2:
(Left panel): The HSC-Y3 cosmological constraints, obtained from the comparison of the HSC-Y3 weak lensing measurements with the predictions of the standard model of the universe, the ΛCDM model (taken from Miyatake et al. 2023). Here we show the 2D projected posteriors (68% and 95% confidence intervals) in the Ω_m-S_8 plane, where Ω_m gives the fractional amount of matter (mainly dark matter) in the today's universe, relative to the total amount of matter and energy, and S_8 is the parameter to describe the "clumpiness" seen in the today's universe. The gray, blue, green and red contours are the results from the different analyses (see text) using the HSC data. For comparison, we also show the results from the *Planck*-2018 CMB data.
(Right panel): Similarly to the upper panel, but the 1D projected posterior for S_8. The value of S8 from the HSC-Y3 results and other weak lensing results (KiDS and DES) is inconsistent with the value of S8, inconsistent with the value of the Planck CMB, at a 2–2.5-sigma level (only about a 1% chance out of 100, if this inconsistency statistically happens) – the so-called S8-tension problem.

played a major role in this international PFS project and envisions that the team will begin conducting the large-scale spectroscopic survey from the early 2025, finally after 15 years since the launch of the project. The PFS, and more excitingly, the combination of the HSC and PFS, promises to resolve the S8 tension and makes a significant advance in our understanding of the universe. Please expect even more exciting results on the mysteries of the universe from our team in the near future!

References

[1] Sugiyama, S., Miyatake, H., et al., "Hyper Suprime-Cam Year 3 results: Cosmology from galaxy clustering and weak lensing with HSC and SDSS using the minimal bias model", Phys. Rev. D 108, 123521 (2023) (selected as the "Viewpoint" paper in the APS journal)
[2] Dalal, R., et al., "Hyper Suprime-Cam Year 3 results: Cosmology from cosmic shear power spectra", Phys. Rev D 108, 123519 (2023) (Viewpoint paper)
[3] Li, X., et al., "Hyper Suprime-Cam Year 3 results: Cosmology from cosmic shear two-point correlation functions", Phys. Rev. D 108, 123518 (2023) (Viewpoint paper)
[4] Miyatake, H., et al., "Hyper Suprime-Cam Year 3 results: Cosmology from galaxy clustering and weak lensing with HSC and SDSS using the emulator based halo model", Phys. Rev. D 108, 123517 (2023) (Viewpoint paper)

6 Awards & Honors

Credit: Hirosi Ooguri

Director Ooguri named an expert advisor for the Universities for International Research Excellence Program

The Japanese Government has created a 10-trillion yen (about 75-billion US dollars) national endowment fund to support a small number of research universities by its annual return, expected to be about 2.5 billion US dollars per year.

Director Hirosi Ooguri of the Kavli Institute for the Physics and Mathematics of the Universe has joined the board of expert advisers to select the candidates, Minister Keiko Nagaoka of Education, Culture, Sports, Science and Technology announced today (April 4, 2023).

Director Hirosi Ooguri named 2023 Guggenheim Fellow

The John Simon Guggenheim Memorial Foundation announced on April 6 that Hirosi Ooguri, Director of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) at the University of Tokyo and the Fred Kavli Professor at California Institute of Technology, has been named a 2023 Guggenheim Fellow. Ooguri will receive a grant of 50,000 US dollars to support his research in quantum gravity.

This year, the Foundation awarded Fellowships to 171 exceptional individuals, encompassing scientists, writes, scholars, and artists across 48 fields. Among them, Ooguri stands as one of only three physicists and holds the distinction of being the first faculty member of the University of Tokyo to receive this prestigious Fellowship.

Since its establishment in 1925, the Guggenheim Fellowship has been awarded to "mid-career individuals who have demonstrated exceptional capacity for productive scholarship or exceptional creative ability in the arts and exhibit great promise for their future endeavors." To date, the Foundation has granted nearly 400 million US dollars in Fellowships to over 18,000 individuals, including 125 Nobel laureates, members of all the national academies, recipients of the Pulitzer Prize, Fields Medal, Turing Award, Bancroft Prize, and the National Book Award.

Credit: Hiraku Nakajima

Hiraku Nakajima receives two Frontier of Science Awards

Hiraku Nakajima, Professor at the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), has been awarded two Frontier of Science Awards for papers he had co-authored in two categories: Homological Algebra, K-Theory and Noncommutative Algebra, and Mathematics of String Theory and Condensed Matter, it was announced at the inaugural International Congress of Basic Science (ICBS) currently being held in Beijing, China.

The ICBS is an annual conference funded and hosted by the Beijing City government, with the aim to support and promote basic research in the sciences worldwide, particularly mathematics, theoretical physics, and theoretical computer and information sciences.

The Frontier of Science Awards commemorates scientific works in 34 areas that have been published in the past 5 years, is of the highest scientific value and originality and has made an important impact on its area, and has been evaluated and accepted by scholars in its area.

The goal of this award is to encourage young scholars to look to the frontiers of basic science, set goals to obtain breakthrough results as early as possible, and contribute wisdom and energy to humankind's study of the mysteries of the natural world.

Credit: Hirosi Ooguri

Hirosi Ooguri elected Honorary Trustee for Life of the Aspen Center for Physics

Hirosi Ooguri, Director of the Kavli Institute for the Physics and Mathematics of the Universe, has been elected an Honorary Trustee for Life of the Aspen Center for Physics.

The Aspen Center for Physics was established in 1962 to nurture cutting-edge research in physics and related disciplines by providing a unique physical and scientific environment ideally suited for stimulating interactions, collaborations, and innovation. Every year, more than 1,000 physicists from around the world come to the Center, located in Aspen, Colorado, to ponder, argue, and discover the new ideas that underlie advances in science and technology. The Center is an independent non-profit corporation not affiliated with any university and run by scientists and a small number of administrative staff.

Ooguri served as a General Members of the Center for 20 years from 2003 to 2023, a Trustee from 2011 to 2016, the President from 2016 to 2019, and is currently the Chair of the Board of Trustees. He was elected an Honorary Trustee for his "exceptional contributions to the leadership and operations of the Aspen Center for Physics."

Past honorary trustees include Phillip Anderson (1977 Nobel Laureate), Hans Bethe (1967 Nobel Laureate), Murray Gell-Mann (1969 Nobel Laureate), Leon Lederman (1988 Nobel Laureate), and Robert Wilson (Founding Director of Fermilab).

Credit: Christian Schnell

Kavli IPMU alumni Christian Schnell elected Fellow of the American Mathematical Society

Stony Brook University Professor and Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI) Visiting Senior Scientist Christian Schnell has been named a Fellow of the American Mathematical Society (AMS) for 2024, it was announced in December 2023 by the Society.

The AMS Fellows program recognizes members who have made outstanding contributions to the creation, exposition, advancement, communication, and utilization of mathematics. Fellows are recognized by their peers for their contributions to the profession.

Schnell joined Kavli IPMU as a Project Researcher from 2011 to 2012, before joining the Department of Mathematics at Stony Brook University. Currently a Visiting Senior Scientist at Kavli IPMU, Schnell studies the geometry and topology of complex algebraic varieties, focusing on Hodge theory and on application of mixed Hodge modules in algebraic geometry.

Credit: Kavli IPMU

Masahiro Takada receives Hayashi Chushiro Prize

Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI) Professor Masahiro Takada has been awarded this year's Hayashi Chushiro Prize, it was announced by the Astronomical Society of Japan.

The prize is named in honor of Japanese theoretical astrophysicist Chushiro Hayashi, who made significant contributions to a wide range of areas including the understanding of nucleosynthesis, stellar evolution, and the origin of the solar system. The prize was established in 1996 when Hayashi received the Kyoto Prize that year, and is awarded every year to a researcher who the society believes has made great achievements in planetary science, astronomy, astrophysics or any other related fields.

Takada is being commended for his, "Pursuit of precision cosmology using data from the Subaru Telescope". For the past few years, Takada and his collaborators have been studying primordial black holes using the Hyper Suprime-Cam (HSC) camera mounted on the Subaru Telescope at the peak of Maunakea in Hawaii. To date he has contributed to breakthroughs including finding that dark matter is not made up of tiny primordial black holes.

Takada has also served as science working group leader of the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP), leading the group analyzing HSC data. Last year, the HSC-SSP measured a value for the "clumpiness" of the universe's dark matter, known to cosmologists as S8, and found their results aligned with values that other weak gravitational lensing surveys had found in looking at the relatively recent universe, but it did not align with the value derived from the Cosmic Microwave Background, leading to further investigations into this curious case.

This year's Hayashi Chushiro Prize also recognizes Takada's efforts in theoretical research, and his work to connect the theory to weak gravitational lensing observations.

Photo by: Makoto Oono

Masamune Oguri awarded the 2024 Japan Academy Prize

Chiba University Center for Frontier Science Professor and Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI) Visiting Senior Scientist Masamune Oguri has been named as one of the recipients of the 2024 Japan Academy Prize, it was announced by The Japan Academy.

The Japan Academy Prize was established in 1910 as the Imperial Academy Prize, before being renamed The Japan Academy Prize in 1948. The award recognizes significant academic theses, books and achievements. Past Kavli IPMU researchers to receive the award include Kavli IPMU Senior Fellow, The University of Tokyo Institute for Cosmic Ray Research Professor and 2015 Nobel Prize Laureate Takaaki Kajita, who received the award in 2012.

Oguri is being recognized for his joint research on pioneering and promoting cosmological research using gravitational lensing effects. His collaborator and a co-recipient of the Japan Academy Prize, National Astronomical Observatory of Japan Subaru Telescope Director Satoshi Miyazaki, developed the ultra-wide field-of-view camera, the Hyper Suprime-Cam (HSC), mounted on top of the Subaru Telescope in Hawaii, which has been helping researchers create a dark matter distribution map of the universe. Oguri took data from the HSC, analyzed it, and used the gravitational lensing effects capture by the telescope to create a 3-dimensional dark matter map over an unprecedented area of the universe. His results pointed out the possibility that the model of cosmic expansion may not be consistent with results found by the cosmic microwave background radiation, which is considered the standard theory of cosmology today.

7 Conferences

Conference Title Date, Place	Attendees (from abroad)
YITP Workshop: Future Science with CMB x LSS April 10-14, 2023, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan	121 (75)
CD3 Opening Symposium April 19-20, 2023, Lecture Hall, Kavli IPMU	92 (31)
Current Trends in Categorically Approach to Algebraic and Symplectic Geometry 2 June 20-21, 2023, Lecture Hall, Kavli IPMU	22 (4)
LiteBIRD Simulation Hands-on Collaboration Meeting June 26-30, 2023, Lecture Hall, Kavli IPMU	44 (22)
The World of Mathematical Sciences August 24-25, 2023, Lecture Hall, Kavli IPMU	127 (7)
Focus Week on Primordial Black Holes November 13-17, 2023, Lecture Hall, Kavli IPMU	57 (17)
CD3 Mini-Workshop "Time-Domain Astronomy and Cosmology in the LSST Era" December 7-8, 2023, Lecture Hall, Kavli IPMU	27 (7)
McKay McKay Correspondence, Tilting Theory and Related Topics December 18-22, 2023, Lecture Hall, Kavli IPMU	101 (20)
Tsinghua-Tokyo Workshop on Calabi-Yau January 15-19, 2024, Fujikensyujyo, Yamanashi, Japan	70 (31)
AI-Driven Discovery in Physics and Astrophysics January 22-26, 2024, Lecture Hall, Kavli IPMU	126 (73)
What Is Dark Matter? — Comprehensive Study of the Huge Discovery Space in Dark Matter March 7-8, 2024, Panasonic Auditorium, Yukawa Hall, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan	62 (12)
Envisaging Future Trajectories in Effective Field Theory (EFT in EFT) March 8-12, 2024, Lecture Hall, Kavli IPMU	30 (13)

8 Conference Presentations and Seminar Talks

Invited talks given by the Kavli IPMU researchers (Selected 12 of 267)

Presenter	Presentation title	Conference name and date
Patrick de Perio	Hyper-Kamiokande: Challenges in Precision Neutrino Physics	Symposium on Frontiers of Underground Physics October 30, 2023
Norihiro Hanihara	Cluster categories and singularity categories	Silting in Representation Theory, Singularities, and Noncommutative Geometry September 11, 2023
Yukari Ito	Women in Science in Japan and AOWM	International Symposium on Diversity, Equity and Inclusion in STEM March 7, 2024
Mikhail Kapranov	Categorification of Euler's continuants, N-spherical functors and periodic semi-orthogonal decompositions	International Conference "Homotopy Algebras and Higher Structures" May 25, 2023
Miho Katsuragawa	X-ray detectors and imaging for nuclear medicine	X-ray detector technologies for physics (XDEP) February 5, 2024
Jia Liu	Cosmology with Massive Neutrinos	CMB-S4 Collaboration Meeting July 31, 2023
Hitoshi Murayama	US Particle Physics for the Next Ten Years	CERN Colloquium February 2, 2024
Maria Mylova	Parity violating graviton non-Gaussianity in alpha-vacuum	Large-scale parity violation workshop December 4, 2023
Hiraku Nakajima	A mathematical definition of Coulomb branches of 3d N=4 SUSY gauge theories	International Congress of Basic Sciences July 18, 2023
Ippei Obata	Axion dark matter search with the observations of cosmic birefringence	Dark Matter 2023: From the Smallest to the Largest Scales May 30, 2023
Masahito Yamazaki	Eisenstein Series and Ensemble Averages in Holography	Number theory, machine learning and quantum black holes October 5, 2023
Jun'ichi Yokoyama	Primordial Black Holes from Single- field Inflation?	Future Perspectives on PBHs December 12, 2023

9 OUTREACH AND PUBLIC RELATIONS

Event Title	Date	Venue	Number of Participants
28th Kavli IPMU x ICRR Hybrid Joint Public Lecture: "How Gamma Rays Are Seen in Astronomy and Medicine"	April 22, 2023	Kashiwanoha Conference Center & Online	342
Science Café in English "Universe" 2023 "Why Do Galaxies Look the Way They Do? A Journey from the First Generation of Galaxies to the Last"	July 15, 2023	Tamarokuto Science Center	62
Summer Holiday Science Workshop at Tokatsu Techno Plaza	August 3, 2023	Tokatsu Techno Plaza	45
Science Café in English "Universe" 2023 "The Geometric Origins of Supersymmetry"	September 16, 2023	Tamarokuto Science Center	24
Open Campus Kashiwa 2023	October 27-28, 2023	Kashiwa Campus, The University of Tokyo & Online	3,118
9th Kavli IPMU / ELSI / IRCN Joint Public Lecture: "A Question of Origins"	November 5, 2023	70th Anniversary Auditorium, Tokyo Institute of Technology & Online	398
The 12th WPI Science Symposium	November 23, 2023	Akira Suzuki Hall, Hokkaido University & Online	270
8th Of Course I Love Physics: Careers for Girls in Physics	November 25, 2023	Online	15
29th Kavli IPMU x ICRR Joint Online Public Lecture: "Gravitational Waves x Computational Cosmology"	December 10, 2023	Yasuda Auditorium, The University of Tokyo & Online	697
Fundamentalz Festival (2021-2023)	December 16-27, 2023	Komaba Museum, The University of Tokyo	820
2024 AAAS Annual Meeting	February 15-17, 2024	Colorado Convention Center, U.S.A.	4,500

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

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

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

ISSN 2187-7386 Printed in Japan