Research Center for the Early Universe

Graduate School of Science

University of Tokyo

Annual Report

2024

令和6年度 年次研究報告

東京大学大学院理学系研究科附属

ビッグバン宇宙国際研究センター

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Preface

We are pleased to present the annual report of Research Center for the Early Universe (RESCEU) for the fiscal year of 2024 (from April 2024 to March 2025).

RESCEU was founded in 1999 as an institute belonging to Faculty of Science, the University of Tokyo, led by the first director, Prof. Katsuhiko Sato of Physics Department. In 2015 we reorganized the research projects in RESCEU, and we have had three major projects including (1) Evolution of the universe and cosmic structures (led by Jun'ichi Yokoyama), (2) Gravitational-wave astrophysics and experimental gravity (led by Kipp Cannon), and (3) Formation and characterization of planetary systems (led by Yasushi Suto). Those projects have been supported by a variety of collaboration among our research affiliates in Departments of Physics, Astronomy, and Earth and Planetary Sciences of Faculty of Science, the University of Tokyo. Since the two leaders of the projects are leaving from the center (Professor Suto retired from the University of Tokyo and Professor Yokoyama has become the Director of Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI).) and other members will exchange in the coming year, we have been reorganizing the projects. Thus this year's annual report describes the achievements of each laboratory and does not include achievements of the projects performed with affiliates mentioned above.

We were also able to conduct our annual summer school, which has traveled around Japan every year, this year in Kanazawa City for face-to-face meetings. We also co-organized Quantum probes for gravity workshop 2024 on September 9-10 at Hongo Campus.

Furthermore, we invited Professor Daniel Nathan Kasen of University of California, Berkeley as a visiting professor in the Visiting Professor Division, which is the only division that the Graduate School of Science maintains.

We are pleased to announce the following awards for our RESCEU members this year. Professor Kana Moriwaki was awarded the 3rd Marie Sklodowska Curie Award, Grand Prize (May 23) for her "Theoretical Study of Large-Scale Structure in the Early Universe".

There were two press-releases from the center: i)"The case of the missing black holes" by Mr. Jason Kristiano and Prof. Jun'ichi Yokoyama. ii)"Fresh wind blows from historical supernova" by Mr. Takatoshi Ko, Prof. Toshikazu Shigeyama, and Prof. Aya Bamba.

In this academic year, Dr. Yuta Michimura joined RESCEU as an associate professor, and Takahiro Yamamoto as a postdoc. On the other hand, Project Assistant Professor Hiroto Mitani has moved to a postdoctoral position at the University of Duisburg-Essen in Germany.

We would appreciate your further support for our activities.

November 2025
Director Toshikazu Shigeyama

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I

Reports on overall activities at RESCEU in 2024

1 Members

RESCEU members

Toshikazu Shigeyama [茂山俊和]	Director
Jun'ichi Yokoyama [横山順一]	Professor (Concurrent)
Kipp Cannon	Professor
Kenta Hotokezaka [仏坂健太]	Associate Professor
Yuta Michimura [道村唯太]	Associate Professor
Kana Moriwaki [森脇可奈]	Assistant Professor
Kentaro Komori [小森健太郎]	Assistant Professor
Takahiro Yamamoto [山本貴宏]	Project Assistant Professor
Akihiro Suzuki [鈴木昭宏]	Project Assistant Professor
Kenneth Wong	Project Assistant Professor
Koh Ueno [上野昂]	Postdoctoral Fellow (Kakenhi Grant of Prof. Yokoyama)
Christopher M. Irwin	Postdoctoral Fellow (Kakenhi Grant of Prof. Hotokezaka)
Kazuya Takahashi [高橋和也]	Postdoctoral Fellow (RESCEU)
Takuya Takahashi [高橋卓弥]	Postdoctoral Fellow (RESCEU)
Wang Haoyu	Postdoctoral Fellow (Kakenhi Grant of Prof. Michimura)
Yuki Takei [武井勇樹]	Postdoctoral Fellow (RESCEU)
Chiyo Ueda [上田千代]	Secretary
Nao Watanabe [渡辺菜穂]	Secretary
Tomoko Ishida [石田智子]	Secretary
Mami Narita [成田満美]	Secretary

RESCEU affiliates

Naoki Yoshida [吉田直紀]	Professor, Dept. of Physics
Tomonori Totani [戸谷友則]	Professor, Dept. of Astronomy
Kotaro Kohno [河野孝太郎]	Professor, Institute of Astronomy
Aya Bamba [馬場彩]	Associate Professor, Dept. of Physics
Akito Kusaka [日下暁人]	Associate Professor, Dept. of Physics
Kazuhiro Shimasaku [嶋作一大]	Associate Professor, Dept. of Astronomy
Masaki Ando [安東正樹]	Associate Professor, Dept. of Physics
Nobunari Kashikawa [柏川伸成]	Professor, Dept. of Astronomy

2 Projects

Project 1. Evolution of the Universe and cosmic structures

Name	Research themes
Jun'ichi Yokoyama	Physics of the Early Universe
Toshikazu Shigeyama	Coevolution of galaxies and stars
Naoki Yoshida	Evolution of compact objects and time domain astronomy
Tomonori Totani	Evolution of the Universe probed by gamma-ray bursts and fast radio bursts
Kotaro Kohno	Dust-enshrouded growth of galaxies and supermassive black holes
Aya Bamba	Chemical evolution of the Universe with supernova remnant study
Akito Kusaka	Observational cosmology based on cosmic microwave background radiation
Kazuhiro Shimasaku	Galaxy formation and evolution
Nobunari Kashikawa	Distant objects and early Universe
Kohei Kamada	Particle cosmology
Kana Moriwaki	Machine learning and cosmology

Project 2. Gravitational-wave astrophysics and experimental gravity

Name	Research themes
Kipp Cannon	Detection and interpretation of gravitational waves emitted by the collisions of compact objects
Kenta Hotokezaka	Electromagnetic counterparts of gravitational-wave neutron star mergers
Mamoru Doi	Identifications of gravitational-wave sources by wide-field and multi-color optical observations
Masaki Ando	Gravitational-wave experiment and astrophysics
Kentaro Komori	Gravitational-wave experimental astrophysics
Yuta Michimura	Experimental gravity

3 Symposia and Meetings

RESCEU Summer School 2024

Place: Garden Hotel Kanazawa, Ishikawa, Japan
Time: 2025 September 5 (Thu) – 2024 September 7 (Sat)
Web: https://www.resceu.s.u-tokyo.ac.jp/workshops/resceu24s/index.php

Program

September 5 (Thu)

12:50–13:00	Jun'ichi Yokoyama	Opening

(chair: Yuta Michimura)

13:00–14:20	(L) Yanbei Chen	Lecture 1a: Lectures on Gravitational-Wave Astronomy
14:20–15:40	(L) Anupreeta More	Lecture 2a: Introduction to Gravitational lensing

break

(chair: Kipp Cannon)

16:00–16:15	Soichiro Kuwahara	Foreground subtraction from the perspective of anisotropy observation
16:15–16:30	Daiki Watarai	Post-innermost Stable Circular Orbit Ringdown of a Rapidly Spinning Black Hole
16:30–16:45	Suyog Garg	GW waveform generator using Machine Learning
16:45–17:00	Hayato Imafuku	Statistical properties of parameter estimation in scalar-tensor polarization search
17:00–18:20	(L) Yanbei Chen	Lecture 1b: Lectures on Gravitational-Wave Astronomy

September 6 (Fri)

– 12:00 Morning Free discussion

(chair: Kenneth Wong)

13:20–14:40	(L) Anupreeta More	Lecture 2b: Strong Gravitational lensing
14:40–16:00	(L) Surhud More	Lecture 3a: Weak Gravitational Lensing

break

(chair: Kazuya Takahashi)

16:20–16:35	Takahiro S. Yamamoto	TBD
16:50–17:05	Reiko Harada	Estimation of the Hubble parameter from compact object catalogues without threshold
17:05–17:20	Hanchun Jiang	Impact of Reionization History on Constraining Primordial GWs with CMB B-modes
17:20–17:35	Jason Kristiano	Comparing sharp and smooth transitions of the second slow-roll parameter in single-field inflation
17:35–17:50	Jeong Hyun	The role of Higgs field after R^2 inflation
19:00–	Workshop dinner	

September 7 (Sat)

(chair: Toshikazu Shigeyama)

09:00–10:20	(L) Martijn Oei	lecture 4a
10:20–10:35	Takatoshi Ko	Type Iax SN occured in 1181
10:35–10:50	Shota Takahashi	機械学習を用いた超新星中ニュートリノの Eddington tensor の推定
10:50–11:05	Ryoga Honjo	Polarization of aspherical shock breakout
11:05–11:20	Daisaburo Kido	The propagation of jet in merger ejecta and the instability at jet head
11:20–11:35	Yuka Yamada	Void detection on Line Intensity maps
11:35–11:50	Fumihiro Naokawa	Cosmic birefringence and polarized radio galxies
lunch		

(chair: Kenta Hotokezaka)

13:20–14:40	(L) Surhud More	Lecture 3b: Weak Gravitational Lensing
14:40–16:00	(L) Martijn Oei	Lecture 4b

(L: Lecture)

4 RESCEU colloquia

- RESCEU Colloquium No. 68
  Aswin Vijayan (University of Sussex)
  "The early Universe through the FLARES (First Light And Reionisation Epoch Simulations) lens"
  January 10, 2025, 13:00-14:30

- RESCEU Colloquium No. 67
  Derek Inman (RIKEN / iTHEMS)
  "Structure Formation on Very Small Scales at Very Early Times"
  December 12, 2024, 15:30-17:00

- RESCEU Colloquium No. 66
  Ben Horowitz (Kavli IPMU)
  "Fast Inference in Cosmology and Astrophysics with Differentiable Simulations"
  November 19, 2024, 14:00-15:30

- RESCEU Colloquium No. 65
  Carolina Cuesta-Lazaro (MIT/CfA)
  "Cosmology ' s Midlife Crisis: Embracing the Machine Learning Makeover"
  November 14, 2024, 15:30-16:30

- RESCEU Colloquium No. 64
  Patricia Diego Palazuelos (Max Planck Institute for Astrophysics)
  "Cosmic birefringence: searching for parity-violating physics with the CMB polarization"
  October 3, 2024, 15:00-16:00

- RESCEU Colloquium No. 63
  Achamveedu Gopakumar (TIFR, Mumbai)
  "Galaxy-based gravitational wave observatory and its promises"
  July 31, 2024, 13:00-14:30

- RESCEU Colloquium No. 62
  Anton Jaelani (Institut Teknologi Bandung)
  "Hunting for Gravitational Lensing Systems in Astronomical Images"
  July 11, 2024, 13:00-14:30

- RESCEU Colloquium No. 61
  Anowar Shajib (University of Chicago)
  "The strong-lensing revolution in the JWST-Roman-Rubin era: from resolving the Hubble tension to constraining baryonic feedback"
  June 11, 2024, 14:00-15:30

II

Reports
on the research activities
of RESCEU in 2024
(in Japanese)

2024年度
RESCEU
研究活動報告

5 横山順一研究室

5.1 横山 (順) 研究室

当研究室は一般相対性理論、場の量子論、素粒子物理学等の基礎物理学理論に基づいて宇宙論と重力理論の理論的研究を幅広く行うとともに、理学部物理学教室の教育と研究に参画しています。

1) Loop effects in cosmological perturbation 2) Constraining primordial black hole formation through higher order cosmological perturbation 3) Gravitational-wave data analysis 4) Lorentzian analysis of vacuum decay in cosmology 5) Higgs R^2 inflation, and 6) Evolution of cosmological magnetic fields.

1) We have shown that an inflationary model in which the three-point correlation function (non-Gaussianity) is large enough to be observationally significant would necessarily induce large quantum corrections to the two-point correlation function, i.e., the power spectrum, through higher-loop effects of fluctuations, thereby conflicting with the observed isotropy of the cosmic microwave background. Conversely, single-field inflation models that produce curvature perturbations on large scales consistent with observations inevitably predict only small non-Gaussianity. Therefore, if future observations were to detect significant non-Gaussianity, it would imply the need for mechanisms beyond single-field inflation.

2) It is known that to realize large-amplitude fluctuations at specific scales during inflation, the presence of a transient ultra-slow-roll (USR) phase is desired. During this phase, the mode that would normally decay instead grows, so the quantum nature of the fluctuations is expected to persist. Indeed, when we explicitly computed the higher-order quantum corrections to the fluctuations in such models, we found that their effects extend even to large scales. Consequently, models that generate large density perturbations at small scales—sufficient to produce primordial black holes—turn out to conflict with the observed isotropy of the cosmic microwave background on large scales.

3) Gravitational-wave detectors contain not only gravitational-wave signals but also various types of noise, some of which can be monitored by environmental sensors. To separate these noise components from the detector output and efficiently extract the gravitational-wave signal, we have been developing an approach based on independent component analysis (ICA). While conventional analyses have been limited to cases where the noise components are linearly mixed, by applying variational methods we have succeeded in developing a framework that can handle arbitrary nonlinear couplings between noise and signal. We have verified the effectiveness of this method using real data from the KAGRA detector.

4) Vacuum decay induced by cosmological first-order phase transitions has traditionally been analyzed using the Euclidean (imaginary-time) path integral formalism. We performed an analysis in real time and, by applying the Picard–Lefschetz prescription, identified the appropriate integration contour, thereby obtaining a more general result. We showed that in the case where a critical bubble is formed, our result reproduces the conventional one, while for larger bubbles, the process can be interpreted as evolving in imaginary time up to the critical bubble and in real time thereafter. This provides, for the first time, a justification of the conventional approach. We also carried out a similar analysis for phase transitions seeded by black holes.

5) The Higgs inflation and Starobinsky models are known as the simplest inflationary scenarios that successfully reproduce the observations of the cosmic microwave background. We considered a mixed model in which both the Higgs field and the squared Ricci scalar term are present, and we investigated its reheating process in detail. We showed that in Higgs inflation, the production of particles with energies exceeding the cutoff scale during preheating can be avoided by including the R^2 term.

6) We have formulated the evolution of cosmic magnetic fields analytically and comprehensively by incorporating the effects of magnetic reconnection suggested by recent results from state-of-the-art MHD simulations, together with a newly discovered conserved quantity.

受賞

報文

(原著論文)

[1] A. G. Abac *et al.* [LIGO Scientific, KAGRA and VIRGO], Astrophys. J. **977** (2024) no.2, 255 doi:10.3847/1538-4357/ad8de0 [arXiv:2410.09151 [astro-ph.HE]].

[2] G. Raman *et al.* [LIGO Scientific, KAGRA, Virgo, Swift and Swift-BAT/GUANO], Astrophys. J. **980** (2025) no.2, 207 doi:10.3847/1538-4357/ad9749 [arXiv:2407.12867 [astro-ph.HE]].

[3] J. Kristiano and J. Yokoyama, JCAP **10** (2024), 036 doi:10.1088/1475-7516/2024/10/036 [arXiv:2405.12145 [astro-ph.CO]].

[4] F. Uchida, M. Fujiwara, K. Kamada and J. Yokoyama, JCAP **08** (2025),

017 doi:10.1088/1475-7516/2025/08/017 [arXiv:2405.06194 [astro-ph.CO]].

[5] A. G. Abac *et al.* [LIGO Scientific, KAGRA and VIRGO], Astrophys. J. Lett. **970** (2024) no.2, L34 doi:10.3847/2041-8213/ad5beb [arXiv:2404.04248 [astro-ph.HE]].

[6] A. G. Abac *et al.* [KAGRA, LIGO Scientific and VIRGO], Phys. Rev. D **110** (2024) no.4, 042001 doi:10.1103/PhysRevD.110.042001 [arXiv:2403.03004 [astro-ph.CO]].

(会議抄録)

(国内雑誌)

[7] 横山順一 「横山教授に聞く科学のふしぎ」 子ども新聞「風っ子」連載 上毛新聞。

(学位論文)

[8] F. Uchida, "Probing the Early Universe with the Evolution of Promordial Magnetic Fields", (博士論文).

[9] 渡慶次孝気, "Stochastic Selection in the Inflationary Universe" (博士論文).

[10] 鄭玄, "R^2 インフレーション再加熱機における物質と時空の進化 (Cosmological evolution after R^2 inflation)" (修士論文).

(著書)

[11] J. Kristiano and J. Yokoyama, doi:10.1007/978-981-97-8887-3_3 [arXiv:2405.12149 [astro-ph.CO]]. In "Primordial Black Holes" (Springer 2025).

学術講演

(国際会議)

一般講演

[12] J. Yokoyama, "Developing a New Nonlinear Independent Component Analysis Scheme," (poster) 10th KAGRA International Workshop, 2023/5/29 National Tsing Hua University.

[13] J. Yokoyama, "Developing a New Nonlinear Independent Component Analysis Scheme,"(poster) ICRC 2023 Nagoya University, 2023/8.

[14] K. Kamada, " Baryon (over)production from large lepton flavor asymmetry", PLANCK 2023, 2023/5/25.

[15] R. Jinno, "Quartic Gradient Flow," Higgs as a Probe of New Physic, Osaka Univ., 2023/6 .

[16] R. Jinno, "Higgsless simulations of first-order phase transitions and gravitational wave production," 2023 Shanghai Symposium on Particle Physics and Cosmology: Phase Transitions, Gravitational Waves, and Colliders, TD Lee Institute, Shanghai, China, 2023/9.

[17] R. Jinno, "Gravitational waves from feebly-interacting particles in a first-order phase transition," CTPU homecoming workshop, 2023/10.

[18] R. Jinno, "Gravitational waves from feebly-interacting particles in a first-order phase transition," Gravitational Wave Probes of Physics Beyond Standaerd Model, Osaka City University, 2023/11.

[19] R. Jinno, "Gravitational waves from feebly-interacting particles in a first-order phase transition," Jeju workshop, 2023/11.

[20] Jun'ya Kume, "Back-reactions in axion inflation with U(1) gauge field"(poster), RESCEU Summer School 2023, 2023/8.

[21] Jun'ya Kume, "Updates on KAGRA B-L vector boson search", LIGO-Virgo-KAGRA collaboration meeting September 2023, Toyama International Conference Center, Japan, 2023/9.

[22] Jun'ya Kume, "A fate of catalyzed first order phase transition -black holes from primordial black holes-", INFN TAsP meeting, Università di Torino, Italy, 2024/11.

[23] Jun'ya Kume, "Ultralight dark matter search with KAGRA -the O3GK result and toward the O4 analysis-", FY2023 "What is dark matter? - Comprehensive study of the huge discovery space in dark matter", YITP, 2024/3.

[24] F. Uchida, and R. Jinno, "Monopole-wrapping axion domain wall", COSMO'23, IFT, Madrid, 2023/9/11.

[25] K. Tokeshi, "Borel resummation for secular divergences in stochastic inflation", Planck 2023, Warsaw University, Poland, 2023/05/22-26.

[26] K. Tokeshi, "Borel resummation for secular divergences in stochastic inflation", RESCEU Summer School 2023, Shinshu University, Japan, 2023/08/09-12.

[27] K. Tokeshi, "Stochastic selection effect in the early Universe, 32nd Workshop on General Relativity and Gravitation (JGRG32), Nagoya University, Japan, 2023/11/27-12/01.

[28] J. Kristiano, "One-loop correction in primordial black hole formation from single-field inflation" The 26th International Conference on Particle Physics and Cosmology (COSMO), IFT, Spain, 2023/09/11-15.

[29] J. Kristiano, "Superhorizon evolution of the squeezed bispectrum" Correlators in Cortona, Italy, 2023/09/18-22.

[30] J. Kristiano, "One-loop correction in primordial black hole formation from single-field inflation" Focus Week on Primordial Black Holes, Kavli IPMU, 2023/11/13-17.

[31] J. Kristiano, “Superhorizon evolution of the squeezed bispectrum” The 32nd Workshop on General Relativity and Gravitation in Japan (JGRG), Nagoya University, 2023/11/27.

[32] M. Hong, “Quartic Gradient Flow” (poster), RESCEU Summer School 2023, Shinshu University, 2023/8/9-12.

[33] M. Hong, “Quartic Gradient Flow”, The 32nd Workshop on General Relativity and Gravitation in Japan, Nagoya University, 2023/11/27-12/1.

[34] M. Hong, “Starobinsky Inflation and beyond in Einstein-Cartan Gravity”, Berkeley Week at the University of Tokyo, The University of Tokyo, 2024/3/11-15

[35] F. Naokawa, ”The rotation of axion by the rotation of photon”, RESCEU Summer School, Nagano, Japan, 2022/8/12.

[36] F. Naokawa,”Cosmic birefringence by rotating ALP”, Large Scale Parity Violation Workshop, ASIAA, Taiwan, 2023/12/5.

[37] F. Naokawa,”Rotating axion and cosmic birefringence”, Extreme Mass Dark Matter Workshop, YITP, Japan, 2024/03/06.

[38] F. Naokawa,”A phase uncertainty of cosmic birefringence”, What is dark matter? -Comprehensive study of the huge discovery space in dark matter-, YITP, Japan, 2024/03/07.

[39] H. Jeong, ”Are primordial black holes produced after R^2 inflation?”, The 32nd Workshop on General Relativity and Gravitation in Japan, Nagoya University, 2023/11/27-12/1.

招待講演

[40] J. Yokoyama ”Stochastic inflation and beyond” Starobinsky memorial online conference ”Quantum gravity and all of that” 2024/4/20.

[41] J. Yokoyama ”Loop corrections to non-standard inflation,” CosPA2024 Ningbo University, China, 2024/6/15.

[42] J. Yokoyama ”Quantum aspects of inflationary cosmology” 2024 Joint Annual Conference of Physical Societies in Guangdong-Hong Kong-Macao Greater Bay Area, Macao, 2024/7/30

[43] J. Yokoyama ”Quantum loop effects in inflationary cosmology,” Pacific 2024, Gamp Station, UCLA, Tahiti, 2024/8/28.

[44] J. Yokoyama ”Quantum aspects of inflationary cosmology” ICTP-AP winter school, UCAS, Beijing, 2024/11/28.

(国内会議)

一般講演

[45] R. Jinno, “Quartic Gradient Flow / Tunneling potential formalism,” Second Mini-workshop on the Early Universe, Suwa lake, Nagano, 2023/7/3-5.

[46] 神野隆介, “渦上のニュートリノゼロモードとトポロジカル不変量,” 日本物理学会 2023 年年次大会, 東北大学, 2023/09/16-19.

[47] F. Uchida, “Do primordial magnetic fields survive until today?”, Second Mini-workshop on the Early Universe, Suwa lake, Nagano, 2023/7/3.

[48] F. Uchida, “The baryon isocurvature problem of primordial magnetic fields”, Berkeley week, the University of Tokyo, Hongo, Tokyo, 2024/3/15.

[49] K. Tokeshi, “確率形式における制約付き Langevin 方程式”, 日本物理学会 2023 年年次大会, 東北大学, 2023/09/16-19.

[50] 洪木子, “四次グラディエントフロー法”, 日本物理学会第 78 回年次大会 (2023 年), 東北大学, 2023/9/16-19.

[51] 洪木子, “アインシュタイン・カルタン重力における Nieh-Yan 項および Holst 項によるインフレーション”, 日本物理学会 2024 年春季大会, オンライン, 2024/3/18-21

[52] 直川史寛, ”Tomo-e Gozen の時間分解能を空間分解へ活かす”, 木曽シュミットシンポジウム 2023, 木曽, 2023/5/30.

[53] 直川史寛, ”宇宙複屈折の位相不定性”, 日本天文学会 2024 年春季年会, 東京大学+オンライン開催, 2023/3/13.

[54] 直川史寛, ”旋回するアクシオンによる宇宙複屈折”, 日本物理学会 2024 年春季年会, オンライン開催, 2023/3/24.

[55] 鄭玄, ”R^2 インフレーション理論におけるバリオン数生成”, 日本物理学会第 78 回年次大会 (2023 年), 東北大学, 2023/9/16-19.

[56] 鄭玄, ”R^2 インフレーション再加熱期における原始ブラックホール生成”, 日本物理学会 2024 年春季年会, オンライン開催, 2023/3/18-21.

招待講演

[57] 神野隆介, “高エネルギー初期宇宙における一次相転移と重力波生成,” 研究会「熱場の量子論とその応用」, KEK, 2023/8/28-30.

[58] R. Jinno, “First-order phase transitions and gravitational wave production in the early Universe,” Joint workshop on General Relativity and Cosmology, Chiba, 2024/3/6-8

(セミナー)

[59] J. Yokoyama, “Primordial Black Holes from Single-field Inflation?” Universitià Degli Studi di Milano Bicocca 2023/3/21

[60] J. Yokoyama, “Primordial Black Holes from Single-field Inflation?” Universiti di Padova 2023/3/25

[61] K. Kamada, “Axion inflation meets chiral magnetohydrodynamics”, Nordita, 2023/5/31.

[62] K. Kamada, “Axion Inflation as the origin of Baryon asymmetry of the Universe”, 早稲田大学宇宙物理学研究室, 2023/6/30.

[63] 鎌田耕平, “カイラル磁気不安定性による初期宇宙のレプトンフレーバー非対称性への制限”、横浜国立大学素粒子理論研究室, 2023/7/21.

[64] 神野隆介, “高エネルギー初期宇宙における一次相転移と重力波生成,” 宇宙物理学コロキウム, 立教大学, 2023/5/9.

[65] R. Jinno, “First-order phase transitions & GW production in the early Universe,” Kobe University, 2023/5/24.

[66] Jun'ya Kume, “U(1) gauge field production in axion inflation -backreaction from charged particles-”, Institute for Basic Science, Center for Cosmology, Gravity and Astroparticle physics (CGA), Korea, May 2023.

[67] Jun'ya Kume, “Cosmic strings in the Abelian-Higgs model and the recent results of Pulsar Timing Array”, University of Münster, Germany, December 2023.

[68] Jun'ya Kume, “How is fermion chirality produced by chiral gravitational waves?”, University of Münster, Germany, December 2023.

[69] F. Uchida, “Quantum algorithm for collisionless Boltzmann simulation”, 東京大学素粒子論研究室セミナー, 2023/5/29.

[70] F. Uchida, “Monopole wrapped by domain wall?”, RESCEU Summer School, Shinshu University, Nagano, 2023/8/9.

[71] F. Uchida, “BBN constraint on the origin of the cosmological magnetic field”, internal seminar at NORDITA, 2023/9/25.

[72] F. Uchida, “BBN constraint on the origin of the cosmological magnetic field”, internal seminar at Waseda University, 2023/11/24.

[73] K. Tokeshi, “Constrained random processes in stochastic inflation”, 立教大学理論物理学コロキウム, 立教大学, 2023/11/07.

[74] K. Tokeshi, “Borel resummation in stochastic formalism of inflation”, 東北大学 TUHEP セミナー, 東北大学, 2023/12/07.

[75] J. Kristiano, “Bispectrum and one-loop correction in PBH formation from single-field inflation”, Zooming in on Primordial Black Holes Seminar, Leiden University, The Netherlands, 2023/04/03 (Online).

[76] J. Kristiano, “Primordial black holes from single-field inflation?”, Leung Center for Cosmology and Particle Astrophysics (LeCosPa) Seminar, National Taiwan University, Taiwan, 2023/04/17 (Online).

[77] J. Kristiano, “Exploring possibilities of the inflationary potential”, Colloquium, Rikkyo University, 2023/04/18.

[78] J. Kristiano, “Bispectrum and one-loop correction in PBH formation from single-field inflation”, Department of Physics (Particle Theory and Cosmology Group) Seminar, Tohoku University, 2023/05/18.

(アウトリーチ)

[79] 横山順一　「宇宙：始まりと終わり」　新島学園短期大学創立 40 周年記念講演会　高崎市文化センター　2023/10/14

6 Kipp Cannon研究室

6.1 Kipp Cannon's Laboratory

Our research group studies black holes, neutron stars, exotic astrophysical objects, and the Universe using gravitational waves, and electromagnetic observations. Gravitational waves are waves of space-time curvature generated by the movement of mass and momentum. There are many reasons why gravitational waves are an interesting way to explore the sky. Because gravitational waves are generated by physical processes different from those that produce light or radio waves (which are generated by the movement of electric charges and currents), gravitational waves carry different information about their sources than is carried by electromagnetic waves. Gravitational waves interact weakly with matter allowing them to pass through material that would be opaque to radio waves and light. For example, although they have not yet been observed we expect that gravitational waves can escape the dense deep cores of supernovæ, and show us the earliest moments of the Big Bang. The Earth, too, is transparent to gravitational waves, so gravitational-wave telescopes can see the sky below them through the Earth as easily as they can see the sky above, allowing gravitational-wave telescopes to monitor the whole sky continuously, day and night. Gravitational waves are the only significant form of energy expected to be radiated by some of the most exotic events in the Universe like the collisions of black holes. However, because everything is nearly transparent to gravitational waves, it is very difficult to build a device that can detect them, and the first detection of this form of energy was only achieved in 2015. It is even more difficult to build a device that can generate gravitational waves with detectable amplitudes, and so observation of highly energetic astronomical phenomena provides our only opportunity to explore this aspect of the natural world.

Our research group's members are members of the KAGRA Collaboration, and we analyze data collected by the two LIGO gravitational-wave antennas in the United States, the Virgo antenna in Italy, the GEO600 antenna in Germany, and the KAGRA antenna in Japan. Throughout the 2024 fiscal year, we participated in the fourth observation period of the LIGO, Virgo and KAGRA detectors, called "O4". This data collecting period started in May 2023 and is expected to conclude in November 2025. In addition, various theoretical studies are needed to maximize the scientific results obtained from the data, and members of our group are active in almost all areas of the exploration of astronomy, cosmology, and fundamental physics with gravitational waves.

In the 2024 fiscal year, our group was joined by one new Master's student. One of our Master's students graduated to the doctoral program, and one doctoral student graduated with his Ph.D. We are delighted that one of our group's postdoctoral fellows, Dr. Takahiro Yamamoto, has been hired as an assistant professor and will be remaining with our research group, and that we were joined in this fiscal year by Dr. Alvin Li, a new postdoctoral fellow.

6.1.1 Testing General Relativity with Gravitational Waves

Compact Object Collisions in Alternative Gravity Theories

One challenge confronting people attempting to use observations of gravitational waves to constrain gravity theories is that only for general relativity — the prevailing theory of gravity — have extensive theoretical and numerical studies of the behaviour of spacetime during compact object collisions been performed. Comparatively little is known about the waves produced by compact object collisions in alternate theories of gravity. The standard approach taken to using gravitational wave observations to test for evidence of non-general relativity gravity is to introduce *ad hoc* parameterized perturbations to the waveform models, and use observed signals to constrain the value of the perturbation parameters. The difficulty with this is there is often no physical interpretation of the meaning of the perturbation parameters, it's not clear what the inferred constraints are constraining, and it's not understood if it is reasonable to imagine the parameters being varied independently.

Our group is engaged in an effort to translate combinations of perturbation parameters into physically meaningful quantities, for example a "non-conservation of energy" parameter. The goal is to allow, for example in that specific case, one to require that energy be conserved when varying the waveform perturbation parameters. This allows a more refined, careful, analysis of the observed waveforms to be performed and allows smaller departures from general relativity's predictions to be detected.

Testing Gravitational Wave from Compact Object Collisions for non-GR Polarization States

Just as in the case of Maxwell's equations and electromagnetic waves, general relativity predicts gravitational waves have only exactly two polarization states. In the future, when enough gravitational-wave antennas are available with sufficient sensitivity it will be possible to test directly for the presence of additional degrees of freedom in the wave, however at this time we are limited in our ability to test this prediction of general relativity. One approach, which members of our group have been pursuing, is to use the rate at which the orbit of a colliding pair of black holes decays, and use that to test for evidence of energy being lost from the system at too high a rate. Observing this would suggest that energy is being radiated into more degrees of freedom than the 2 of general-relativity. This effect is partially degenerate with other properties of the systems being observed, and so careful statistical analysis is required to disentangle the effects of additional polarization states. One approach is to gather evidence from ensembles of black hole collisions under the assumption that they all obey the same laws of gravity.

6.1.2 Cosmology with Gravitational Waves

Inferring the Hubble Parameter from Compact Object Collisions

Gravitational waves from compact object collisions can provide measurements of the Hubble parameter that are independent of the cosmic distance ladders derived from electromagnetic observations, and cosmological probes such as the cosmic microwave background, as demonstrated following the detection of GW170817. However, unlike the case of GW170817, most of the GW candidates observed so far do not have electromagnetic counterparts and thus their host galaxies cannot be identified, *i.e.*, their red-shift information cannot be obtained directly. In recent years, measurements of the Hubble parameter have been obtained from ensembles of black hole collisions using a galaxy catalogue and the distribution of signal amplitudes of sources. Those studies have typically used only significant events, for example events with a signal-to-noise-ratio of 11 or higher. While efforts have been made in the past to correct for the selection bias, it is expected that using a lower threshold in the event selection and utilizing all candidates detected by detection pipelines reduces the risk that a measurement of the Hubble parameter is affected by human-induced selection bias. Many of the sub-threshold candidates originate from noise in detectors rather than from compact binary collisions, and they must be properly handled, which makes the analysis more complex. We have formulated an analysis technique that enables inclusion of sub-threshold candidates by utilizing intermediate data products accumulated during the detection process of GWs.

6.1.3 Expanding Compact Object Detection Parameter Space

Synthesizing Eccentric Merger Waveforms with Neural Networks

As mentioned above, searches for gravitational waves from compact object collisions rely on parametric models of the signals. These are constructed using fits to numerical simulations of spacetime and matter during a compact object collision. One weakness of the models that are currently available is their inability to simulate the signals from highly eccentric collisions. There exists eccentric waveform models, but they are slow, requiring integration of many simultaneous differential equations, and that makes it impractical to use such models for Monte Carlo parameter estimation algorithms, which need to evaluate enormous numbers of waveform models. Our group is in the process of experimenting with the use of neural networks to construct accurate eccentric waveform model predictions with comparatively little computational cost. The hope is that this will make tests for the presence of eccentricity compact object collisions fast and easy.

6.2 List of Achievements

Awards, etc.

- Li, Alvin. Croucher Fellowships for Postdoctoral Research. Croucher Foundation, Hong Kong. Sep 2024 – Aug 2026.
- Li, Alvin. Outstanding Presentation Award. The 33rd Workshop on General Relativity and Gravitation in Japan, Kindai University, Osaka. Dec 2024.

Publications

(Refereed Publications)

[1] Fletcher, C. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). A joint Fermi-GBM and Swift-BAT analysis of gravitational-wave candidates from the third gravitational-wave observing run. *Astrophys. J.*, 964(2):149, Mar 2024. DOI:10.3847/1538-4357/ad1eed.

[2] Abbott, R. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). Search for gravitational-wave transients associated with magnetar bursts in Advanced LIGO and Advanced Virgo data from the third observing run. *Astrophys. J.*, 966(1):137, Apr 2024. DOI:10.3847/1538-4357/ad27d3.

[3] Watarai, D. *et al.*. Physically consistent gravitational waveform for capturing beyond general relativity effects in the compact object merger phase. *Phys. Rev. D*, 109(8):084058, Apr 2024. DOI:10.1103/PhysRevD.109.084058.

[4] Abac, A. G. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). Observation of gravitational waves from the coalescence of a 2.5–4.5 $m_\odot$ compact object and a neutron star. *Astrophys. J. Lett.*, 970(2):L34, Jul 2024. DOI:10.3847/2041-8213/ad5beb.

[5] Abbott, R. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). Search for gravitational-lensing signatures in the full third observing run of the LIGO-Virgo network. *Astrophys. J.*, 970(2):191, Jul 2024. DOI:10.3847/1538-4357/ad3e83.

[6] Abac, A. G. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). Ultralight vector dark matter search using data from the KAGRA O3GK run. *Phys. Rev.*, D110(4):042001, Aug 2024. DOI:10.1103/PhysRevD.110.042001.

[7] Abac, A. G. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). Search for eccentric black hole coalescences during the third observing run of LIGO and Virgo. *Astrophys. J.*, 973(2):132, Sep 2024. DOI:10.3847/1538-4357/ad65ce.

[8] Abac, A. G. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). A search using GEO600 for gravitational waves coincident with fast radio bursts from SGR 1935+2154. *Astrophys. J.*, 977(2):255, Dec 2024. DOI:10.3847/1538-4357/ad8de0.

[9] Watarai, D. *et al.*. Ringdown of a postinnermost stable circular orbit of a rapidly spinning black hole: Mass ratio dependence of higher harmonic quasinormal mode excitation. *Phys. Rev. D*, 110(12):124029, Dec 2024. DOI:10.1103/PhysRevD.110.124029.

[10] Harada, R. *et al.*. Testability of the quark-hadron transition using gravitational waves from merging binary neutron stars. *Phys. Rev. D*, 110(12):123005, Dec 2024. DOI:10.1103/PhysRevD.110.123005.

[11] Raman, G. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration and KAGRA Collaboration). Swift-BAT GUANO follow-up of gravitational-wave triggers in the third LIGO-Virgo-KAGRA observing run. *Astrophys. J.*, 980(2):207, Feb 2025. DOI:10.3847/1538-4357/ad9749.

[12] Chan, J. C. L. *et al.*. Detectability of lensed gravitational waves in matched-filtering searches. *Phys. Rev. D*, 111(8):084019, Apr 2025. DOI:10.1103/PhysRevD.111.084019.

(Dissertations)

[13] Imafuku, H. On Constraining Scalar-Tensor Polarization of Gravitational Waves via Observations of Compact Object Collisions (Master's Thesis).

[14] Kuwahara, S. Construction of a Novel Foreground Subtraction Method by Jointly Estimating Multicomponent Isotropic and Anisotropic Stochastic Gravitational-Wave Backgrounds (Doctoral Thesis).

Presentations — Talks and Posters

(International Conferences)

[15] (contributed poster) R. Harada, "Estimation of the Hubble parameter from compact object catalogues without threshold". LIGO-Virgo-KAGRA Conference, Pullman Melbourne Albert Park Hotel, Australia, Mar 2024.

[16] (contributed poster) S. Garg, "Machine Learning model for fast GW template generation". LIGO-Virgo-KAGRA Meeting, Melbourne, Australia, Mar 2025.

[17] (contributed poster) R. Harada, "Estimation of the Hubble constant from compact object catalogues without threshold". Gravitational Wave Physics and Astronomy Workshop (GWPAW 2024), The University of Birmingham, United Kingdom, May 2024.

[18] (contributed poster) R. Harada, "Estimation of the Hubble parameter from compact object catalogues without threshold". KAGRA F2F, Tokyo City University, Japan, Aug 2024.

[19] (invited talk) K. Cannon, "Compact Objects Searches". KAGRA F2F — Early Career Scientist Satellite Meeting, Tokyo City University, Japan, Aug 2024.

[20] (contributed poster) S. Garg, "Low-latency GW Template Bank Generation using Machine Learning". LIGO-Virgo-KAGRA Meeting, Barcelona, Spain, Sep 2024.

[21] (contributed talk) S. Garg, "GW Waveform Generation using Machine Learning". RESCEU Summer School, The University of Tokyo, Sep 2024.

[22] (contributed talk) L. Alvin, "The Current Status and Future of Targeted Sub-threshold searches for Strongly Lensed Gravitational Waves", 33rd Workshop on General Relativity and Gravitation in Japan, Kindai University, Osaka, Japan, Dec 2024.

[23] (contributed poster) R. Harada, "Estimation of the Hubble parameter from compact object catalogues without threshold". KAGRA F2F, The University of Tokyo, Japan, Dec 2024.

[24] (contributed talk) S. Garg, "Fast GW Waveform generation using Machine Learning", 33rd Workshop on General Relativity and Gravitation in Japan, Kindai University, Osaka, Japan, Dec 2024.

[25] (invited talk) K. Cannon, "Selection Effects in Gravitational-Wave Observations". Theories of Astrophysical Big Bangs 2025, RIKEN, Saitama, Japan, Feb 2025.

(Domestic Conference)

[26] (invited talk) K. Cannon, "Activities and Outlook of the RESCEU Group", Grant-in-Aid for Transformative Research Areas (A), "Multimessenger Astrophysics": The second annual conference, Minakami, Japan, Nov 2024.

(Seminars)

[27] S. Garg, "Machine Learning for Gravitational-Wave Astrophysics". RESCEU Semianr, University of Tokyo, Japan, Jun 2024.

[28] S. Garg, "Research Showcase: Machine Learning for Gravitational Waves". University of Tokyo Open House, University of Tokyo, Japan, Jul 2024.

[29] S. Garg, "On Eccentric Compact Binaries", Eccentric Seminar, Tokyo City University, Japan, Aug 2024.

[30] K. Cannon, "Information Field Theory". RESCEU Semianr, University of Tokyo, Japan, Dec 2024.

[31] S. Garg, "Fast Gravitational Wave approximants generation using Machine Learning models". Fudan University (Cosimo Bambi Group), Shanghai, China, May 2025.

(Public Talks and Outreach)

[32] K. Cannon, "Science-y in Space". Space Cafe, Shimokitazawa, Tokoyo, Apr 2024.

7 茂山俊和研究室

7.1 Research activities

Our laboratory explores transient celestial phenomena and the role of these phenomena in the entire history of the universe by constructing theoretical models. More specifically, we investigate phenomena associated with supernovae and stellar mergers. We will explain the achievements published in the fiscal year 2024 in the following.

7.1.1 Theoretical model for the remnant of a supernova generated by white dwarf merger

A strong stellar wind was discovered from an object that appears to be the result of the merger of a white dwarf composed of oxygen and neon and a slightly lighter white dwarf composed of carbon and oxygen, and a model to explain the observations was constructed with Kazumi Kashiyama and Kotaro Fujisawa in 2019. Recently, X-rays were observed from an extended region surrounding the stellar wind of that object and from a central point-like region. It was also pointed out that this object can be linked to a supernova that exploded in 1181, which is recorded in the Azuma Kagami. We modeled the X-ray emission from the broad region by assuming that the X-rays are emitted from the shock wave generated by the collision of the supernova ejecta with the interstellar medium, and the point-like X-rays are emitted from the shock wave generated by the stellar wind hitting the supernova from the inside. To test the predictions of the model for the emission, we are attempting to observe the object covering multiple wavelengths from radio to x-rays.[6, 8, 9, 14, 11, 16, 1, 2]

7.1.2 Stationary accretion flows with nuclear burning onto compact objects

We construct spherically symmetric models of stationary trans-sonic accretion flows composed of pure helium onto compact objects taking into account the effects of energy from nuclear burning. We found that there are critical accretion rates above which the flow truncates at a finite distance from the compact object where the velocity of the supersonic flow becomes equal to the local sound speed again. [18]

7.1.3 Mass eruption from massive stars

Some massive stars that undergo a gravitational collapse supernova are thought to suddenly brighten a few years before the explosion and eject a large amount of their outer layers. We have developed a phenomenological model of this brightening. This year, in order to pursue the physical cause of this phenomenon, we are investigating the pulsation in the carbon burning stage.[15, 21]

Particularly, we have conducted evolutionary hydrodynamic simulations of red supergiants with initial masses of 13–18 solar masses by using an open-source code Mesa (Modules for Experiments in Stellar Astrophysics). We clarified that more massive red supergiants more likely experience rapid growth of radial pulsations, followed by possible mass ejection. This finding could explain the apparent lack of luminous red supergiants in type IIP supernova progenitor sample (known as the red supergiant problem). [13, 20]

7.1.4 Numerical modelings of interaction-powered transients

Several classed of supernovae and related transients show “interaction signature” indicting that the ejected matter collides with slowly expanding matter ahead of them (circumstellar material; CSM). We have been developing a multi-dimensional radiation-hydrodynamics code for modeling interaction-powered transients. In this year, we have conducted simulations of an exploding red supergiant with disk-like CSM, aiming at explaining observed properties of the nearby hydrogen-rich supernova SN 2023ixf. [12, 17] We also collaborate with groups working on observational studies of supernovae for revealing the origin of supernovae interacting with hydrogen-rich CSM (type IIn). [4]

7.1.5 Numerical modelings of jet-powered transients

X-ray and gamma-ray transient survey missions have revealed several classes of high-energy transient phenomena, including gamma-ray bursts, X-ray flashes, and others. Relativistic jets are believed to play a critical role in the high-energy emission from these phenomena. For example, the gravitational collapse of massive stars is sometimes accompanied by a gamma-ray burst or a fast X-ray transient, which is also potential source of high-energy neutrinos. Recently launched missions such as Einstein Probe and SVOM are efficiently detecting and localizing gamma-ray and X-ray transients, and are expected to significantly increase the available sample size. We have been investigating such jet-powered transients through a series of three-dimensional special-relativistic hydrodynamic simulations combined with semi-analytic light curve models. [3, 24, 22]

7.1.6 Observational studies of young galaxies

One of the members (AS) is involved in the Subaru telescope intensive program, "Extremely Metal-Poor Representative Explored by the Subaru Survey (EMPRESS)" (PI: Prof. Masami Ouchi). As a part of the program, we have been investigating young galaxies at various redshift. In this year, we analyzed galaxies with strong high-ionization lines arising from He and Ne ions. The spectral analysis can put constraints on the ionizing photon source that produces such high-ionization lines. We concluded that the spectra of our sample are consistent with galaxies harboring intermediate-mass black holes with $M_{\rm bh} \sim 10^3$–10^5 solar masses. [5]

7.2 業績リスト

報文

(原著論文)

[1] Ko, T., Suzuki, H., Kashiyama, K., et al. 2024, Astrophys. J. , 969, 2, 116. doi:10.3847/1538-4357/ad4d99

[2] Ko, T., Tsuna, D., Hatsukade, B., et al. 2024, Publ. Astron. Soc. Japan, 76, 3, 475. doi:10.1093/pasj/psae023

[3] Suzuki, A., Irwin, C. M., & Maeda, K. 2024, Publ. Astron. Soc. Japan, 76, 4, 863. doi:10.1093/pasj/psae055

[4] Hiramatsu, D., Matsumoto, T., Berger, E., Ransome, C., Villar, V. A., Gomez, S., Cendes, Y., De, K., Bostroem, K. A., Farah, J., Howell, D. A., McCully, C., Newsome, M., Padilla Gonzalez, E., Pellegrino, C., Suzuki, A., Terreran, G. 2024, Astrophys. J. , 964, 2, 181. doi:10.3847/1538-4357/ad2854

[5] Hatano, S., Ouchi, M., Umeda, H., Nakajima, K., Kawaguchi, T., Isobe, Y., Aoyama, S., Watanabe, K., Harikane, Y., Kusakabe, H., Matsumoto, A., Moriya, T. J., Nishigaki, M., Ono, Y., Onodera, M., Sugahara, Y., Suzuki, A., Xu, Y., Zhang, Y. 2024, Astrophys. J. , 966, 2, 170. doi:10.3847/1538-4357/ad335c

学術講演

(国際会議)

一般講演

[6] Takatoshi Ko, "The multi-layer structure of SNR 1181 with a white dwarf in its center", 2024/8: The Progenitors of Supernovae and their Explosions, Dali (talk)

[7] Takatoshi Ko, "The features of interaction-powered supernovae explored by binary population synthesis", 2024/8: IAU General Assembly 2024 Focus Meeting 4 "Bridging the final stages of massive stars to supernovae and transients", Cape Town (talk)

[8] Takatoshi Ko, "The structure of a historical supernova 1181 remnant and a white dwarf in its center", 2024/7: 23rd European Workshop on White Dwarfs, Barcelona

[9] Takatoshi Ko, "The multi-layer structure of SNR 1181 with a white dwarf in its center", 2024/6: Supernova Remnants III: An Odyssey in Space after Stellar Death, Chania (poster)

[10] Takatoshi Ko, "Fast winds blowing from a white dwarf left by the historical supernova 1181 and its X-ray emission", 2024/6: The X-ray Mysteries of Neutron Stars and White Dwarfs, Madrid (poster)

[11] Takatoshi Ko, et al., "The newest unidentified historical supernova SN 1181 with a peculiar white dwarf", 2024/1: East Asian Young Astronomers Meeting 2024 (EAYAM2024), Chiang Mai (talk)

[12] Akihiro Suzuki, "Multi-dimensional simulations of interaction-powered supernovae", 2024/6: Supernova Remnants III: An Odyssey in Space after Stellar Death, Chania (poster)

[13] Akihiro Suzuki, "Radial pulsation instability in massive red supergiants during carbon shell burning and implications to hydrogen-rich supernovae", 2025/2: Theories of Astrophysical Big Bangs 2025, Saitama, Japan (poster)

招待講演

[14] Takatoshi Ko, “A Dynamical Model for the Remnant of Type Iax SN 1181 and a Massive White Dwarf in its Center”, 2025/1, Astro Seminar, Monash University

(国内会議)

[15] 茂山俊和, ” 大質量星の Shell Burning の不安定性とその後の進化”, 超新星ミーティング@福井, 福井県あわら市清風荘, 2024 年 10 月

日本天文学会 2024 年秋季年会、関西学院大学、2023/9/11-13

[16] 黄天鋭, 津名大地, 廿日出文洋, 茂山俊和, ” 白色矮星を残した超新星爆発 SN 1181 の残骸からの電波放射とその観測提案”, 2024 年 9 月 12 日, N21a

[17] 鈴木昭宏, ” 円盤状星周物質と相互作用する II 型超新星の 2 次元輻射流体力学シミュレーション”, 2024 年 9 月 13 日, N31a

[18] 茂山俊和, 土肥明, “球対称降着流における熱核反応の役割 II ―ヘリウム降着―”, 2024 年 9 月 13 日, N32a

日本天文学会 2025 年春季年会、水戸市民会館、2025/3/17-20

[19] 黄天鋭, 衣川智弥, 津名大地, 平井遼介, 武井勇樹, ” 連星種族合成計算で明かす Ibn 型超新星爆発の姿”, 2025 年 3 月 18 日, N29a

[20] 鈴木昭宏, 茂山俊和, ” 炭素殻燃焼時の大質量赤色超巨星の動径振動と超新星爆発への示唆”,2025 年 3 月 18 日, N32a

[21] 加藤数麻, 津名大地, 茂山俊和, ” 長い増光時間を持つ IIn 超新星の星周物質形成機構”, 2025 年 3 月 18 日, N40a

一般講演

[22] 鈴木昭宏, “GRB jets colliding with massive circumstellar materials and associated electromagnetic transients”, 2024/6/8, Exploring Extreme Transients: Emerging Frontiers and Challenges, 京都大学基礎物理学研究所

招待講演

[23] 鈴木昭宏, “重力崩壊型超新星からの初期電磁波放射”、2025/3/3, 第 11 回超新星ニュートリノ研究会, 東京大学駒場キャンパス

(セミナー)

[24] 鈴木昭宏、“GRB jets colliding with massive circumstellar materials and associated electromagnetic transients”、2024/7/8、東北大学天文学教室談話会、宮城県仙台市

(アウトリーチ)

8 仏坂健太研究室

8.1 研究活動報告

当研究室は、白色矮星、中性子星、ブラックホールなどのコンパクト天体に関する宇宙物理学を理論的に研究しています。特にコンパクト連星からの重力波やそれらに付随する電磁波放射に関する研究を観測グループと連携して行っています。

8.1.1 連星中性子星

中性子星合体と状態方程式

中性子星の内部状態は、宇宙物理学における大きな謎の一つである。特に、高密度領域では核物質から QCD 物質への相転移が起こることが期待されている。連星中性子星合体において、合体後に大質量中性子星が形成される場合、中心領域は QCD 相転移が起こるような高密度に達すると考えられている。我々は、連星中性子星合体の重力波から QCD 相転移の性質を検証できる可能性を調べた [3]。また異なる QCD 相転移の性質を反映した複数の状態方程式で数値相対論シミュレーションを行い、合体のダイナミクスに現れる QCD 相転移の影響を調べた [7]。その結果、1 次相転移の場合とクロスオーバーの場合で、大質量中性子星の寿命の連星質量に対する依存性が大きく異なることを示した。具体的には、クロスオーバーの場合は、質量に応じて徐々に寿命が減少するのに対して、1 次相転移の場合はある質量で急激に変化することが明らかになった。これは、合体直後の中心密度が 1 次相転移領域に達した場合、急激に状態方程式が柔らかくなることに起因する。このような違いは、例えば降着円盤の質量などと強く相関するため将来の電磁波対応天体の観測によって検証できる可能性があることを示した。

キロノバの研究

キロノバは連星中性子星合体に付随する電磁波対応天体の一つであり、合体時に放出された中性子過剰物質の放射性崩壊によって輝く現象である。この現象は特に重元素の起源に関連するという重要性がある。我々はキロノバに関する観測・理論の両目から研究を行った。[5, 6]。

キロノバ の研究における重要な課題の一つは、観測される分光データから原子による吸収線や輝線を特定し、エジェクタの熱力学的な状態や組成を明らかにすることである。しかし、正確な原子データが不足しているため、原子データの整備を行い、輻射輸送シミュレーションなどを用いることでどのような性質が分光データに現れるのかを確かめる必要がある。我々は、Te, Gd, Th のイオンによる観測的性質を理論的に調べた。

電波対応天体の研究

中性子星合体は非相対論的なキロノバエジェクタだけなく、相対論的なジェットも駆動する。このジェットと星間物質の間に形成された衝撃波によって加速された非熱的な電子によって放射されるシンクロトロン光が電波から X 線まで幅広い波長で観測される。我々はこのシンクロトロン放射に関する研究を行い、数年から数 10 年程度ほど明るいキロノバ残骸の電波による観測可能性を議論した [4]。特に、合体後に準安定な大質量中性子星が一定の回転エネルギーをエジェクタの運動エネルギーに変換された場合は、電波で非常に明るくなるため、現在の電波サーベイ観測によって検出可能であることを示した。

中性子星合体を用いた重力パリティ対称性の検証

一般相対論を超えた重力理論では，パリティの破れが生じうる。連星合体からの重力波の偏波の情報を用いることで、このような理論を検証することが可能であるが、連星ブラックホール合体では、連星の軌道面の向きを重力波以外の方法で決定できないために検証に限界がある。そこで我々は、ジェットが付随する中性子星合体では、残光の超光速度運動から連星の軌道面を決定できるという性質利用して、新しい重力パリティ対称性の検証方法を提案した [2]。

8.1.2 大質量星の爆発に伴うショックブレイクアウトとジェットの研究

大質量星が爆発する際に、衝撃波が星表面を突き破る瞬間に光が放射される。この現象はショックブレイクアウトと呼ばれる。ショックブレイクアウトの性質は、星の質量、半径、爆発エネルギー、衝撃波の速度などに依存する。我々は、ショックブレイクアウトの理論研究やジェットが駆動するような爆発現象に関する研究を行った [8, 10, 18, 19, 20]。

8.1.3 恒星・ブラックホール連星の探査

恒星とブラックホールからなる連星は、これまで主に質量交換をする X 線連星として発見されおり、現在数１０天体が報告されている。しかし、質量交換は特定の条件が揃った場合のみ生じる現象であり、広い連星パラメータの中でも限られた領域のものに

限定される。そこで我々は、系外惑星探査衛星 TESS の測光観測サーベイデータから伴星にブラックホールを持つ天体に特徴的な変光を検出することで質量交換を伴わない恒星・ブラックホール連星を発見することを目指してデータ解析を行っている。これまで、重い白色矮星を伴星に持つ恒星を複数発見することに成功した。[16, 17]

8.1.4 中性子星の磁場

中性子星の初期磁場の分布やその時間発展はよく理解されていない。パルサーのような磁場 10^{12}G が典型的で、マグネターような強磁場を持つ中性子星は滅多に生まれないのか？なぜマグネターの磁場は速く減衰するのか？などの問題がある。我々は、銀河系内で観測されている中性子星を統一的に扱うことで、中性子星の初期磁場分布や磁場の時間発展の経験則を求める研究を行なっている [9]。

8.1.5 レプトジェネシス

初期宇宙におけるバリオン非対称性の生成機構は、宇宙論および素粒子物理学おける未解決問題である。この最も有力なメカニズムとして、右巻きニュートリノを介してレプトン数が生成されるレプトジェネシスが知られている。我々は、レプトジェネシが起こる時期に、大振幅の音波が存在した場合に最終的に生成されるレプトン数がどのような変更を受けるかを調べた [21]。

8.2 業績リスト

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(原著論文)

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(会議抄録)

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(著書)

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(国際会議)

一般講演

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招待講演

(セミナー)

9 道村唯太研究室

9.1 Research activities

The Michimura Group is a new RESCEU research group established in 2024. We experimentally study gravity through both the development of the large-scale cryogenic gravitational wave telescope KAGRA, and various related tabletop experiments. In fiscal year 2024, we made significant progress in formulating the upgrade plan for KAGRA and in developing in-vacuum photodiodes to reduce scattered light noise. We also published the first results of a B–L dark matter search using KAGRA data from the observing run in 2020 as a LIGO-Virgo-KAGRA Collaboration paper. Furthermore, we successfully demonstrated a sensitivity enhancement method for the tabletop axion search experiment DANCE using a wavelength tunable laser.

In fiscal year 2024, our project researcher Haoyu Wang was appointed as a Research Assistant Professor at Institute of Science Tokyo.

9.1.1 KAGRA detector developments

KAGRA is a cryogenic laser interferometric gravitational wave detector with 3 km arms, constructed underground in Kamioka, Gifu. KAGRA suffered significant damage in the Noto Peninsula earthquake in January 2024, including the detachment of magnets used to control the interferometer mirrors. However, the detector was restored by October 2024, and by March 2025, we achieved approximately a three-fold improvement in sensitivity compared to the performance before the earthquake. In June 2025, KAGRA achieved a sensitivity approximately five times higher, corresponding to a binary neutron star range of about 7 Mpc, and rejoined the LIGO-Virgo-KAGRA observing run O4.

We are participating in the commissioning efforts for improving KAGRA's sensitivity and have been evaluating the impact of inhomogeneous birefringence of the sapphire mirrors on interferometer control. In particular, we developed a new method to reconstruct the birefringence map of KAGRA's sapphire mirrors using the results of transmitted wavefront error measurements, and demonstrated the method by comparing it with in-situ measurements at the KAGRA site [3]. In addition, during this fiscal year we calibrated the polarization optics used to monitor the birefringence and adjusted the signal conditioning in preparation to long term observations.

In addition, we have been working on formulating upgrade plans for KAGRA in preparation for the next observing run O5 and beyond. As for the O5 upgrade, our group is responsible for developing in-vacuum photodiodes, which are necessary for reducing scattered light noise, and this fiscal year we have worked on the development of their enclosures. Furthermore, we have prepared the KAGRA Instrument Science White Paper 2024, which reviews technologies potentially applicable to KAGRA upgrades and summarizes the required R&D items. As a member of the KAGRA O5 Task Force, we have contributed to the evaluation of various upgrade plans and led the formulation of a high frequency upgrade strategy to focus on neutron star physics.

9.1.2 Laser interferometric dark matter searches

Using the precision optical metrology employed in KAGRA, it is possible to search not only for gravitational waves but also for ultralight dark matter. For example, by utilizing the polarization optics installed in KAGRA, we can probe the tiny rotation of laser polarization caused by interactions between axion dark matter and photons. In fact, since KAGRA resumed observations in June 2025, it has been conducting, for the first time as a gravitational wave detector, simultaneous observations of both gravitational waves and axions.

By utilizing KAGRA, the world's only gravitational wave detector that employs both fused silica and sapphire mirrors, it is also possible to search for B–L vector dark matter. If B–L vector dark matter exists, it exerts periodic forces of different amplitudes on the silica and sapphire mirrors, leading to changes in KAGRA's auxiliary interferometer signals. In fact, using auxiliary data from KAGRA's observation in 2020, we conducted the first search for B–L vector dark matter and successfully set upper limits [4]. This paper became the first LIGO-Virgo-KAGRA Collaboration paper based solely on KAGRA data. Our limits were orders of magnitude less stringent than those from previous experiments. Nevertheless, this study demonstrates the feasibility of using auxiliary channels of gravitational wave detectors like KAGRA for astrophysical observations.

We are also conducting tabletop experiments for axion dark matter searches. In the DANCE (Dark matter Axion search with riNg Cavity Experiment) project, which we proposed and are conducting, a bowtie optical ring cavity is used to perform broadband axion searches. Previously, the sensitivity in the low-mass region was degraded due to the phase difference between polarizations upon reflection of the cavity mirrors. By utilizing the wavelength dependence of this phase difference, we proposed and successfully demonstrated a method to adjust it using a wavelength-tunable laser.

9.1.3 Optomechanical experiments

We are also pursuing optomechanical experiments that utilize the interaction between milligram-scale mirrors and light to test the quantum nature of macroscopic objects and of gravity.

Towards optical levitation experiments, where mirrors are supported solely by the radiation pressure of light, we are collaborating with Laboratoire des Matériaux Avancés (LMA) in France on the development of milligram-scale mirrors. In June 2024, a laser cutting machine was newly installed at LMA, and we have been developing a method to cut 25 um-thick high-reflectivity-coated fused silica substrates into 3 mm-diameter mirrors.

Also, in collaboration with Institute of Science Tokyo, we successfully demonstrated a method to enhance the optical spring via the Kerr effect by introducing a nonlinear crystal into an optical cavity [6]. Optical springs are used for signal amplification in gravitational-wave detectors and in optomechanical experiments, and their enhancement leads to improved sensitivity in a wide range of optical precision measurements.

9.2 List of Achievements

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(Refereed Publications)

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Presentations

(International Conferences)

Contributed

[14] Yuta Michimura, "KAGRA high-frequency upgrade for neutron star physics," Theories of Astrophysical Big Bangs 2025, RIKEN Wako, February 2025 (poster)

[15] Yuta Michimura, "Updates from UTokyo on QFilter activities," The Post-QFilter QFilter Workshop, LKB, Paris, September 2024

[16] Yuta Michimura, "Future Strategy of KAGRA," The 33rd KAGRA Face-to-Face meeting, Tokyo City University, August 2024

Invited

[17] Yuta Michimura. "Laser interferometric searches for signatures of dark matter and quantum gravity," QUPosium2024, Tsukuba, December 2024

[18] Yuta Michimura, "First results from ultralight vector dark matter search with KAGRA," 29th International Symposium on Particles, String and Cosmology, Quy Nhon, Vietnam, July 2024

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Contributed

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