*Research Center for the Early Universe*

*Graduate School of Science*

*University of Tokyo*

# Annual Report

# 2019

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

I am pleased to deliver the annual report of Research Center for the Early Universe (RESCEU) for the fiscal year of 2019 (from April 2019 to March 2020).

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 now we have three major projects including (1) Evolution of the universe and cosmic structures (led by Prof. Jun'ichi Yokoyama), (2) Gravitational-wave astrophysics and experimental gravity (led by Prof. Kipp Cannon), and (3) Formation and characterization of planetary systems (led by myself). 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.

During March 27 to 29, 2019, we organized and hosted the RESCEU symposium "From Protoplanetary Disks through Planetary System Architecture to Planetary Atmospheres and Habitability". This symposium was intended to bring together scientists from a broad range of research topics such as planetary atmospheres, habitability, and planet formation and evolution, aiming for the participants to share current understanding regarding such important topics for the extra-solar and solar-system planets.

The visiting professors and researchers of RESCEU include Prof. Alexei Starobinsky (Landau Institute for Theoretical Physics, from late November to December, 2019).

We are happy to report that many new members joined RESCEU in the fiscal year of 2019. Dr. Kenta Hotokezaka joined RESCEU as an associate professor starting on September 16, 2019. Dr. Kotaro Fujisawa and Dr. Haruki Nishino joined RESCEU as a project assistant professor starting on April 1, 2019, and Dr. Yuji Chinone also as a project assistant professor starting on October 1. In addition, Dr. Yusuke Yamada and Dr. Tatsuya Matsumoto joined RESCEU as a post-doctoral fellow starting on April 1, 2019.

Finally we are pleased to announce the awards for our RESCEU members. Dr. Kazumi Kashiyama, our assistant professor, received the 31th young astronomer award from Astronomical Society of Japan in March 2020. We would like to congratulate him for his wonderful achievement.

August 2020

Director Yasushi Suto

# 目 次

# 1 Members

**RESCEU members**

| | |
|---|---|
| Yasushi Suto [須藤靖] | Director |
| Jun'ichi Yokoyama [横山順一] | Professor |
| Kipp Cannon | Professor |
| Toshikazu Shigeyama [茂山俊和] | Professor |
| Kenta Hotokezaka [仏坂健太] | Associate Professor (2019/9/16 –) |
| Masamune Oguri [大栗真宗] | Assistant Professor |
| Kazumi Kashiyama [樫山和己] | Assistant Professor |
| Kohei Kamada [鎌田耕平] | Assistant Professor |
| Atsushi Nishizawa [西澤篤志] | Assistant Professor |
| Takuma Suda [須田拓馬] | Project Assistant Professor (– 2019/5/31) |
| Toyokazu Sekiguchi [関口豊和] | Project Assistant Professor (– 2019/9/30) |
| Yuu Niino [新納悠] | Project Assistant Professor |
| Kotaro Fujisawa [藤澤幸太郎] | Project Assistant Professor (2019/4/1 –) |
| Haruki Nishino [西野玄記] | Project Assistant Professor (2019/4/1 –) |
| Yuji Chinone [茅根 裕司] | Project Assistant Professor (2019/10/1 –) |
| Ayako Ishii [石井彩子] | Postdoctoral Fellow (– 2019/9/30) |
| Koh Ueno [上野昂] | Postdoctoral Fellow |
| Kazuhiro Kanagawa [金川和弘] | Postdoctoral Fellow |
| Yusuke Yamada [山田悠介] | Postdoctoral Fellow (2019/4/1 –) |
| Tatsuya Matsumoto [松本達矢] | Postdoctoral Fellow (2019/4/1 –) |
| Yi-Peng Wu | Research Fellow (–2019/9/13) |
| Heather Fong | Research Fellow |
| Sayuri Nagano [永野早百合] | Secretary |
| Chiyo Ueda [上田千代] | Secretary |
| Reiko Sugiyama [杉山礼子] | Secretary |

**RESCEU affiliates**

| | |
|---|---|
| Naoki Yoshida [吉田直紀] | Professor, Dept. of Physics |
| Tomonori Totani [戸谷友則] | Professor, Dept. of Astronomy |
| Mamoru Doi [土居守] | Professor, Institute of Astronomy |
| Kotaro Kohno [河野孝太郎] | Professor, Institute of Astronomy |
| Motohide Tamura [田村元秀] | Professor, Dept. of Astronomy |
| Seiji Sugita [杉田精司] | Professor, Dept. of Earth and Planetary Science |
| Eiichi Tajika [田近英一] | Professor, Dept. of Earth and Planetary Science |
| Satoshi Yamamoto [山本智] | Professor, Dept. of Physics |
| 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 |
| Masahiro Ikoma [生駒大洋] | Associate Professor, Dept. of Earth and Planetary Science |
| Hajime Kawahara [河原創] | Assistant Professor, Dept. of Earth and Planetary Science |

# 2 Projects

### Project 1. Evolution of the universe and cosmic structures

| Name | Research thema |
|---|---|
| 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 |
| Aya Bamba | Chemical evolution of the universe with supernova remnant study |
| Kazuhiro Shimasaku | Galaxy Formation and Evolution |
| Akito Kusaka | Observational cosmology using cosmic microwave background |
| Masamune Oguri | Unveiling the nature of dark matter and dark energy |
| Kohei Kamada | Particle cosmology |
| Kazumi Kashiyama | Evolution of compact objects and time domain astronomy |

### Project 2. Gravitational-wave astrophysics and experimental gravity

| Name | Research thema |
|---|---|
| Kipp Cannon | Detection and interpretation of gravitational waves emitted by the collisions of compact objects |
| Kenta Hotokezaka | Multi-messanger astrophysics of compact binary mergers |
| Mamoru Doi | Identifications of gravitational-wave sources by wide-field and multi-color optical observations |
| Kotaro Kohno | Radio/submm follow up of candidate sources of gravitational waves |
| Masaki Ando | Gravitational-Wave Experiment and Astrophysics |

### Project 3. Formation and characterization of planetary systems

| Name | Research thema |
|---|---|
| Yasushi Suto | Dynamical evolution of orbit and angular momentum of exoplanetary systems |
| Motohide Tamura | Exoplanet observations and instrumentations |
| Seiji Sugita | An asteroid sample-return mission and feasibility study for an exoplanet observation satellite |
| Satoshi Yamamoto | Physics and chemistry of protoplanetary disk formation |
| Eiichi Tajika | Diversity and evolution of habitable planets |
| Masahiro Ikoma | Diversity and origins of exoplanetary atmospheres |
| Hajime Kawahara | Exploring instrumentation and methods for characterizing exoplanets |

# 3 Symposia and Meetings

## 3.1 Planet$^2$ / RESCEU Summer School

**Place:** Kakunodate Onsen Kayokan, Semboku city, Akita, Japan
**Time:** 2019/8/23 (Fri) – 2019/8/26 (Mon)

**Program**

**8/23 (Fri)**

| | | |
|---|---|---|
| 14:00–14:10 | Yasushi Suto | Opening remark |
| 14:10–15:10 | (L) Tanmay Vachaspati | Primordial magnetic fields (1) |
| 15:10–15:20 | Break | |
| 15:20–16:20 | (L) Konstantin Batygin | Core nucleated accretion theory of giant planet formation |
| 16:20–16:30 | Break | |
| 16:30–17:00 | Erik Petigura | Formation and Erosion of Small Planet Cores and Envelopes |
| 17:00–17:15 | Hiroto Mitani | Photoevaporation of Exoplanet Atmosphere |
| 17:15–17:30 | Shijie Wang | Planetary migration and accretion effect on the long-term orbital stability of a multi-planetary system: case of HL Tau |
| 17:30–17:45 | Gianni Cataldi | Gaseous debris disks |
| 17:45–18:00 | Masataka Aizawa | Systematic study of alignment of disk orientations in nearby star-forming regions |

**8/24 (Sat) morning**

| | | |
|---|---|---|
| 09:00–10:00 | (L) Konstantin Batygin | Angular momentum evolution of giant planets and the hot Jupiter radius inflation problem |
| 10:00–10:10 | Break | |
| 10:10–11:10 | (L) Tanmay Vachaspati | Primordial magnetic fields (2) |
| 11:10–11:20 | Break | |
| 11:20–11:35 | Kazuhiro Kanagawa | Effects of dust feedback on evolutions of a protoplanetary disk and a giant planet |
| 11:35–11:50 | Yuta Tarumi | R-process enrichment of Ultra-Faint Dwarf galaxies |
| 11:50–12:05 | Hiroaki Tahara | Angular stability condition for static and spherically symmetric spacetime |
| 12:05–12:20 | Soichiro Hashiba | Dark matter and baryon-number generation in quintessential inflation via hierarchical right-handed neutrinos |

**8/24 (Sat) afternoon**

| | | |
|---|---|---|
| 13:35–14:35 | (L) Konstantin Batygin | Chaos and long-term dynamical evolution of planetary systems |
| 14:35–14:45 | Break | |
| 14:45–15:00 | Ayako Ishii | Radiative Transfer Simulation for Early Emission from Binary Neutron Star Merger |
| 15:00–15:15 | Naoto Kuriyama | Eruptive mass loss from progenitors of type Ibn/IIn Supernovae |
| 15:15–15:30 | Conor Omand | Radio and Submillimetre Constraints on the Pulsar-Driven Supernova Model |
| 15:30–15:45 | Break | |
| 15:45–16:00 | Yi-Peng Wu | Black hole mass function from peaks of primordial density perturbations |
| 16:00–16:15 | Takumi Hayashi | Thermal effect of blackhole on Higgs instability |
| 16:15–16:30 | Heather Fong | Searching for compact binaries using gravitational waves |
| 16:30–16:45 | Atsushi Nishizawa | All-sky distribution of stellar-mass binary black-hole mergers |
| 16:45–17:00 | Break | |
| 17:00–18:00 | (L) Patrick Brady | Cosmic collisions - progress and prospects for gravitational-wave astronomy (1) |

**8/25 (Sun)**

| | | |
|---|---|---|
| 09:00–10:00 | (L) Tanmay Vachaspati | Cosmic Strings |
| 10:00–10:10 | Break | |
| 10:10–11:10 | (L) Patrick Brady | Cosmic collisions - progress and prospects for gravitational-wave astronomy (2) |
| 11:10–11:20 | Break | |
| 11:20–11:35 | Haoxiang Lin | Off-Axis Very-High-Energy Afterglows from Binary Neutron Star Mergers |
| 11:35–11:50 | Soichiro Morisaki | Prompt and accurate sky localization of gravitational-wave sources |
| 11:50–12:05 | Takuya Tsutsui | Rough rapid localization of GW source |
| 12:05–12:20 | Junya Kume | Application of independent component analysis to KAGRA data |
| 12:20–12:35 | Hiroaki Oota | Modelling Selection Biases in Searches for Gravitational Waves from Compact Object Collisions |
| 12:35– | Free discussion | |

**8/26 (Mon)**

| | | |
|---|---|---|
| 09:00–10:00 | (L) Patrick Brady | Cosmic collisions - progress and prospects for gravitational-wave astronomy (3) |
| 10:00–10:10 | Break | |
| 10:10–10:25 | Daichi Tsuna | Emission from Galactic Isolated Black Holes and Their Detectability |
| 10:25–10:40 | Toshinori Hayashi | A strategy to search for an inner binary black hole from the motion of the tertiary star |
| 10:40–10:55 | Saku Iwata | The diversity of young neutron stars determined by fallback accretion onto and energy deposition from the central object in supernova |
| 10:55–11:10 | Takahiro Sudoh | TeV Mysteries : coming solutions from HAWC |
| 11:10–11:25 | Break | |
| 11:25–11:40 | Kana Moriwaki | The cross-power spectrum between 21-cm and metal line emitters during early cosmic reionisation |
| 11:40–11:55 | Minxi He | Rotation and Formation Threshold of Primordial Black Holes |
| 11:55–12:10 | Takashi Hiramatsu | Parasitic higher winding strings in Abelian-Higgs model |
| 12:10–12:20 | Toshikazu Shigeyama | Closing |

## 3.2 Planet2 / RESCEU Symposium 2019 From Protoplanetary Disks through Planetary System Architecture to Planetary Atmospheres and Habitability

**Place:** Bankoku Shinryokan, Okinawa, Japan
**Time:** 2019/10/14 (Mon) – 2019/10/18 (Fri)

**Program**

**Session 1 10/15 Tue 8:50-10:30 Lower atmosphere (Chair: A. Fukui)**

| | | |
|---|---|---|
| 08:50–08:55 | Yasushi SUTO | Welcome address |
| 08:55–09:00 | Masahiro IKOMA | Goal of the conference |
| 09:00–09:30 | Jean-Michel DESERT | Characterizing Exoplanets' Atmospheres to Unveil Planetary Origins and Climate |
| 09:30–10:00 | Vivien PARMENTIER | Understanding the Diversity of Exo-atmospheres, From Hot to Ultra-hot Jupiters |
| 10:00–10:15 | Kazumasa OHNO | Clouds of Fluffy-Aggregates: How They Form in Exoplanetary Atmospheres and Influence Transmission Spectra |
| 10:15–10:30 | Kensuke NAKAJIMA | Effect of Cloud Formation on the Structure and Transport Properties in Planetary Atmospheres |

**Session 2 10/15 Tue 11:00-12:30 Lower atmosphere (Chair: H. Kawahara)**

| | | |
|---|---|---|
| 11:00–11:30 | Ingo WALDMAN | Understanding Atmospheric Retrievals with Machine Learning |
| 11:30–11:45 | Yui KAWASHIMA | Effect of Disequilibrium Chemistry on the Spectra of Exoplanet Atmospheres |
| 11:45–12:15 | Jeremy LECONTE | When retrieving 3D atmospheres with 1D algorithms goes south! |
| 12:15–12:30 | Takeshi KURODA | Simulation of the Water Environment on the Present and Past Mars Using a Global Climate Model |

**Session 3 15 Tue 14:00-15:30 Upper atmosphere and escape (Chair: D. Ehrenreich)**

| | | |
|---|---|---|
| 14:00–14:30 | Enric PALLE Ultra | Hot Jupiter Atmospheres and Atmospheric Escape |
| 14:30–14:45 | Guo CHEN | A Peek View of Irradiated Atmospheres with Alkali Lines at Low- and High-resolution |
| 14:45–15:00 | Stevanus K. NUGROHO | Probing the Atmosphere of Ultra Hot Jupiters using High-resolution Spectroscopy |
| 15:00–15:15 | Kiyoe KAWAUCHI | Studies of Very Hot Jupiter Atmosphere with High Resolution Transmission Spectroscopy |
| 15:15–15:30 | Nuria CASASAYASBARRIS | Atmospheric Characterisation of the Ultra Hot Jupiter MASCARA-2b/KELT-20b Combining HARPS-N and CARMENES Observations |

**Session 4 10/15 Tue 16:00-17:30 Upper atmosphere and escape (Chair: K. Seki)**

| | | |
|---|---|---|
| 16:00–16:30 | Shingo KAMEDA | WSO-UV/UVSPEX for Earth-like Exoplanets |
| 16:30–16:45 | Julia Victoria SEIDEL | Wind of Change: Revealing Thermospheres of Exoplanets from Highresolution Spectroscopy |
| 16:45–17:00 | Leonardo DOS SANTOS | An Extensive Search for Metallic Ions in the Exosphere of GJ 436 b |
| 17:00–17:15 | John LIVINGSTON | GJ9827: Mass Constraints of a Benchmark System from Spitzer Transit Timing Measurements |
| 17:15–17:30 | Ilaria CARLEO | GJ9827 b: Constraints on Atmospheric Loss Using HST Data |
| 17:30–19:00 | Poster Session | |

**Session 5 10/16 Wed 9:00-10:30 Upper atmosphere and escape (Chair: M. Ikoma)**

| | | |
|---|---|---|
| 09:00–9:30 | Colin JOHNSTONE | The Aeronomy of Terrestrial Planetary Atmospheres around Active Stars |
| 09:30–09:45 | Naoki TERADA | DSMC Simulation of Slow Hydrodynamic Escape from Earth-like Exoplanets |
| 09:45–10:15 | Kanako SEKI | Atmospheric Escape from Mars and Its Relation to Habitability |
| 10:15–10:30 | Shotaro SAKAI | Effects of a Weak Intrinsic Magnetic Field on Atmospheric Escape from Mars |

**Session 6 10/16 Wed 11:00-12:30 Climate and Habitability (Chair: J. Leconte)**

| | | |
|---|---|---|
| 11:00–11:30 | Jun YANG | Transition from Eyeball to Snowball Driven by Sea-ice Drift on Tidally Locked Terrestrial Planets |
| 11:30–12:00 | Ravi KOPPARAPU | Atmospheric Characterization of Habitable Worlds in The Next Decade and Beyond (via ZOOM) |
| 12:00–12:15 | Masaki ISHIWATARI | Numerical Experiments on Climate of Land Planets Using an Atmospheric General Circulation Model |
| 12:15–12:30 | Tiziano ZINGALES | Deep Convolutional Neural Networks to Better Understand Exoplanets |

**Session 7 10/17 Thu 9:00-10:30 Evolution, Tectonics, & Climate (Chair: M. Ikoma)**

| | | |
|---|---|---|
| 09:00–09:30 | Masaki OGAWA | A Numerical Model of Evolution of the Wet Mantle Caused by Magmatism and Mantle Convection: Implication for the Surface Environment of Mars |
| 09:30–10:00 | Diana VALENCIA | Tectonics and Climates of Super-Earths |
| 10:00–10:15 | Yuichi ITO | Photo-evaporation of Mineral Atmosphere from Hot Rocky Exoplanets |
| 10:15–10:30 | Martin TURBET | The Runaway Greenhouse Radius Inflation Effect and Observational Impacts |

**Session 8 10/17 Thu 11:00-12:30 Disk & Delivery (Chair: Y. Suto)**

| | | |
|---|---|---|
| 11:00–11:30 | Ruobing DONG | Observational Planet Formation |
| 11:30–12:00 | Shogo TACHIBANA | Hayabusa2: Sample Return Mission from C-type Asteroid Ryugu |
| 12:00–12:15 | Takahiro UEDA | Formation of the Building Blocks of the Terrestrial Planets at the Deadzone Inner Edge |
| 12:15–12:30 | Yuhiko AOYAMA | Theoretical Modeling of Spectral Profile from the Two Protoplanets PDS70b and c |

**Session 9 10/17 Thu 14:00-15:30 Planet Formation (Chair: Y. Hori)**

| | | |
|---|---|---|
| 14:00–14:30 | André IZIDORO | Water Delivery and Terrestrial Planet Formation |
| 14:30–15:00 | Shigeru IDA | Rocky Planetesimal Formation and Volatile Delivery to the Earth During Pebble Accretion |
| 15:00–15:15 | Nader HAGHIGHIPOUR | Accurate and Quantitative Modeling of the Formation of Terrestrial Planet and the Origin of Earth's Water |
| 15:15–15:30 | Mohamad ALI-DIB | Limit to Protoplanet Growth by Accretion of Small Solids |

**Session 10 10/17 Thu 16:00-17:30 Planet Formation (Chair: T. Guillot)**

| | | |
|---|---|---|
| 16:00–16:30 | Nikku MADHUSUDHAN | Constraints on Planet Formation Mechanisms from Exoplanetary Spectroscopy |
| 16:30–16:45 | Kazuhiro KANAGAWA | Termination of an Inward Migration of a Gap-opening Planet due to the Dust Feedback |
| 16:45–17:00 | Shangfei LIU | The formation of Jupiter's Diluted Core by a Giant Impact |
| 17:00–17:10 | Yuki TANAKA | Possibility of Giant Planet Formation by Pebble Accretion in Class 0/I Phases |

**Session 11 10/18 Fri 9:00-10:25 Planetary System Architecture (Chair: K. Kanagawa)**

| | | |
|---|---|---|
| 09:00–09:20 | Yasushi SUTO | Spin-orbit Architecture of Planetary Systems |
| 09:20–09:35 | Shu-ichiro INUTSUKA | An Origin of Misaligned Planets: Angular Momentum Accretion in Star Formation Process |
| 09:35–09:50 | Eiichiro KOKUBO | Orbital Architecture of Planetary Systems Formed by Gravitational Scattering and Collision |
| 09:50–10:05 | Matthieu LANEUVILLE | Observational Strategies to Answer Exoplanet Population Questions |
| 10:05–10:25 | Hajime KAWAHARA | Transiting Planets near the Snow Line |

**Session 12 10/18 Fri 10:40-12:40 Future Prospects (Chair: M. Ikoma)**

| | | |
|---|---|---|
| 10:40–11:10 | Monika LENDL | Observing Exoplanet Atmospheres with CHEOPS |
| 11:10–11:25 | Norio NARITA | MuSCAT 1 to 3 for a global multi-color transit photometry network |
| 11:25–11:55 | Giovanna TINETTI | ARIEL |
| 11:55–12:10 | Billy EDWARDS | The Ariel Mission Reference Sample |
| 12:10–12:40 | Tristan GUILLOT | Lessons from Juno & Cassini: linking atmosphere and interior of Jupiter and Saturn & SUMMARY |

**Poster Session**

| | | |
|---|---|---|
| 1 | Ryoya SAKATA | Effects of an intrinsic magnetic field on the ion loss from ancient Mars |
| 2 | Takahito SAKAUE | Stellar atmosphere and wind model for cool main-sequence stars |
| 3 | Tadahiro KIMURA | Effects of water vapor contamination on accumulation of primordial atmospheres of terrestrial planets |
| 4 | Yuki MORI | Study of proton escape from Mars based on MAVEN observations |
| 5 | Kotaro SAKAKURA | Composition of the ion escape from Mars: Polar plume observations by MAVEN |
| 6 | Shungo KOYAMA | Stability of atmospheric redox states of Mars-like planets inferred from time response of the regulation of H and O losses |
| 7 | Tatsuya YOSHIDA | Hydrodynamic escape of a reduced Martian proto-atmosphere |
| 8 | Yasunori HORI | Do the TRAPPIST-1 Planets Have Hydrogen-rich Atmospheres? |
| 9 | Quentin CHANGEAT | Towards a more complex description of chemical profiles in exoplanet retrievals: A 2-layer parameterisation |
| 10 | Kai Hou | YIP Integrating light-curve and atmospheric modelling of transiting exoplanets |
| 11 | Adam JAZIRI | Photochemistry of planetary atmospheres with 3D Global Climate Model |
| 12 | Konstantinos KALOGERAKIS | Understanding the OH Meinel Band Emissions in Planetary Atmospheres |
| 13 | Monika STANGRET | FeI and FeII in the atmosphere of MASCARA-2b/KELT-20b |
| 14 | Rafael LUQUE | GJ 357: a planetary trio including a transiting, hot, Earth-sized planet optimal for atmospheric characterization |
| 15 | Mayuko MORI | Ground-based Transmission Spectroscopy of the Atmosphere of TRAPPIST-1g |
| 16 | Yuka TERADA | Multi-band observations of the transiting warm Jupiter WASP-80b with MuSCAT/MuSCAT2 |
| 17 | Felipe MURGAS | Stellar spots versus Rayleigh scattering: the case of HAT-P-11b |
| 18 | Akihiko FUKUI | A New Approach to Find Planets around the Snow Line: Galactic-disk Microlensing |
| 19 | Akifumi NAKAYAMA | Geochemical carbon cycle and climate of ocean terrestrial planets in the habitable zone |
| 20 | Sarah MCINTYRE | Planetary magnetism as a parameter in exoplanet habitability |
| 21 | Yuta NAKAGAWA | Obliquity of an earth-like exoplanet from frequency modulation of its directly imaged light curves: analysis of the GCM data for the Earth |
| 22 | Riouhei NAKATANI | Radiation Hydrodynamics Simulations of Photoevaporating Protoplanetary Disks: Metallicity Dependence |

| | | |
|---|---|---|
| 23 | Seongjoong KIM | Deriving the dust properties using the synthetic ALMA multiband analysis |
| 24 | Chenen WEI | Comparing the complex organic molecules in protoplanetary disks with comet 67P/C-G |
| 25 | Sheng JIN | New constraints on the dust and gas distribution in the LkCa 15 disk |
| 26 | Daisuke TAKAISHI | Star-disk alignment in the protoplanetary disks: SPH simulation of the collapse of turbulent molecular cloud cores |
| 27 | Hideko NOMURA | Modelling Infrared Line Spectra of Complex Organic Molecules in Protoplanetary Disks |
| 28 | Masanobu KUNITOMO | Dispersal of Protoplanetary Disks with Magnetically-driven and Photoevaporative Winds |
| 29 | Stuart TAYLOR | Unexpected Peak-Gap-Peak Shape of the Main Pileup of the LogPeriods of Planets of Metal-Rich Sunlike Single Stars and its Influence on Correlations of Eccentricity with Five Parameters |
| 30 | Natalia ENGLER | The VIBES Exoplanet Survey with SPHERE |
| 31 | Jerome DE LEON | Systematic search for young planets in nearby clusters with TESS |
| 32 | Yuting LU | Systematic comparison of photometric and asteroseismic rotation periods of 33 Kepler stars with transiting planets |
| 33 | Toshinori HAYASHI | A strategy to search for an inner binary black hole from the motion of the tertiary star |
| 34 | Kenji KUROSAKI | Giant impact on a rotating planet: Implication of the origin of the Uranus's obliquity |
| 35 | Takehiro MIYAGOSHI | Thermal convection with adiabatic compression and its applications to mantle convection in super-Earths |
| 36 | Cong YU | In Situ Formation of Super-Earths in Dispersing Protoplanetary Disk |
| 37 | Yuji MATSUMOTO | Formation of Close-in Super-Earths by Giant Impacts around M dwarfs: Effects of Planet Ejection |
| 38 | Yuhito SHIBAIKE | Formation of the Galilean satellites by pebble accretion |
| 39 | Ngan NGUYEN | The effect of disc instabilities on migrating planets |
| 40 | Mayuko OZAWA | Study of solid accretion in mean motion resonances with gas giants via N-body simulations: Toward understanding the formation of Uranus and Neptune |
| 41 | Shijie WANG | Effects of Planetary migration on the long-term orbital stability of a multi- planetary system: case of HL Tau |
| 42 | Su WANG | Formation and Stability of Planetary systems in Mean Motion Resonances |
| 43 | Gang ZHAO | Planetesimal Dynamics in Inclined Binary Systems |
| 44 | Masahiro MORIKAWA | Variety of Planets from the Outer-Edge of the Inner Hole |

# 4 RESCEU colloquia

- Toshiki Sato (RIKEN)
  "The Origin of the X-ray Clumpy Ejecta in Type Ia Supernova Remnants"
  April 04, 2019, 13:30-14:30

- Eiichiro Komatsu (Director of Max Planck Institute for Astrophysics)
  "Non-Gaussian gravitational waves from inflation"
  April 18, 2019, 16:00-17:00

- Renyue Cen (Princeton University)
  "Computing the Universe: from Intergalactic to Interstellar Medium"
  May 30, 2019, 16:45-17:45

- Manami Sasaki (Dr. Karl Remeis Observatory, Bamberg, Friedrich-Alexander-University Erlangen-Nurnberg)
  "The eROSITA View of Stellar Endpoints"
  August 27, 2019, 13:00-14:00

- Kenneth C. Wong (Kavli IPMU)
  "A 2.4% Measurement of H0 from Lensed Quasars"
  September 26, 2019, 13:30-14:30

- Richard Shaw (University of Liverpool)
  "Probing Dark Energy with CHIME"
  October 23, 2019, 13:30-14:30

- Joseph Gelfand (NYU Abu Dhabi)
  "The Extreme Physics of Pulsar Wind Nebulae"
  December 19, 2019, 13:30-14:30

# 5 Project 1. Evolution of the universe and cosmic structures

## 5.1 Activity Report

This project aims at clarifying the origin and evolution of both matters and structures of the Universe based on theoretical and observational studies. It covers physics of the early universe including but not limited to inflation, cosmological phase transition, formation and evolution of density perturbation, as well as formation and evolution of the hierarchical structure of the universe, namely, stars, galaxies, and clusters of galaxies in terms of numerical simulations and optical and X-ray observations. Cosmic microwave background radiation and gravitational waves are also important probe of the Universe and are actively investigated in this project. These studies not only clarifies the evolution of our Universe but also provide us with invaluable informations on the nature of dark matter and dark energy. Below are some highlights of the FY2019.

### 5.1.1 Inflationary cosmology

We studied inflationary cosmology, especially focusing on the generation of matter and radiation after inflation, which includes the generation of stochastic gravitational waves as well as the primordial black holes (PBHs). On the generation of matter, we studied the gravitationally produced right-handed neutrinos as well as the chiral gravitational waves, which results in the baryon asymmetry of the Universe. We identified in which case the scenarios can be responsible for our Universe. On the PBHs, we have improved the techiniques of the estimates of their abundance, by taking into account the effect of angular velocity as well as by adopting the peak theory. We also considered the reheating mechanism of a specific but well-motivated inflation model, that is, Higgs-$R^2$ mixed model. The reheating process in this model is quite non-trivial, but some characteristics are identified. (Yokoyama, Kamada)

### 5.1.2 Origin of life in an inflationary universe

Emergence of life was considered in the cosmological context, especially an inflationary universe. The real size of the homogeneous universe should be much larger than the observable universe (including $10^{22}$ stars), and likely includes more than $10^{100}$ stars. It was shown that an RNA molecule longer than 40–100 nucleotides can be formed somewhere in such a large volume only by random reactions of adding monomers. Therefore, there is a reasonable path of emergence of life in an inflationary universe, though the expected number of abiogenesis events may be much smaller than unity within our observable universe. (Totani)

### 5.1.3 Modified Gravity

We studied theories of modified gravity, such as supergravity in higher dimension and Horndesky theory. One of the remarkable achivements is the discovery of the anisotropic attractor solution in the Horndesky theory in the higher dimension, which can be used for the compactification of the extra dimension so that our four dimensional space time is realized. We also identified the stability condition for the parity-even mode in the phase direction in the Horndesky theory around the spherical symmetric configuration. (Yokoyama, Kamada)

### 5.1.4 Statistical Computational Astrophysics

We applied a modern deep-learning method called Generative Adversarial Network to image analysis of intensity maps. In particular, we devised a set of deep neural networks that can extract designated signals from data from intensity mapping observations such as NASA's SPHEREx. We trained the networks by using 30,000 mock galaxy distribution maps generated by a publicly available code PINOCCHIO that populates dark matter halos in a large cosmological volume. Galaxies are assigned to the dark halos by assuming an emipirical relation between the luminosity of a galaxy and the host halo mass. The trained networks successfully extract galaxies at redshift 1.3 from intensity maps that are confused with another signal from redshift 2.0. We continue our study by considering detector noises of SPHEREx, and by utilizing multi-line observations with a set of frequency bins. (Yoshida)

### 5.1.5 Cosmic shear cosmology with the Subaru Hyper Suprime-Cam first-year data

We obtained cosmological constraints from the cosmic shear power spectrum analysis with the Subaru Hyper Suprime-Cam (HSC) survey first-year data covering 137 deg$^2$ of the sky. From a tomographic analysis of cosmic shear with galaxies brighter then 24.5 mag and at the redshift range $0.3 < z < 1.5$, we derived one of the tightest constraints on the amplitude of the matter power spectrum obtained so far. Specifically, assuming a flat $\Lambda$ cold dark matter model, we obtained $S_8 \equiv \sigma_8(\Omega_{\rm m}/0.3)^{0.45} = 0.800^{+0.029}_{-0.028}$. While our result is consistent with the Planck cosmic microwave background result within $2\sigma$ level, the slightly lower $S_8$ found in the HSC survey as well as in other competing surveys such as Dark Energy Survey and Kilo-Degree Survey hints the possibility of a tension between the early and late Universe. (Oguri)

### 5.1.6 High redshift galaxies

We examine the galaxy-IGM connection at $z \sim 2.5$ using hydrodynamical galaxy formation simulations and observations. The simulations show that more massive galaxies have a stronger spatial correlation with the IGM HI, while no significant correlation is seen in the observed data. The observations show a large variation in the galaxy-IGM correlation among galaxy populations, suggesting complicated physics that determines the IGM environment of galaxies. We develop a new method to search for the cores of proto-clusters that uses a pair of massive galaxies as tracers of cores. We then successfully apply this method to the COSMOS field, finding 75 core candidates at $z = 1.5 - 3$. We find that galaxies in cores have a more top-heavy stellar mass function and a higher quiescent fraction compared with field galaxies, implying that cluster environment has already influenced galaxy evolution as early as $z \sim 2$. (Shimasaku)

### 5.1.7 Astrophysical transients: their origins and consequences

The following topics were studied on this topic.

- Binary neutron star mergers in faint dwarf spheroidal galaxies (Shigeyama)
- Optical emission immediately after binary neutron star mergers (Shigeyama)
- Start of survey observations with Tomo-e Gozen camera mounted on the KISO Schmidt telescope (Shigeyama; Doi, M.)
- Observations of the early light from type Ia supernovae (Shigeyama; Doi, M.)
- Influence of Pop III supernova explosions on the companion stars (Shigeyama)
- Rapidly rotating massive white dwarfs as a result of binary white dwarf mergers (Kashiyama, Fujisawa, Shigeyama)
- Emission of type IIn supernovae (Shigeyama, Tsuna, Kashiyama, Takei)
- Eruptive mass loss from a massive star a few years before the core collapse (Shigeyama, Kuriyama)

- Rotational equilibria on the 2D Lagrange coordinates (Fujisawa)
- The W4 method: a new multi-dimensional root-finding scheme for nonlinear systems of equations (Fujisawa)

where the names of researchers are listed in the parentheses.

### 5.1.8 Fast radio bursts and binary neutron star mergers

We constructed a new model of nonthermal afterglow emission from binary neutron star (BNS) mergers, in which a more realistic electron energy distribution is incorporated than previous studies. As a result, we obtained a qualitativley different best-fit solution of the jet model to GW 170817. Using this model, detectability of radio afterglows in the locations of past fast radio bursts (FRBs) was estimated, as a test of the scenario that a fraction of FRBs are generated by BNS mergers. A new model of the Galactic halo component for dispersion measures of extragalactic sources was constructed, in light of the latest diffuse X-ray background data. This will be useful for future FRB studies. (Totani)

### 5.1.9 X-ray study of energetic astrophysical objects

The universe looks quiet and cold world at a glance, but actually it is a quite hot and energetic world. The targets of our group are such high energy phenomena in the universe. Understandings of the origin of heavy elements and cosmic rays is one of our main goals.

This year, we have made several achievements. From the supernova remnant expansion measurements, we found that the uniformity of expansion has variety among samples. We also showed that accelerated particles on the shocks of supernova remnants escape into the space as the shocks age. Black holes distort the time-space by general relativity, This year, we also succeeded to include the general relativity into the Monte-Carlo simulation tool called MONACO and enable to make realistic emission models for the accreted matter onto black holes. For the next-generation observations, we develope a new generation X-ray satellite called XRISM, planned to launch on Japanese fiscal year of 2021, and charges the science magegement of galactic diffuse sources and softwares. We also study on future missions to measure the X-ray polarimetory, using CMOS sensors and coded apertures, named as "cipher". The design concept got the grand prix on the 27th satellite design contest. (Bamba)

### 5.1.10 Observational cosmology using cosmic microwave background

Observational cosmology using Cosmic Microwave Background (CMB) is being studied mainly with the Polarbear, Simons Array, and Simons Observatory experiments.

The Polarbear experiment and its successor, Simons Array, are designed to measure both inflationary signature and the gravitational lensing effect in CMB polarization. Polarbear has concluded its observation campaign and we analyzed the data. We achieved a measurement of the gravitational lensing deflection power spectrum reconstructed with the CMB polarization data. We also published the first measurement of cross-correlation between the lensing potential reconstructed from the CMB polarization data, and the cosmic shear field from galaxy shapes by Subaru Hyper Suprime-Cam data. Using the same CMB polarization data, we measured $B$-mode polarization delensing on subdegree scales at more than $5\sigma$ significance, achieving the highest to date for internal delensing.

The Simons Array experiment is about to be deployed. The first upgraded receiver cryostat arrived at the site in Chile at the end of 2018, and we started test observations in 2019. We have characterized and continually improved our instruments with the initial observation data. In parallel, we have been developing a data analysis pipeline for Simons Array.

The Simons Observatory experiment is scheduled for the first light in 2021. We plan to deploy three 0.4 m Small Aperture Telescopes (SATs), which are dedicated for the inflationary signal, and one 6 m Large Aperture Telescope (LAT), which will measure (or limit) the sum of neutrino masses, and the dark content of the universe. We have been primarily focusing on the design and development for the SAT instrument. We also focus on developing techniques for high-performance computation (HPC) enabling data analysis for Simons Observatory as well as Simons Array, producing order-of-magnitude larger data volume than the current instruments. (Kusaka, Kiuchi, Chinone, Nishino)

## 5.2 Publication List


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## 5.3 International Conference Talks

### 5.3.1 Contributed talks

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[84] S. Hashiba: "Gravitational particle creation for dark matter and reheating", Future Perspective in Cosmology and Gravity, Nagoya, Aichi, 2019/04/3.

[85] J. Kume, T. Sekiguchi, S. Morisaki, Y. Itoh and J. Yokoyama: "The effectiveness of Independent Component Analysis with iKAGRA data : continuous waves", KAGRA 22nd f2f meeting, ICRR, Kashiwa, Japan, 2019/4/19-21.

[86] Oguri M.: "HSC Catalogs", First HSC-eROSITA-DE joint collaboration meeting, Max Planck Institute for Extraterrestrial Physics, Garching, Germany (May 13–16, 2019)

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[89] Kojiro Kawana: "Emission from thermonuclear explosions in white dwarf TDEs" FOE19 Fifty-one Erg (Raleigh, United States of America, May 20 - 24, 2019)

[90] K. Kamada: "Baryon asymmetry from cosmological (hyper)magnetic fields", The Mysterious Universe: Dark Matter - Dark Energy - Cosmic Magnetic Fields, Mainz Institute for Theoretical Physics, Mainz, Germany, 2019/05/24.

[91] Y. P. Wu: "Leptogenesis from heavy Higgs relaxation", IAS program on particle theory, Hong Kong University of Science and Technology, Hong Kong, 2019/05/30.

[92] T. Kasuga, T. Sato, K. Mori, H. Yamaguchi, & A. Bamba: "Doppler Velocity Measurement of Fe Ejecta in Kepler's Supernova Remnant", "Supernova Remnants II: An Odyssey in Space after Stellar death", Minoa Palace Luxury Resort & Spa, Greece, 2019.06.03–2019.06.08 (talk)

[93] Conor M. Omand: "SubmillimetreConstraintsonthePulsar-DrivenSN Model", Supernova remnants II : An odyssey in space after stellar death (Chania, Crete, Greece, 3-8 June 2019)

[94] Hiromasa Suzuki, Aya Bamba, Hirokazu Odaka, Ryo Yamazaki, Hiroya Yamaguchi, Yutaka Ohira: "A systematic study on escaping of cosmic rays from SNR shocks through observations of thermal X-ray plasmas", Supernova Remnants II an odyssey in space after stellar death,3-8 June 2019, Chania, Crete, Greece (poster with 1 min oral)

[95] Tilman Hartwig: "Multiplicity of the first stars from machine learning-based classification of stellar fossils", EWASS, Lyon (June 20, 2019)

[96] Tilman Hartwig: "Under the Same Sky: Teaching the Teachers in Liberia", EWASS, Lyon (June 21, 2019)

[97] S. Hashiba: "Dark matter and baryon-number generation in quintessential inflation via hierarchical right-handed neutrinos", Beyond General Relativity, Beyond Cosmological Standard Model, Warsaw, Poland, 2019/07/2.

[98] Oguri M.: "Comparison of CAMIRA and XXL clusters: Selection bias and cluster astrophysics", Joint XXL-HSC meeting, Ovronnaz, Switzerland (July 4–5, 2019)

[99] Kojiro Kawana: "Emission from thermonuclear explosions in white dwarf TDEs", Workshop to bring together experts on High Energy Astrophysics from Japan and Israel (Saitama, Japan, July 18-23, 2019)

[100] S. Hashiba: "Dark matter and baryon-number generation in quintessential inflation via hierarchical right-handed neutrinos" (poster), COSMO19, Aachen, Germany, 2019/09/02-06.

[101] M. He: "Preheating in the Mixed Higgs-$R^2$ Model" (poster), COSMO19, Aachen, Germany, 2019/09/02-06.

[102] K. Kamada: "Affleck-Dine Magnetogenesis" (poster), COSMO19, Aachen, Germany, 2019/09/02-06.

[103] H. Tahara: "Angular stability of a static and spherically symmetric solution in the Horndeski theory", COSMO19, Aachen, Germany, 2019/09/04.

[104] Yusuke Yamada: "Horndeski model coupled to pure de Sitter supergravity", COSMO19, Aachen, Germany, 2019/09/04.

[105] T. Sekiguchi "Dynamics of axion strings and implications for axion dark matter", TAUP2019, Toyama, Japan, 2019/09/10.

[106] Tilman Hartwig: "Multiplicity of the first stars from machine learning-based classification of stellar fossils", Conference "CEMP Stars as Probes...", Geneva (September 10, 2019)

[107] Y. Wada, T. Enoto, K. Nakazawa, Y. Furuta, T. Yuasa, Y. Nakamura, T. Morimoto, T. Matsumoto, K. Makishima, H. Tsuchiya: "Downward Terrestrial Gamma-ray Flash Observed in a Winter Thunderstorm", The Cosmos at High Energies: Exploring Extreme Physics Through Novel Instrumentation, Kavli IPMU, Japan, October 2019 (poster)

[108] Tsubasa Tamba, Hirokazu Odaka, and Aya Bamba: "Xtend Pile-up Simulator", XRISM Xtend Meeting, Ehime University, 2019/10/8 (oral)

[109] J. Kume, T. Sekiguchi, Y. Itoh, S. Morisaki and J. Yokoyama: "Application of independent component analysis to KAGRA data", GWPAW 2019, University of Tokyo, Tokyo, Japan, 2019/10/16.

[110] T. Kasuga, T. Sato, K. Mori, H. Yamaguchi, & A. Bamba: "Doppler velocity measurement of Fe ejecta in type Ia SNRs", "The cosmos at high energies: exploring extreme physics through novel instrumentation", The University of Tokyo, Japan, 2019.10.16–2019.10.18 (poster)

[111] Tsubasa Tamba, Aya Bamba, Hirokazu Odaka, and Teruaki Enoto: "The hard-tail properties of the magnetar SGR 1900+14 unveiled by XMM-Newton and NuSTAR observations", The cosmos at high energies, Kavli IPMU, 2019/10/16–18 (poster)

[112] Tsubasa Tamba, Aya Bamba, Hirokazu Odaka, and Teruaki Enoto: "The hard-tail properties of the magnetar SGR 1900+14 unveiled by NuSTAR and XMM-Newton observations", The Future of X-ray Timing, University of Amsterdam, 2019/10/21–25 (oral)

[113] Hiromasa Suzuki (The university of Tokyo, Harvard-Smithsonian center for astrophysics): "An observational study on supply of cosmic rays by supernova remnants", The Japan-US Science Forum in Boston 2019, 2 November, 2019, Boston, USA (poster + 1 min oral)

[114] Taira Oogi: "Clustering and halo occupation of AGNs using a semi-analytic model of galaxy formation", The first Shanghai Assembly on Cosmology and Galaxy Formation (Shanghai, China, November 8, 2019)

[115] J. Yokoyama: "Dark matter and baryon number generation in quintessential inflation", 14th Asia Pacific Physics Conference, Kuching, Malaysia, 2019/11/19.

[116] M. He: "Formation Threshold of Rotating Primordial Black Holes", APPC2019, Kuching, Malaysia, 2019/11/20.

[117] J. Kristiano: "Coleman-De Luccia Tunneling Wave Function", APPC2019, Kuching, Malaysia, 2019/11/20.

[118] Naoki Yoshida: "Cosmological SImulations of Galaxy Formation", UTokyo-ENS Joint Workshop (University of Tokyo, November 25, 2019)

[119] S. Hashiba: "Gravitational production of right-handed neutrinos after quintessential inflation", The 29th Workshop on General Relativity and Gravitation in Japan (JGRG29), Kobe, Hyogo, 2019/11/26.

[120] M. He: "Formation threshold of rotating primordial black holes", The 29th Workshop on General Relativity and Gravitation in Japan (JGRG29), Kobe, Japan, 2019/11/27.

[121] Y. P. Wu: "Statistical bias for black hole mass functions from the inflationary power spectrum", APCTP School/Workshop on Gravitational-Wave Cosmology, Academia Sinica, Taiwan 2019/11/30.

[122] Yuji Chinone: "Constraints on primordial gravitational waves from POLARBEAR data and the cross-correlation of gravitational lensing with optical survey by the Subaru HSC," TeV Particle Astrophysics (TeVPA) 2019, Dec 2019, Sydney, Australia.

[123] Y. Wada, T. Enoto, Y. Nakamura, Y. Furuta, T. Yuasa, K. Nakazawa, T. Morimoto, M. Sato, T. Matsumoto, D. Yonetoku, T. Sawano, H. Sakai, M. Kamogawa, T. Ushio, K. Makishima, H. Tsuchiya: "Simultaneous detection of gamma-ray glow and downward terrestrial gamma-ray flash", AGU Fall Meeting, San Francisco, USA, December 2019 (talk)

[124] Hiromasa Suzuki, Paul P. Plucinsky, Terrance Gaetz, Aya Bamba: "Analysis of the ACIS Particle Background and Generation of Model Spectra", P124, 20 Years of Chandra Science Symposium, December 3-6, 2019, Boston, USA (poster)

[125] M. He: "Formation Threshold of Rotating Primordial Black Holes", Focus Weeks on PBHs, Kavli IPMU, University of Tokyo, Chiba, Japan, 2019/12/05.

[126] T. Kasuga, T. Sato, K. Mori, H. Yamaguchi, & A. Bamba: "Doppler Expansion Measurement of Heated Ejecta in Type Ia SNRs using Chandra", "20 Years of Chandra Science Symposium", Boston Park Plaza Hotel, USA, 2019.12.03–2019.12.06 (poster)

[127] Y. P. Wu: "Statistical bias for black hole mass functions from the inflationary power spectrum", Focus Week on Primordial Black Holes, IPMU, the University of Tokyo, Japan 2019/12/06.

[128] Taira Oogi: "Clustering and halo occupation of X-ray AGNs using a semi-analytic model", Galaxy Formation and Evolution Across the Cosmic Time (Taipei, Taiwan, December 9, 2019)

[129] Hiromasa Suzuki, Tsubasa Tamba, Hirokazu Odaka, Aya Bamba, Ayaki Takeda, Koji Mori, Takahiro Hida, Masataka Yukumoto, Yusuke Nishioka: "Development of the detector simulation framework for the Wideband Hybrid X-ray Imager onboard FORCE", 12th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, 14-18 December 2019, Hiroshima, Japan (oral)

[130] Kana Moriwaki: "Emission line as a tracer of ISM properties and the large-scale structure of the universe", The interstellar medium of high redshift galaxies (Sesto, Italy, January 13-17, 2020)

[131] Kojiro Kawana: “Emission from thermonuclear explosions in white dwarf TDEs”, Tidal Disruptions in Kyoto: Confronting Theory with Observations (Kyoto, Japan, January 14-16, 2020)

[132] Taira Oogi: “Semi-analytic modeling of AGNs: clustering and halo occupation”, HSC-AGN face-to-face meeting (Kyoto University, 1/23, 2020)

[133] K. Kamada: “ Magnetogenesis mechanisms for baryogenesis from hypermagnetic helicity decay”, Remnants of the Big Bang or TanmayFest2020, Arizona State University, AZ, USA, 2020/01/24.

[134] Kotaro Fujisawa, Hirotada Okawa, Misa Ogata, Yu Yamamoto,Shoichi Yamada, Nobutoshi Yasutake: “Rotational equilibria on the 2D Lagrange coordinates”, The Evolution of Massive Stars and Formation of Compact Stars: from the Cradle to the Grave (Waseda University, Japan, 2020, Feb. 26-28)

[135] Natsuki H. Hayatsu: “What is Darth Vader: the story and background”, Japan (March 2020)

### 5.3.2 Invited talks

[136] Naoki Yoshida: “Formation of the First Galaxies and Blackholes”, European Week of Astronomy and Astrophysics 2018 (Liverpool, UK, April 3-6, 2018)

[137] Naoki Yoshida: “Cosmology and Fundamental Physics with AI”, Information Search, Integration and Personalization 2019 (Crete, Greece, May 10, 2019)

[138] A. Bamba: “Observational study of Nonthermal phenomena on SNR shocks”, Supernova Remnants II: An Odyssey in Space after Stellar death, Crete, Greece, 2019, Jun. 3-8

[139] K. Kamada: “Baryon Asymmetry, Chiral Asymmetry, and the Magnetic Fields in the Universe”, 43rd John Hopkins Workshop, Kavli IPMU, University of Tokyo, Chiba, Japan, 2019/06/03.

[140] T. Sekiguchi: “Self-heating dark matter”, IDS workshop, University of Jyväskylä (Finland), 2019/06/06.

[141] K. Kamada: “Baryogenesis from cosmological magnetic fields and magnetogenesis”, 3rd NRF-JSPS Workshop in particle physics, cosmology, and gravitation, Okinawa, Japan, 2019/06/18.

[142] Kazumi Kashiyama: “Optically thick rotating magnetic wind from a massive white-dwarf merger product”, High Energy Astrophysics Japan Israel Workshop (Kobe, Japan, July 22, 2019)

[143] Naoki Yoshida: “Formation of the First Stars and Blackholes”, First Light (Sao Paulo, Brazil, August 2, 2019)

[144] Oguri M.: “New directions in strong lensing”, CosmoCruise 2019: From the Early to the Late Universe, Venice, Italy (August 18–25, 2019)

[145] Y. Wada, K. Nakazawa, K. Makishima, T. Hayashi, M. Ishida: “X-ray Views of the Dwarf Nova GK Persei”, The Golden Age of Cataclysmic Variables and Related Objects V, Mondello, Italy, September 2019

[146] Oguri M.: “Gravitational waves in the inhomogeneous Universe”, Cosmological Frontiers in Fundamental Physics 2019, Perimeter Institute for Theoretical Physics, Waterloo, Canada (September 3–6, 2019)

[147] A. Bamba: “Recent progress on X-ray study of supernova remnants as remnants of supernovae”, X-ray Astronomy 2019, Bologna, Italy, 2019 Sep. 8-13

[148] Kazumi Kashiyama: “White dwarf merger remnants and fast radio bursts”, YITP long-term workshop: Multi-Messenger Astrophysics in the Gravitational Wave Era (Kyoto, Japan, September 26, 2019)

[149] Totani, T.: “ Fast Radio Bursts, Neutron Star Mergers, Supernovae, ... and the Cosmological Constant”, the cosmos at high energies: exploring extreme physics through novel instrumentation, IPMU, Univ. of Tokyo, Kashiwa, Oct. 16-18, 2019,

[150] Naoki Yoshida: “Formation and Evolution of Stars”, ISYA2019 (Yunnan, China, October 17, 2019)

[151] Tomonori Totani: “GRBs as a reionization probe / Fast radio bursts from neutron star mergers”, Yokohama GRB 2019 workshop, Oct. 28-Nov. 1, 2019, Yokohama

[152] Shigeyama, Toshikazu: “Diversity of neutron stars determined by fallback in supernovae”, Collaborative Meeting on Supernova Remnants between Japan and USA (RIKEN and Kyoto University, Japan, 2019 November 7-12)

[153] A. Bamba: “Gender equality activities in astronomical society of Japan”, Astronomy for equality, diversity and inclusion, Tokyo, Japan, 2019 Nov.12-15

[154] Oguri M.: “SDSS, Gravitational Lensing, and Quasars”, Wide-Field Sky Survey of the Universe: From the Past to the Future of Astronomy, Univ. of Tokyo, Tokyo, Japan (November 13, 2019)

[155] K. Kamada: "Baryogenesis from Primordial Helical Hypermagnetic Fields", Baryon and Lepton Violation 2019, Institute for Theoretical Physics (IFT), Universidad Autónoma de Madrid, Madrid, Spain, 2019/10/22.

[156] Yusuke Yamada: "Nonlinearly realized supergravity and its applications", APPC2019, Kuching, Malaysia, 2019/11/20.

[157] J. Yokoyama: "Garvitational waves as a probe of the early universe", APCTP School/Workshop on Gravitational-wave cosmology, Academia Sinica (Taipei) 2019/11/30.

[158] Shigeyama, Toshikazu: "R-process element cosmic rays from neutron star mergers", JINA-CEE IReNA / NAOJ workshop (National Astronomical Observatory of Japan, Mitaka, Japan, 2019 December 3-4)

[159] Oguri M.: "Weak Lensing and Cluster Science with Subaru HSC-SSP Survey", Science with Subaru: An Indian Perspective, Tata Institute of Fundamental Research, Mumbai, India (December 18–20, 2019)

[160] Oguri M.: "Gravitational waves in the inhomogeneous Universe", Dark Odyssey 2020: Gravitational-Wave Probes of Dark Universe, Seoul National University, Seoul, South Korea (January 3–7, 2020)

[161] Naoki Yoshida: "Physics of the ISM", The interstellar medium of high redshift galaxies (Sest, Italy, January 16, 2020)

[162] K. Kamada: "Magnetic Fields in the Early Universe", KIAS and NRF-JSPS Workshop on Particle, String and Cosmology, High 1 resort, Korea, 2020/02/04.

[163] Tilman Hartwig: "Exploring new Frontiers with Gravitational Waves from Massive Black Holes", First Stars VI, Concepcion (2020/03/03)

[164] Oguri M., "Science with gravitationally lensed quasars", The blind search for hidden galaxies in an abundant line of sight, zoom (March 11–12, 2020)

[165] K. Kamada: "Magnetic Fields and Quantum Anomaly in the Early Universe", The 3rd Univ. Ryukyus International Symposium. of Theoretical and Computational Science (RIS-TCS 2020). -Frontier of Physics and Chemistry- (held as a virtual conference), University of the Ryukyus, Okinawa, Japan, 2020/03/20.

# 6 Project 2. Gravitational-wave astrophysics and experimental gravity

## 6.1 Activity Report

Our research group studies black holes, neutron stars, exotic astrophysical objects, and the Universe using gravitational waves. We do this together with other observational techniques, as well as exploring new detection methods. Gravitational waves are waves of spacetime 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 fundamentally different information about their sources than is carried by electromagnetic waves. Gravitational waves interact weakly with matter allowing them to propagate through material that would be opaque to electromagnetic energy. For example 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. Because everything is nearly transparent to gravitational waves they pass easily through any device one builds, making it difficult to detect this form of energy.

Our research group's members are members of the LSC and 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 being built in Japan. The Advanced LIGO and Advanced Virgo antennas began their third observational data-taking run, "O3", just before the start of this past academic year, and the observations continued throughout the 2019/2020 academic year. Aside from the improved sensitivity of the detectors, a notable change in this observation run is the release of public alerts from the low-latency detection systems, including the GstLAL detection system developed by members of our research group. Members of our group are active in all aspects of observational gravitational-wave astronomy, cosmology, and fundamental physics. The following are some highlights from FY2019.

### 6.1.1 Compact Objects

When heavy stars exhaust their fuel supply they undergo gravitational collapse. The end state of this process can be a neutron star or a black hole. There are many of these in the Universe, and occasionally they collide with one another. These collisions are very powerful sources of gravitational radiation. Since the first detection of gravitational waves from the collision of a pair of black holes in September, 2015, we have been able to study the behaviour of strongly curve spacetime.

This past academic year saw many new discoveries of black hole and neutron star collisions. Two of these are especially noteworthy. The gravitational wave signal GW190425 (doi:10.3847/2041-8213/ab75f5) appears to be the result of the collision of a pair of neutron star like objects. The signal was discovered by the GstLAL detection system developed by members of RESCEU, and it was only seen in a single GW detector. This was the first time a detection claim was published without confirmation from at least one other detector, marking a significant step forward in the maturity of the field, and the confidence placed in the detection software by the scientific community. A second remarkable discovery with the collision of an asymmetric mass system, GW190814, consisting of a 23 solar mass black hole and a 2.6 solar mass compact object of unknown composition (doi:10.3847/2041-8213/ab960f). This signal was discovered by the GstLAL detection system and created a puzzle: if the 2.6 solar mass object is a neutron star it would be extremely heavy and its existence could have significant implications for nuclear physics, whereas it is extremely light if it is a black hole since there are no mechanisms known for forming so small a black hole from stellar evolution.

This past academic year saw the first measurement of the Hubble parameter inferred from the redshift of gravitational waves from a black hole collision (doi:10.3847/2041-8213/ab14f1). The signal used for this analysis was GW170814, which was discovered by the GstLAL detection system, and was the first gravitational-wave signal detected by the Virgo antenna.

Following these detections, our group contributed to the interpretation of the signals, performing the parameter estimation. Because of the high event rate anticipated during the O3 run, members of our group have worked to automate the parameter estimation system, and this effort has been quite successful. In addition, improvements to the Monte Carlo sampling algorithms have been developed and are undergoing internal review that are expected to lead to an enormous performance improvement over the existing system.

Other on-going projects within our group include the development of techniques for removing signals from detector data for the purpose of constructing clean noise models, the development of an ultra high-speed sky mapping system suitable for use in early-warning detection systems, and the development of a system to estimate the sensitivity of a search for gravitational waves mathematically, replacing the current computationally costly technique of hiding fake signals in the data and searching for them with the detection software.

### 6.1.2 Cosmic strings

Cosmic strings are theoretical topological defect structures left over from the cooling process of the early Universe. Although none have been discovered, a broad spectrum of theories of fundamental physics predict their existence. Even if they exist, they might be so rare that none are present in the part of the Universe visible to us. Either way, searching for them and either confirming their existence or putting limits on their number will teach us a great deal about fundamental physics. Members of our group led the development of the LSC and Virgo Collaboration's cosmic string detection pipeline and are currently analyzing the data collected during the O3 observing run, searching for evidence of these signals using a new analysis system developed by RESCEU members. The new system is more computationally efficient than the previous system, and makes use of more sophisticated statistical analyses allowing it to make a confident detection claim should a signal ever be found in the future.

### 6.1.3 Stochastic Gravitational-wave Background

While some gravitational wave sources like GW170817 are close, loud, and infrequent, we also anticipate classes of gravitational wave sources that are distant, quiet, and numerous. Rather than distinct, impulsive, signals being detected from such sources we expect to observe them collectively as a diffuse "glow" of random gravitational radiation coming from all directions on the sky — a stochastic gravitational-wave background. Spacetime fluctuations in the very early Universe are expected to contribute to a cosmological gravitational-wave background, but that is expected to be undetectable with modern equipment. A detectable astrophysical stochastic background of gravitational radiation could come from more recent processes, for example black hole collisions in the early Universe, a population of cosmic strings, and so on. Many of the possible sources of a stochastic gravitational wave background are conjectural; their discovery would be a tremendous breakthrough. One possible source are clouds of bosonic particles condensed around spinning black holes. Such a cloud, if it exists, is expected to extract rotational energy from the hole via the super-radiant instability. This past year members of our group began a new search for gravitational waves generated by this mechanism using stochastic gravitational-wave detection techniques.

### 6.1.4 Kilonovae

We studied the heating rate of r-process nuclei and thermalization of decay products in neutron star merger ejecta and kilonova light curves. Thermalization of charged decay products, i.e., electrons, alpha-particles, and fission fragments, is calculated according to their injection energy. The gamma-ray thermalization processes are also properly calculated by taking the 粒-ray spectrum of each decay into account. We showed that the beta-decay heating rate at later times approaches a power-law decline as $t^{-2.8}$. We presented a new analytic model to calculate kilonova light curves, in which the density structure of the ejecta is accounted for. We demonstrate that the observed bolometric light curve and temperature evolution of the kilonova associated with GW170817 are reproduced well by the beta-decay heating rate with the solar r-process abundance pattern. We interpreted the break in the observed bolometric light curve around a week as a result of the diffusion wave crossing a significant part of the ejecta rather than a thermalization break. The code for computation of the heating rate and light curve for given initial nuclear abundances is publicly available.

### 6.1.5 Long-term radio flares

The jet opening angle and inclination of GW170817, the first neutron star merger, were vital to understand its energetics, relation to short gamma-ray bursts, and refinement of the standard siren-based determination of the Hubble constant. These basic quantities were determined through a combination of the radio light curve and Very Long Baseline Interferometry (VLBI) measurements of proper motion. In this paper we discusseed and quantifieed the prospects for the use of radio VLBI observations and observations of scintillation-induced variability to measure the source size and proper motion of merger afterglows, and thereby infer properties of the merger including inclination angle, opening angle and energetics. We showed that these techniques are complementary as they probe different parts of the circum-merger density/inclination angle parameter space and different periods of the temporal evolution of the afterglow. We also found that while VLBI observations will be limited to the very closest events it will be possible to detect scintillation for a large fraction of events beyond the range of current gravitational wave detectors. Scintillation will also be detectable with next generation telescopes such as the Square Kilometre Array, 2000 antenna Deep Synoptic Array and the next generation Very Large Array, for a large fraction of events detected with third generation gravitational wave detectors.

### 6.1.6 Test of gravity

Gravitational waves bring us a novel opportunity to probe for strong and dynamical aspects of gravity that had been difficult to be tested with other observational means. These new tests play a significantly important role for fundamental physics because we do not know whether general relativity is genuinely a correct theory of gravity in a strong and nonlinear regime of gravity or a dynamical regime at cosmological scales, where modification of Einstein's gravity may resolve the problem of the current accelerating expansion of the Universe or a curvature singularity at center of a black hole. One of such tests is to check the existence of GW polarizations predicted in general relativity and to search for additional polarizations such as scalar and vector modes. We have studied the mode separability for gravitational waves from compact binary coalescences, showing that a mixture of the polarization modes are separable with the same number of detectors as the number of the modes. We also show that the mode separation with smaller number of detectors is possible due to the long duration of a signal ($\gtrsim 1$ hour) and the time-evolving detector antenna patterns with the third-generation detectors such as Einstein Telescope or Cosmic Explorer, or by fixing a source direction by the observation of an electromagnetic counterpart. Another model-independent test of gravity with gravitational waves is to directly measure the properties of GW propagation. Based on the parametrized framework we proposed in 2017, we estimated the future sensitivity of gravitational wave observation to propagation speed, amplitude damping, and graviton mass, and found that stronger tests of gravity at cosmological scale is possible with gravitational waves in the future.

### 6.1.7 Population of binary black holes

The tens of binary black-hole mergers have been detected by advanced LIGO and advanced Virgo so far. Although there have been several astrophysical formation channels proposed for such stellar-mass black-hole binaries, their origin (dominant channel of formation) is unknown. To distinguish these astrophysical models, we need to measure the distributions of binary parameters (mass, spin, eccentricity, etc.) or properties of host galaxies (mass, star formation rate, spacial clustering, etc.). We have investigated a possible connection between black-hole binaries and host galaxies by computing a two-point angular correlation function or angular power spectrum and found that such association is measurable with hundreds of binary black-hole mergers. We also have studied angular correlations between black-hole binaries and gamma-ray bursts or supernovae, indicating that they provide complementary information about the binary evolution to the host-galaxy association.

### 6.1.8 People and Things

During the 2019 through 2020 academic year, our research group was joined by Dr. Kenta Hotokezaka, a new associate professor expertised on gravitational wave astronomy, and Ms. Minori Shikauchi, a Master's student who is studying the association of radio transients and compact object collisions. One of our doctoral students successfully defended his thesis, and Dr. Soichiro Morisaki has secured a research position at the University of Wisconsin-Milwaukee, where he will continue his work on the interpretation of gravitational-wave signals.

## 6.2 Affiliates

### Masaki Ando

Ando group is working on experimental research for gravitational-wave observation, in particular for large projects such as KAGRA and B-DECIGO. KAGRA is a gravitational-wave antenna at Kamioka, Gifu prefecture in Japan. We are playing a key role since conceptual study phase before the start of the project in 2010. The installation of main components has been finished in FY2018, and we are in the phase of commissioning; shakedown and tuning for the full operation of the interferometer. In FY2019, the KAGRA interferometer was operated in a power-recycled Fabry-Perot Michelson configuration for the first time, and started observation run. Our group members led this commissioning works and operation of the interferometer. We are also working on B-DECIGO, which is a space-borne gravitational wave antenna with observation band around 0.1 Hz. We made theoretical study on science cases by this mission as well as experimental development of critical subsystems, such as laser interferometer, stabilized laser source, drag-free system, and low-noise thruster. In FY2019, we made a system design study with company. This was the first intensive study to show the feasibility of the full mission, which was realized by financial support by RESCEU. In addition to these experimental work, we are also working on theoretical and data-analysis research. The motivation is to test the theory of gravity using polarization information of the observed gravitational-wave signal. We made estimations of test precisions using current and future gravitational-wave antennae.

### Mamoru Doi

Tomo-e Gozen is a wide-field optical camera with 84 2k $\times$ 1k CMOS sensors for the 1.05 m Kiso Schmidt telescope. The CMOS array enables us to take consecutive images with a frame rate of 2 fps covering an instantaneous field-of-view (FoV) of 20 deg$^2$. A scientific survey operation of Tomo-e Gozen started in October 2019.

With the wide FoV and the high-speed readout, we can survey a large area of sky repeatedly in one night. From October to December 2019, we have conducted 7000 deg$^2$ sky surveys above an elevation limit of 35 deg 3–5 times every night. Starting from January 2020, we have carried out a mixed survey with a single scan of the 7000 deg$^2$ sky and a frequent survey of a 2000 deg$^2$ sky area more than 10 times every night with intervals shorter than 1 hour. The obtained data have been processed with dedicated pipeline software which searches for transient/moving objects using machine learning techniques. More than 10 newly discovered near-Earth objects, and supernovae have been found so far.

The fiscal year of 2019 was also a period of the third observing run (O3) of gravitational wave (GW) detectors of the LIGO-Virgo Collaboration (LVC, the LIGO-Virgo-KAGRA Collaboration in later stages of O3). O3 started in April 2019 and stopped in March 2020 (originally scheduled to the end of April 2020, but interrupted by the COVID-19 outbreak), with a pause for 1 month in October 2019. Localization precisions of GW events are still as large as a few 100 deg$^2$ in most cases, and hence large FoV follow-ups of GW events by facilities of electromagnetic observations are required.

During O3, we have carried out a GW event follow-up program with Tomo-e Gozen using an automated observation system developed in 2018. 56 event alerts (excluding false alerts) have been issued from the LVC, and follow-up observations using Tomo-e Gozen have been performed for 26 events, covering more than 7000 $deg^2$ in total. No promising candidates of electromagnetic counterparts of GW events were found during O3 by Tomo-e Gozen or any other follow-up facilities. Since the automated follow-up observation system of Tomo-e Gozen has worked well throughout O3, it will search for optical counterparts of GW events quickly once alerts of nearby GW events are received in future observing runs of the GW detectors.

The Research Center for the Early Universe supported this project with a part of construction cost of high speed network to transfer data obtained with Tomo-e Gozen from the Kiso observatory to Tokyo, and also partial salary for a project assistance professor.

## 6.3 Publication List


[1] Omand, C., Kashiyama, K., Murase, K.: "Dust formation in embryonic pulsar-aided supernova remnants", 2019, MNRAS, 484, 5468

[2] Tsuna, D., Kashiyama, K., Toshikazu, S.: "Type IIn Supernova Light Curves Powered by Forward and Reverse Shocks", 2019, ApJ, 884, 87

[3] Law, C., Omand, C., Kashiyama, K., et al.: "A Search for Late-time Radio Emission and Fast Radio Bursts from Superluminous Supernovae", 2019, ApJ, 886, 24

[4] Kashiyama, K., Fujisawa, K., Shigeyama, T.: "The optically thick rotating magnetic wind from a massive white dwarf merger product", 2019, ApJ, 887, 39

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## 6.4 International Conference Talks

### 6.4.1 Contributed talks

[54] Kenta Hotokezaka: "Kilonova heating rate and light curve", GWPAW (Tokyo Japan, 14-17 Oct 2019).

[55] Atsushi Nishizawa: "Cross-correlating the angular distributions of binary black holes and electromagnetic counterparts", Innovative Area Gravitational Wave Physics and Astronomy: Genesis, The Third Annual Area Symposium (Kobe, Japan, 10-12 February 2020).

[56] Atsushi Nishizawa, Shun Arai, Purnendu Karmakar: "Observational predictions of the viable generalized scalar-tensor theory", APCTP Workshop: Gravitational-Wave Cosmology (Taipei, Taiwan, 30 November - 1 December 2019).

[57] Atsushi Nishizawa, Shun Arai, Purnendu Karmakar: "Observational predictions of the viable generalized scalar-tensor theory", JGRG 29 (Kobe, Japan, 25-29 November 2019).

[58] Atsushi Nishizawa: "Identifying the host-galaxies of binary black holes with multi-messenger observations", the Yukawa International Seminar (YKIS) 2019 "Black Holes and Neutron Stars with Gravitational Waves" (Kyoto, Japan, 7-11 October 2019).

[59] Atsushi Nishizawa: "Testing gravity at cosmological distance with GW propagation", GR22 / Amaldi13 (Valencia, Spain, 8-12 July 2019).

[60] Minori Shikauchi, Jun Kumamoto, Ataru Tanikawa, Michiko S. Fujii: "Detectability of Black Hole Main Sequence Star Binaries Formed in Open Clusters using Gaia", Innovative Area Gravitational Wave Physics and Astronomy: Genesis, The Third Annual Area Symposium (Kobe, Japan, 10-12 February 2020).

[61] Minori Shikauchi: "The Method of Comparing BNS Merger Rate Estimated by SGRBs and by GWs", Multi Messenger Astrophysics in the Gravitational Wave Era (Kyoto, Japan, 24 September - 25 October 2019).

[62] Leo Tsukada, Thomas Callister, Patrick Meyers and Andrew Matas: "A first search for stochastic gravitational-wave backgrounds from ultra-light bosons", GR22 / Amaldi13 (Valencia, Spain, 8-12 July 2019).

[63] Leo Tsukada, Alex Jenkins, Tania Regimbau, Mairi Sakellariadou: "Anisotropic GW background Mock data study", Gravitational Wave Physics and Astronomy Workshop (Tokyo, Japan, 14-17 October 2019).

[64] Leo Tsukada: "Stochastic gravitational wave backgrounds from ultra-light vectors", JGRG 29 (Kobe, Japan, 25-29 November 2019).

[65] Mamoru Doi: "A wide-field CMOS Camera Tomo-e Gozen and IR optimized telescope TAO", Time-domain astronomy workshop 2019 (Sendai, Japan, 17 October 2019).

### 6.4.2 Invited talks

[66] Kenta Hotokezaka: "Kilonova Nebula and r-process origin", YKIS 2019 (Kyoto, Japan, 7-11 Oct 2019).

[67] Atsushi Nishizawa: "KAGRA scientific contribution to the global detector network", The 6th KAGRA International Workshop (Wuhan, China, 21-23 June 2019).

# 7 Project 3. Formation and characterization of planetary systems

## 7.1 Activity Report

Project 3 “Formation and characterization of planetary systems” approaches the problem both theoretically and observationally through the collaboration with members in Departments of Physics, Astronomy, and Earth and Planetary Sciences. We show several highlights of our research this year.

### 7.1.1 Stellar rotation periods from photometric variation and asteroseismology

The stellar rotation period is one of the most fundamental parameters characterizing the star. High-cadence monitoring of stars by *Kepler* enables us to estimate the rotation period very precisely, but a conventional estimate from the photometric variation suffers from uncertainties due to the surface differential rotation and the presence of multiple stellar spots. Indeed there are several cases where photometrically determined rotation periods are different from that estimated from asteroseismology[11]. We perform systematic comparison of different photometrtic methods including the Lomb-Scargle periodogram, the wavelet analysis and the autocorrelation function to understand the robustness and reliability of the photometric rotation periods. This is expected to improve the estimate of the stellar obliquity and thus the spin-orbit angle of exoplanetary systems combined with asteroseismology[92].

### 7.1.2 Architecture of multiplanetary systems predicted from the observed protoplanetary disk, HL Tau

A number of protoplanetary disks observed with ALMA so far provide direct examples of initial conditions for planetary systems. In particular, the HL Tau disk has been intensively studied, and its rings/gaps are conventionally interpreted to be a result of unseen massive planets embedded in the gaps. Based on this interpretation, we carried out N-body simulations to investigate orbital evolution of planets within the protoplanetary disk and after the disk dispersal. Before the disk dispersal, our N-body simulations include both migration and mass-growth of the planet coupled with evolution of the disk. We found the outer planet is more massive than the inner one, and the migration of the innermost planet is inefficient due to the accretion of outer planet(s). Most simulated systems remain stable for at least 10 Gyr[59, 91].

### 7.1.3 Star-disk alignment from SPH simulation

Observed exoplanetary systems are known to exhibit diverse properties that are quite different from those of our Solar system. In particular, the presence of the spin-orbit misaligned planetary systems is supposed to carry important information concerning the initial condition of the protoplanetary disk and the subsequent formation and dynamical evolution of multi-planetary systems.

We have performed the SPH simulation of the collapse of turbulent molecular cloud cores with varying the thermal and turbulent energy contributions relative to the gravitational energy of those systems. Our overall conclusion is that the stellar spin and disk rotation axes of a protoplanetary disk system out of a turbulent cloud core are aligned less than $\sim 20^\circ$ [55].

### 7.1.4 Long-period Transiting Planet Catalog of Kepler

While astronomers have confirmed 4,000 exoplanets so far, it is still difficult to directly compare exoplanets with solar planets because most of the transiting exoplanets discovered so far have an orbital period shorter than one year. Using graphic processing unit (GPU) computing and techniques in machine learning, we surveyed 200,000 stars observed by the Kepler spacecraft for signals of transiting planets whose orbital period is larger than two years. Most of these signals were overlooked because only one or two transits occurred in four-year light curves, and they were difficult to identify through standard periodic analysis of the detection pipelines. We identified dozens of long-period transiting exoplanets and finally published the catalog of these planets including Jupiter-like gas giants. Also, we found that Neptunian-sized planets around the snow line (at a few au) are common around FGK stars. It is difficult to explain this population using the current formation theory. Known exoplanets near the snow line are located too far to measure their nature even for its mass [2]. This was also used to estimate planet mutual inclination of the exoplanet systems [49].

### 7.1.5 Self-lensing discovery of a low-mass white dwarf

We report the discovery of the fifth self-lensing binary in which a low-mass white dwarf (WD) gravitationally magnifies its 15th magnitude G-star companion, KIC 8145411, during eclipses. A joint analysis of the TRES radial velocities, the HDS spectrum, and the Kepler photometry of the primary star determines the WD mass $0.20\pm0.01$ Msol, orbital semimajor axis $1.28\pm0.03$ au, and orbital eccentricity $0.14\pm0.02$. Because such extremely low-mass WDs cannot be formed in isolation within the age of the Galaxy, their formation is believed to involve binary interactions that truncated evolution of the WD progenitor. However, the observed orbit of the KIC 8145411 system is at least 10 times wider than required for this scenario to work. The presence of this system in the Kepler sample, along with its similarities to field blue straggler binaries presumably containing WDs, may suggest that some 10% of post-asymptotic giant branch binaries with Sun-like primaries contain such anomalous WDs [**?**].

### 7.1.6 REACH: High-Dispersion Coronagraphy on Subaru telescope

Exoplanet characterization using High-Resolution Spectroscopy (HRS) is now one of the most promising techniques to detect atmospheric molecules along side space-borne spectroscopy of transiting planets. To enable this, we connect the high-contrast instrument (SCExAO) to the high-resolution IR spectrograph (IRD) at the Subaru Telescope, in a project named REACH ( Rigorous Exoplanetary Atmosphere Characterization with High dispersion coronography). Post-coronagraphic HRS will improve molecular species detection by significantly reducing photon noise and speckle noise at the planet position.

The REACH project weill enable several science cases. Atmospheric characterization of self-luminous planets is one of the main goals of REACH. In addition, REACH enables the efficient search for the molecular lines using the cross-correlation technique. One can search for various molecules in the bands (y, J, and H), such as methane, NH3 (these two can be tracers of the non-equilibirum state of the thermochemical equilibrium), and CO2 for relatively cool planet atmosphere, TiO, VO, FeH for hotter planets, as well as for water in various cases, and other minor molecules such as acetylene, HCN. The REACH is now available for the open-use (since 2020A, see http://secondearths.sakura.ne.jp/reach/ for the details).

### 7.1.7 Exo JASMINE: transiting exoplanet survey using a Japanese IR satellite JASMINE

For the future exploration of terrestrial planet atmospheres, it is crucial to find good targets prior to the characterization. Among transiting planets, those in the HZ around late-type stars are best suited for two reasons. First, the HZ planets around low-luminosity, late-type stars have much shorter orbital periods than the Earth. This makes it more plausible to find them via the transit method in the first place, and also enhances the chance to follow-up their transits multiple times. Second, the small radii of late-type stars make the transit signal deeper than around Sun-like stars. Various efforts have been made, both from ground and space, to detect such terrestrial planets transiting late-type dwarfs. Transiting

Exoplanet Survey Satellite (TESS) is an all-sky survey and has already delivered such a planet around an early-M dwarf, TOI-700b. Because of the 10.5 cm diameter of the TESS cameras, TESS is mainly suited for targeting bright early- to mid-M dwarfs. By contrast, the ground-based surveys such as MEarth, TRAPPIST, SPECULOOS, take advantage of a larger telescope aperture to find terrestrial planet around ultracool dwarfs with even later spectral types.

The Exo-JASMINE project, as one of a major part of a Japanese satellite JASMINE (approved in 2019), can fill a gap in those existing surveys. It is difficult for TESS to search for terrestrial planets around ultracool dwarfs because of the modest 10.5 cm aperture. For ground-based surveys, HZ terrestrial planets around earlier-type stars exhibit too shallow transits and have too long orbital periods. With the 30 cm aperture and NIR passband of JASMINE, along with its capability of performing long continuous monitoring from space, JASMINE will be a unique probe of terrestrial planets in the HZ around mid- to late-M dwarfs which have orbital periods of several weeks or semi-major axes of 0.03–0.3 AU. Those targets are located in between the known TOI-700 and TRAPPIST-1 systems.

### 7.1.8 New Direct Imaging of LkCa15 with Subaru Extreme Adaptive Optics System

The young star LkCa 15 in Taurus is well known as the first claimed direct detection of protoplanets. Three objects (LkCa 15 b,c,d) were reported to be embedded in the gap of the protoplanetary disk. The disk was first resolved by Subaru/HiCIAO during the SEEDS project. We conducted new near-infrared direct imaging from the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system coupled with Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) integral field spectrograph and multi-epoch thermal infrared imaging from Keck/NIRC2 of LkCa 15 at high Strehl ratios (Currie et al. 2019). Our data did not reveal the claimed planets. Instead, we resolved extended emission tracing a dust disk with a brightness and location comparable to that claimed for LkCa 15 b,c,d. We conclude that there is no direct evidence for the three protoplanets orbiting LkCa 15, although the system likely contains at least one unseen Jovian companion. Our observations cautioned that any protoplanet candidates should be clearly distinguished from disk emission through higher contrast observations and/or modeling.

### 7.1.9 Evidence for Spin-Orbit Alignment in the TRAPPIST-1 System

The TRAPPIST-1 system has attracted a lot of attention because it has seven Earth-size rocky planets and three of which are located in/near the habitable zone. The central star is an M dwarf, and those planets are situated very close to the central star. Therefore, this planetary system is very different from our Solar System. Determining the history of this system is important because it could help determine if any of the potentially habitable planets are actually inhabitable. But it is also an interesting system because it lacks any nearby objects which could have perturbed the orbits of the planets, meaning that the orbits should still be located close to where the planets first formed. We observed TRAPPIST-1 with the Subaru Telescope to look for misalignment between the planetary orbits and the star, taking advantage of a chance when three of the exoplanets orbiting TRAPPIST-1 transited in front of the star (Hirano et al. 2020). Two of the three were rocky planets near the habitable zone. Thanks to the power of the new infrared spectrograph IRD on the Subaru telescope (Kotani, Tamura et al. 2018), we was able to measure the obliquity. We found that the obliquity was low, close to zero. This is the first measurement of the stellar obliquity for a very low-mass star like TRAPPIST-1 and also the first Rossiter-McLaughlin measurement for planets in the habitable zone.

### 7.1.10 Peculiar Chemistry of Disk/Envelope System of the Low-Mass Class I Source Elias 29

We observed the Class I protostellar source Elias 29 with the Atacama Large Millimeter/submillimeter Array. We detected CS, SO, $^{34}$SO, $SO_2$, and SiO line emissions in a compact component concentrated near the protostar. This component is abundant in SO and $SO_2$, but deficient in CS. In contrast, organic molecules ($HCOOCH_3$, $CH_3OCH_3$, CCH, and c-$C_3H_2$) are deficient 29. We attribute this deficiency in organic molecules and richness in SO and $SO_2$ to the evolved nature of the source or the relatively high dust temperature (about 20 K) in the parent cloud of Elias 29. The SO and SO2 emissions trace rotation around the protostar. Assuming the Keplerian motion, the protostellar mass is estimated to be (0.8-1.0) Solar mass.

### 7.1.11 Detection of [$^{13}$C I] in Debris Disk of 49 Ceti

We have detected the submillimeter-wave fine-structure transition ($^3P_1 -^3 P_0$) of $^{13}$C, [$^{13}$C I], in the gaseous debris disk of 49 Ceti with the Atacama Large Millimeter/submillimeter Array (ALMA). Recently, the [C I] $^3P_1 -^3 P_0$ emission has been spatially resolved in this source with ALMA. In this data set, the $F = 3/2 - 1/2$ hyperfine component of [13C I], which is blueshifted by 2.2 km·s$^{-1}$ from the normal species line, [C I], has been identified in the outer part of the 49 Ceti disk, thanks to the narrow velocity widths of the gas components. The [C I]/[$^{13}$C I] line intensity ratio is found to be $12 \pm 3$, which is significantly lower than the isotope ratio of 77 in the interstellar medium. This result clearly reveals that the [C I] emission is optically thick in 49 Ceti. This is the first detection of [$^{13}$C I] $^3P_1 -^3 P_0$ emission not only in debris disks but also in the interstellar medium.

### 7.1.12 Late-stage accretion of gas giant planets

Many giant exoplanets are known to be highly enriched with heavy elements. Such enrichment is considered to have been delivered by the accretion of planetesimals in late formation stages. Our $N$-body simulations of planetesimal accretion onto a growing giant planet show that planets cannot accrete such high masses of heavy elements through "in situ" planetesimal accretion [12]. Then we have investigated whether a giant planet migrating inward can capture planetesimals efficiently enough to significantly increase its metallicity [44]. We have found that the two shepherding processes of mean motion resonance trapping and aerodynamic gas drag inhibit the planetesimal capture of a migrating planet. However, the amplified libration allows the highly-excited planetesimals in the resonances to escape from the resonance trap and to be accreted by the planet. Consequently, we show that a migrating giant planet captures planetesimals with total mass of several tens of Earth masses if the planet forms at a few tens of AU in a relatively massive disc. We also find that planetesimal capture occurs efficiently in a limited range of semi-major axis and that the total captured planetesimal mass increases with increasing migration distances. Our results have important implications for understanding the relation between giant planet metallicity and mass, as we suggest that it reflects the formation location of the planet - or more precisely, the location where runaway gas accretion occurred.

### 7.1.13 Theoretical transmission spectra of super-Earth atmospheres

Some of the exoplanets observed thus far show featureless or flat transmission spectra, possibly indicating the existence of clouds and/or haze in their atmospheres. The James Webb Space Telescope (JWST) is expected to enable a detailed investigation of exoplanet atmospheres, which could provide important constraints on the atmospheric composition obscured by clouds/haze. We have developed transmission spectrum models of close-in exoplanets with hazy hydrogen-rich atmospheres [?]. Then we have applied it to the exoplanets GJ 1214b, GJ 436b, HD 97658b, and Kepler-51b as examples to explore molecular absorption features detectable by JWST [1]. We have found that among the planetary parameters considered, super-Earths with hazy, relatively hydrogen-rich atmospheres are mostly expected to produce detectable molecular absorption features such as a quite prominent $CH_4$ feature at 3.3 $\mu$m, even for the extreme case of the most efficient production of photochemical haze. This investigation shows that, in most cases, the transmission spectra with muted features measured by Hubble Space Telescope do not preclude strong features at the longer wavelengths accessible by JWST.

### 7.1.14 Climate of ocean planets

Terrestrial planets covered globally with thick oceans (termed ocean planets) in the habitable zone were previously inferred to have extremely hot climates in most cases. This is because $H_2O$ high-pressure (HP) ice on the seafloor prevents chemical weathering and, thus, removal of atmospheric $CO_2$. Previous studies, however, ignored melting of the HP ice and horizontal variation in heat flux from oceanic crusts. We have examined whether high heat fluxes near the mid-ocean ridge melt the HP ice and thereby remove atmospheric $CO_2$. We have developed integrated climate models of an Earth-size ocean planet with plate tectonics for different ocean masses, which include the effects of HP ice melting, seafloor weathering, and the carbonate-silicate geochemical carbon cycle [19]. We have found that the heat flux near the mid-ocean ridge is high enough to melt the ice, enabling seafloor weathering. In contrast to the previous theoretical prediction, we showed that climates of terrestrial planets with massive oceans lapse into extremely cold ones (or snowball states) with $CO_2$-poor atmospheres. Such extremely cold climates are achieved mainly because the HP ice melting fixes seafloor temperature at the melting temperature, thereby keeping a high weathering flux regardless of surface temperature. We have estimated that ocean planets with oceans several tens of the Earth's ocean mass no longer maintain temperate climates. These results suggest that terrestrial planets with extremely cold climates exist even in the habitable zone beyond the Solar system, given the frequency of water-rich planets predicted by planet formation theories.

## 7.2 Publication List


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## 7.3 International Conference Talks

### 7.3.1 Contributed talks

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Jeff A Seabrook, Raymond C. Espiritu, A. Hari Nair, Lilian Nguyen, Gregory A Neumann, Carolyn M Ernst, William V Boynton, Micheal C. Nolan, Coralie D. Adams, Micheal C. Moreau, Bashar Rizk, Christian Drouet D'Aubigny, Erica R. Jawin, Kevin J Walsh, Patrick Michel, Stephen R. Schwartz, Ronald L. Ballouz, Erwan M Mazarico, Daniel J. Scheeres, Jay W. McMahon, W Bottke, Seiji Sugita, Naru Hirata, Noayuki Hirata, Sei-ichiro Watanbe, Keara N. Burke, Daniella N. DellaGuistina, Carinna A. Bennet, Dante Lauretta (2019): "The shape of Bennu: Implications for internal structure", PPS03-19, JpGU, 2019.5.26-30, Makuhari Messe Event Hall, Chiba, Japan

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[76] Chiho Sugimoto, Eri Tatsumi, Yuichiro Cho, Kazuo Yoshioka, Hirotaka Sawada, Yasuhiro Yokota, Naoya Sakatani, Masahiko Hayakawa, Moe Matsuoka, Rie Honda, Tomokatsu Morota, Shingo Kameda, Manabu Yamada, Toru Kouyama, Hidehiko Suzuki, Chikatoshi Honda, Kazunori Ogawa, Deborah Domingue, Patrick Michel, Seiji Sugita (2019): "Visible spectra of small bright spots on asteroid 162173 Ryugu", PPS03-10, JpGU, 2019.5.26-30, Makuhari Messe Event Hall, Chiba, Japan

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[78] Masanori Suemitsu, Tomokatsu Morota, Rie Honda, Singo Kameda, Eri Tatsumi, Manabu Yamada, Naoya Sakatani, Toru Kouyama, Yokota Yasuhiro, Yuichiro Cho, Hidehiko Suzuki, Masahiko Hayakawa, Moe Matsuoka, Chikatoshi Honda, Tatsuhiro Michikami, Kazuo Yoshioka, Kazunori Ogawa, Hirotaka Sawada, Seiji Sugita (2019): "Global distribution and spectral characteristics of bright spots on asteroid Ryugu", PPS03-P16, JpGU, 2019.5.26-30, Makuhari Messe Event Hall, Chiba, Japan

[79] Yasuto Watanabe, Eiichi Tajika, Kazumi Ozaki, and Peng K. Hong: "Effects of the formation of hydrocarbon aerosols on the climate stability of Earth-like planets and their habitability", JpGU Meeting 2019 (Makuhari, Japan, May 30, 2019)

[80] Takashi Nakagawa, Shintaro Kadoya, and Eiichi Tajika: "Deep mantle volatile cycle and plate tectonics: Impact to the climate evolution", JpGU Meeting 2019 (Makuhari, Japan, May 30, 2019)

[81] Seiji Sugita, Rie Honda, Tomokatsu Morota, Shingo Kameda, Eri Tatsumi, Chikatoshi Honda, Yokota Yasuhiro, Toru Kouyama, Naoya Sakatani, Manabu Yamada, Hidehiko Suzuki, Kazuo Yoshioka, Yuichiro Cho, Moe Matsuoka, Kazunori Ogawa, Deborah Domingue, Hideaki Miyamoto, Olivier Barnouin, Patrick Michel, Carolyn Ernst, Sei-ichiro Watanabe, Yuichi Tsuda: "Hayabusa2 observations reveals Ryugu's parent body properties", The Main Belt 2019, June 4-7, Villasimius, Sardinia, Italy

[82] Yasuto Watanabe, Eiichi Tajika, Kazumi Ozaki, and Peng K. Hong: "Global Carbon Cycle and Climate Stability in the Early Earth System", AbSciCon 2019 (Washington, USA, June 24-28, 2019)

[83] Nakagawa Y.: "Obliquity of an earth-like planet from photometric frequency modulation: Time-Frequency Analysis of GCM simulation data for the Earth", Planet$^2$ / RESCEU Summer School From the Solar System to the Universe, August 26, Kakunodate

[84] Katharina A. Otto, Rutu Parekh, Klaus-Dieter Matz, Ralf Jaumann, Stefan Schroder, Nicole Schmitz, Tra-Mi Ho, Stephan Elgner, Maximilian Hamm, Rie Honda, Shingo Kameda, Katrin Krohn, Frank Scholten, Hiroki Senshu, Katrin Stephan, Seiji Sugita and Frank Trauthan (2019): "High-resolution Surface Structures of Asteroid Ryugu Derived from MasCam Observations", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland.

[85] Stefan Schroder, Ralf Jaumann , Nicole Schmitz , Katharina Otto , Kathrin Stephan , Frank Preusker , Stephan Elgner , Klaus-Dieter Matz , Thomas Roatsch , Rutu Parekh , Stefano Mottola , Kathrin Krohn , Frank Trauthan , Alexander Koncz , Harald Michaelis , Wladimir Neumann , Jean-Baptiste Vincent , Roland Wagner , and Seiji Sugita (2019): "Ryugu as seen close up by MASCOT", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland

[86] Patrick Michel , Ron-L. Ballouz , Olivier S. Barnouin , , Kevin J. Walsh , Martin Jutzi , Derek C. Richardson , Stephen R. Schwartz , Seiji Sugita , Sei-ichiro Watanabe , Hirdy Miyamoto , Masatoshi Hirabayashi , Willima F. Bottke , Harold C. Connolly Jr., Dante S. Lauretta and the Hayabusa2 and OSIRIS-REx teams: "Disruption and reaccumulation: forming the top shape asteroids Ryugu and Bennu", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland

[87] Eri Tatsumi , Naoya Sakatani , Shingo Kameda , Toru Kouyama , Seiji Sugita , Rie Honda , Tomokatsu Morota , Manabu Yamada , Chikatoshi Honda , Yasuhiro Yokota , Kazunori Ogawa , Hidehiko Suzuki , Hiroaki Sawada Yuichiro Cho , Moe Matsuoka , Masatoshi Hirabayashi , Chiho Sugimoto , Koki Yumoto , Kouhei Kitazato , Naru Hirata , Naoyuki Hirata , Yukio Yamamoto , Deborah Domingue , Faith Vilas ,

Takahiro Hiroi , Tomoki Nakamura, Hikaru Yabuta, Seiichiro Watanabe and Hayabusa2 science team (2019): "Possible Hydrated Minerals on Pole Regions of (162173) Ryugu by ONC-T Observations", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland

[88] M. Hirabayashi1, E. Tatsumi2,3, H. Miyamoto4, G. Komatsu5, S. Sugita2, S. Watanabe6, D. J. Scheeres7, O. S. Barnouin8, P. Michel9, C. Honda10, T. Michikami11, Y. Cho2, T. Morota6, Naru Hirata10, Naoyuki Hirata12, N. Sakatani13, S. R. Schwartz14, R. Honda15, Y. Yokota12,13,15, S. Kameda16, H. Suzuki17, T. Kouyama18, M. Hayakawa13, M. Matsuoka13, K. Yoshioka2, K. Ogawa12, H. Sawada13, M. Yoshikawa13, and Y. Tsuda (2019): "The Western Bulge of 162173 Ryugu Formed as a Result of a Rotationally Driven Deformation Process", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland

[89] M. Yoshikawa , S. Watanabe , Y. Tsuda , S. Sugita , N. Namiki , K. Kitazato , S. Tanaka , M. Arakawa , S. Tachibana , M. Ishiguro , H. Ikeda , T. Okada , H. Demura , M. Abe , Y. Yamamoto , R. Jaumann , J.-P. Bibring , M. Grott , K.-H. Glassmeier , T.-M. Ho , A. MoussiSoffys , S. Nakazawa , F. Terui , T. Saiki , M. Fujimoto , and Hayabusa2 Project Team (2019): "Hayabusa2 - mission and science results up to now", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland.

[90] Masahiko Arakawa , Takanao Saiki , Toshihiko Kadono , Yasuhiko Takagi , Koji Wada , Yu-ichi Iijima , Hiroshi Imamura , Chisato Okamoto , Yuri Shimaki , Kei Shirai , Satoru Nakazawa , Masahiko Hayakawa , Naru Hirata , Hajime Yano , Hirotaka Sawada , Kazunori Ogawa , Rie Honda , Ko Ishibashi , Naoya Sakatani , Tomoaki Toda , Hajime Hayakawa , Seiji Sugita , Tomokatsu Morota , Shingo Kameda , Eri Tatsumi , Chikatoshi Honda , Yasuhiro Yokota , Toru Kouyama , Manabu Yamada , Hidehiko Suzuki , Kazuo Yoshioka , Yuichiro Cho , Moe Matsuoka , and Patrick Michel (2019): "First result of Hayabusa2 impact experiment on Ryugu", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland.

[91] Wang S.: "Planetary Migration and accretion effects on the evolutionary outcomes of a multi-planetary system: HL Tau", Planet2/RESCEU Symposium 2019, (Okinawa, Japan, October 15-18, 2019)

[92] Lu Y.: "Systematic comparison of photometric and asteroseismic rotation periods of 33 Kepler stars with transiting planets", Planet2/RESCEU Symposium 2019, (Okinawa, Japan, October 15-18, 2019)

[93] Toshinori Hayashi, Shijie Wang, Yasushi Suto: "A strategy to search for an inner binary black hole from the motion of the tertiary star", Planet2/RESCEU Symposium 2019, (Okinawa, Japan, October 15-18, 2019)

[94] Kazuhiro D. Kanagawa: "Termination of an Inward Migration of a Gap-opening Planet due to the Dust Feedback", Planet2/RESCEU Symposium 2019, (Okinawa, Japan, October 15-18, 2019)

[95] Nakagawa Y.: "Obliquity of an earth-like exoplanet from frequency modulation of its directly imaged light curves: analysis of the GCM data for the Earth", Planet2/RESCEU Symposium 2019, (Okinawa, Japan, October 15-18, 2019)

[96] Kazuhiro D. Kanagawa, "Observational signatures of a fast inward migration planet and its impacts on planet formation", Planet Formation Workshop 2019, November 25th-28th, 2019, NAOJ

[97] Yasuto Watanabe, Eiichi Tajika, Kazumi Ozaki, and Peng K. Hong: "Haze-free Warm Climatic Condition and Its Stability in the Anoxic Archean Earth", American Geophysical Union 2019 Fall Meeting (San Francisco, USA, December 13, 2019)

[98] Toshihiro Tada, Ryuji Tada, Paul Carling, W. Songtham, L.X. Thuyen, Yu Chang, Eiichi Tajika: "Constraint on the Location of the Australasian Tektite Impact Event based on the Distribution of the Ejecta Deposits acrossin wide area of the Eastern Indochina", American Geophysical Union 2019 Fall Meeting (San Franscisco, USA, December 13, 2019)

[99] Toshinori Hayashi, Shijie Wang, Yasushi Suto: "A strategy to search for an inner binary black hole from the motion of the tertiary star", The Evolution of Massive Stars and Formation of Compact Stars: from the Cradle to the Grave, (Tokyo, Japan, February 26-28, 2020)

### 7.3.2 Invited talks

[100] Seiji Sugita, Rie Honda, Tomokatsu Morota, Shingo Kameda, Eri Tatsumi, Chikatoshi Honda, yokota yasuhiro, Toru Kouyama, Naoya Sakatani, Manabu Yamada, Hidehiko Suzuki, Kazuo Yoshioka, Yuichiro Cho, Moe Matsuoka, Kazunori Ogawa, Deborah Domingue, Hideaki Miyamoto, Olivier Barnouin, Patrick Michel, Carolyn Ernst, Sei-ichiro Watanabe, Yuichi Tsuda (2019): "Asteroid Ryugu's parent body and its properties inferred from Haybusa2 multi-band imaging observations", PPS03-07, JpGU, 2019.5.26-30, Makuhari Messe Event Hall, Chiba, Japan

[101] S. Sugita (2019): "Hayabusa2 update: global observations, sampling touchdown, and comparison with Hayabusa", The Main Belt 2019, June 4-7, Villasimius, Sardinia, Italy

[102] Suto Y.: "From unknown knowns to known knowns: cases of dark baryon and exo-ring", the conference on *Continuous Challenges for X-ray Astronomy*, June 8, 2019, Tokyo

[103] Kazuhiro D. Kanagawa: "Effects of dust feedback on evolutions of disks and planets", Great Barriers in Planet Formation, July 2019, Palm Cove, Queensland, Australia

[104] Sugita, S., R. Honda, T. Morota, S. Kameda, E. Tatsumi, C. Honda, Y. Yokota, M. Yamada, T. Kouyama, N. Sakatani, H. Suzuki, K. Yoshioka, Y. Cho, M. Matsuoka, K. Ogawa, D. Domingue, H. Miyamoto, O. S. Barnouin, P. Michel, C. M. Ernst, T. Hiroi, T. Nakamura, H. Sawada, M. Hayakawa, N. Hirata, N. Hirata, H. Kikuchi, R. Hemmi, T. Michikami, Eric Palmer, R. Gaskell, M. Hirabayashi, R. Jaumann, K. Otto, N. Schmitz, S. E. Schroder, G. Komatsu, S. Tanaka, K. Shirai, M. Yoshikawa, S. Watanabe, Y. Tsuda:, "Ryugu's parent body processes estimated from Hayabusa2 multi-band optical observations", 82nd Meteor. Soc. Mtg., July 8-12, Sapporo, Japan.

[105] Suto Y.: "Spin-orbit architecture of planetary systems with the Rossiter-McLaughlin effect and asteroseismology", JSPS Planet$^2$/RESCEU workshop on exoplanets,August 27, 2019, Tokyo

[106] Kazuhiro D. Kanagawa, Hidekazu Tanaka, Ewa Szuszkiewicz, "Radial evolution of a gap-opening planet within a protoplanetary disk", EPSC-DPS Joint Meeting 2019, September 2019, Centre International of Conferences, Geneva, Switzerland

[107] Sugita, S., R. Honda, T. Morota, S. Kameda, E. Tatsumi, C. Honda, Y. Yokota, M. Yamada, T. Kouyama, N. Sakatani, H. Suzuki, K. Yoshioka, Y. Cho, M. Matsuoka, K. Ogawa, D. Domingue, H. Miyamoto, P. Michel, O. S. Barnouin, C. M. Ernst, T. Hiroi, T. Nakamura, H. Sawada, M. Hayakawa, N. Hirata, N. Hirata, H. Kikuchi, R. Hemmi, T. Michikami, Eric Palmer, R. Gaskell, M. Hirabayashi, R. Jaumann, K. Otto, N. Schmitz, S. E. Schroder, G. Komatsu, S. Tanaka, K. Shirai, M. Yoshikawa, S. Watanabe, Y. Tsuda (2019): "High-resolution imaging and dynamic response observations of asteroid Ryugu", EPSC-DPS Joint Mtg., Sep. 15-20, Geneva, Switzerland.

[108] Suto Y.: "Spin-orbit architecture of planetary systems", JSPS Planet$^2$/the 12th RESCEU International Symposium "From Protoplanetary Disks through Planetary System Achitecture to Planetary Atmospehers and Habitability", October 18, 2019, Okinawa

[109] Kotani, T. et al.: "Development of the Extremely High-Contrast, High Spectral Resolution Spectrometer REACH for the Subaru Telescope", In the Spirit of Lyot 2019, Odaiba, Tokyo, 2019/10/21-25

[110] Lozi, J. et al.: "SCExAO: Current status and upgrades", In the Spirit of Lyot 2019, Odaiba, Tokyo, 2019/10/21-25

[111] Suto, Y.: "Universe unveiled through holes of aluminum plates", The 2019 Kyoto prize workshop " Wide-Field Sky Survey of the Universe: From the Past to the Future of Astronomy", November 13, 2019, Tokyo

[112] Tamura, M.: "Exploring Exoplanet and Star-Formation Studies with Subaru", Subaru Telescope 20th Anniversary Conference, Hawaii, USA, 2019/11/22

[113] Tamura, M.: "Into the unknown of star/planet formation and exoplanets with Subaru", Science with Subaru: An Indian Perspective, Mumbai, India, 2019/12/19

[114] S. Sugita, T. Morota, R. Honda, S. Kameda, E. Tatsumi, S. Tachibana, K. Kitazato, T. Okada, N. Namiki, M. Arakawa, P. Michel, D. Domingue, S. Tanaka, M. Yoshikawa, S. Watanabe, and Y. Tsuda: "The Evolution of Asteroid Ryugu Revealed by Hayabusa2 and Implications for Sample Analyses", AGU 2019 Fall Meeting U54A-01, Dec. 9 - 13. San Francisco, USA.

[115] Suto, Y.: "Lessons from Mars and Earth for future explorations of bio-signatures from earth-like planets", ABC Project/CPS Workshop "Climates of Terrestrial Planets in Various Solar Systems", February 11, 2020, Kobe

[116] Nakagawa Y.: "Planetary obliquity from frequency modulation of direct imaged light curve: mock observation and analysis from GCM simulation of an Earth-like planet", ABC Project/CPS Workshop on Climates of Terrestrial Planets in Various Solar Systems, February 12, 2020, Kobe

[117] Kawahara H.: "Global mapping and Surface Compositions of an Earth-like Exoplanet from Direct Imaging", ABC Project/CPS Workshop on Climates of Terrestrial Planets in Various Solar Systems, February 12, 2020, Kobe