Research Center for the Early Universe

Graduate School of Science

University of Tokyo

Annual Report

2018

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 2018 (from April 2018 to March 2019).

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 workshop "Space Gravitational-Wave Detection" at the University of Tokyo Hongo campus. The aim of this workshop was to discuss future of the multi-frequency gravitational waves with a particular emphasis on detection of low frequency gravitational waves by the detectors launched in space.

The visiting professors and researchers of RESCEU include Prof. Alexei Starobinsky (Landau Institute for Theoretical Physics, from October 31 to November 21, 2018, and from March 9 to 15, 2019), Prof. Bernard Carr (Queen Mary University of London, from February 24 to March 15, 2018), Dr. Stephane Colombi (Institut d'Astrophysique de Paris, from May 29 to June 3, 2018), and Dr. Othman Benomar (New York University Abu Dhabi, from May 11 to June 4, 2018, and from October 22 to December 2, 2018).

We are happy to report that many new members joined RESCEU in the fiscal year of 2018. Dr. Kohei Kamada and Dr. Atsushi Nishizawa joined RESCEU as an assistant professor starting on September 1, 2018 and February 1, 2019, respectively. Dr. Yuu Niino joined RESCEU as a project assistant professor starting on October 1, 2018. In addition, Dr. Koh Ueno and Dr. Kazuhiro Kanagawa joined RESCEU as a post-doctoral fellow starting on April 1 and June 1, 2018. A new secretary Ms. Reiko Sugiyama joined us in March 2019.

Finally we are pleased to announce the awards for our RESCEU members. Dr. Kipp Cannon, our associate professor, received Dunlap Award for Innovation in Astronomical Research Tools from Canadian Astronomical Society in May 2018. Dr. Masamune Oguri, our assistant professor, received the 23rd Hayashi Chushiro Prize from Astronomical Society of Japan in March 2019. Dr. Atsushi Nishizawa, our assistant professor, received the 13th Nakamura Seitaro Award from Yukawa Memorial Foundation in March 2019. We would like to congratulate them for their wonderful achievement.

August 2019

Director Yasushi Suto

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1 Members

RESCEU members

Yasushi Suto [須藤靖]	Director
Jun'ichi Yokoyama [横山順一]	Professor
Toshikazu Shigeyama [茂山俊和]	Associate Professor
Kipp Cannon	Associate Professor
Masamune Oguri [大栗真宗]	Assistant Professor
Kazumi Kashiyama [樫山和己]	Assistant Professor
Kohei Kamada [鎌田耕平]	Assistant Professor (2018/9/1 –)
Atsushi Nishizawa [西澤篤志]	Assistant Professor (2019/2/1 –)
Takuma Suda [須田拓馬]	Project Assistant Professor
Toyokazu Sekiguchi [関口豊和]	Project Assistant Professor
Yuu Niino [新納悠]	Project Assistant Professor (2018/10/1 –)
Ayako Ishii [石井彩子]	Postdoctoral Fellow
Koh Ueno [上野昂]	Postdoctoral Fellow
Kazuhiro Kanagawa [金川和弘]	Postdoctoral Fellow (2018/6/1 –)
Yutaka Komiya [小宮悠]	Research Fellow (– 2018/5/15)
Yi-Peng Wu	Research Fellow
Heather Fong	Research Fellow (2018/11/9 –)
Sayuri Nagano [永野早百合]	Secretary
Chiyo Ueda [上田千代]	Secretary
Reiko Sugiyama [杉山礼子]	Secretary (2019/3/1 –)

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

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
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 RESCEU Summer School

Place: Yunokawa Kahantei, Hakodate city, Hokkaido, Japan
Time: 2018/7/27 (Fri) – 2016/7/30 (Mon)

Program

7/27 (Fri)

14:00–14:10	Yasushi Suto	Opening remark
14:10–15:10	(L) Haibo Yu	Self interacting dark matter and structure formation: I
15:10–15:20	Break	
15:20–16:20	(L) Re'em Sari	Planet formation and stellar dynamics: I
16:20–16:30	Break	
16:30–16:50	Masa Aizawa	Search for exoplanetary rings via transit method
16:50–17:10	Soichiro Hashiba	A non-perturbative method for calculating gravitational particle creation
17:10–17:30	Kana Moriwaki	The distribution and physical properties of high-redshift [OIII] emitters in a cosmological hydrodynamics simulation

7/28 (Sat) morning

9:00–10:00	(L) Kohta Murase	High-energy particle astrophysics: I
10:00–10:10	Break	
10:10–11:10	(L) Haibo Yu	Self interacting dark matter and structure formation: II
11:10–11:20	Break	
11:20–11:40	Kazuhumi Takahashi	Extended Cuscuton: Formulation and Cosmology
11:40–12:00	Leo Tsukada	The search for stochastic gravitational background from superradiance instability
12:00–12:20	Conor Omand	Dust Formation and Emission in Pulsar-Powered Supernova Remnants

7/28 (Sat) afternoon

13:30–14:30	(L) Re'em Sari	Planet formation and stellar dynamics: II
14:30–14:40	Break	
14:40–15:00	Haoxiang Lin	Nonthermal afterglow of GW170817: a more natural electron energy distribution leads to a new solution with radio flux in the low frequency synchrotron tail
15:00–15:20	Toyokazu Sekiguchi	Long-term dynamics of axion string
15:20–15:40	Ooi Ching Pin	Mechanical loss of Crystal Fibres for Torsion Pendulum Experiments
15:40–15:50	Break	
15:50–16:50	(L) Kohta Murase	High-energy particle astrophysics: II
16:50–17:00	Break	
17:00–17:20	Minxi He	Inflation in the Mixed Higgs-R^2 Model
17:20–17:40	Shotaro Yamasaki	Relativistic Fireball Reprise: Radio Suppression at the Onset of Short Magnetar Bursts
17:40–18:00	Kazuhiro Kanagawa	Radial migration of gap-opening planets in protoplanetary disks

7/29 (Sun)

9:00–10:00	(L) Haibo Yu	Self interacting dark matter and structure formation: III
10:00–10:10	Break	
10:10–11:10	(L) Re'em Sari	Planet formation and stellar dynamics: III
11:10–11:20	Break	
11:20–11:40	Yuuki Takei	Inner Structure of Shocked Region in Type IIn Supernovae
11:40–12:00	Yi-Peng Wu	Search for heavy physics in the cosmological collider
12:00–12:20	Soichiro Morisaki	Search for ultralight scalar field dark matter with gravitational-wave detectors
12:20 –	Free discussion	

7/30 (Mon)

9:30–10:30	(L) Kohta Murase	High-energy particle astrophysics: III
10:30–10:40	Break	
10:40–11:00	Riouhei Nakatani	Radiation Hydrodynamics Simulations of Photoevaporation of Protoplanetary Disks: Metallicity Dependence of UV and X-ray Photoevaporation
11:00–11:20	Hiroaki Tahara	Self-anisotropizing universe in Horndeski theory
11:20–11:40	Daichi Tsuna	Detectability of Mass Ejection from Failed Supernovae
11:40–11:50	Jun'ichi Yokoyama	Closing remark

3.2 Space Gravitational-Wave Detection

Place: Room 341, Area C, Faculty of Science Bldg. 1, University of Tokyo (Hongo Campus)
Time: 2019/3/27 (Wed) – 2019/3/29 (Fri)

Program

3/27 (Wed) morning

10:30–10:40	Junichi Yokoyama	Opening Remarks : Why this workshop?
10:40–11:40	Hsien-Chi Yeh	The development of scientific payloads for TainQin mission

3/27 (Wed) afternoon

13:00–14:00	Kiwamu Izumi	LISA
14:15–15:15	Naoki Seto	DECIGO
15:30–16:30	Keitaro Takahashi	PTA
16:45–17:15	Kazumi Kashiyama	The birth and growth of supermassive black holes in the early universe

3/28 (Thu) morning

9:30–10:30	Norichika Sago	Status of Japanese working group for LISA science
10:45–11:15	Tomoya Kinugawa	The remnants of first stars for gravitational wave sources
11:15–11:45	Medeu Abishev	The evaluation of EM forward radiations during the propagation of GWs through the dipole field of the magnetar

3/28 (Thu) afternoon

13:00–14:00	Kent Yagi	Probing Extreme Gravity with Gravitational Waves: Current and Future
14:15–15:15	Atsushi Nishizawa	Testing gravity at cosmological distance with gravitational waves
15:30–16:30	Mitsuru Musha	High power and highly-stable light source for DECIGO/B-DECIGO
16:45–17:45	Yuto Minami	LiteBIRD

3/29 (Fri) morning

9:30–10:30	Shuichi Sato	DECIGO and B-DECIGO
10:45–11:45	Toru Yamada	Future of Space Science in Japan

3/29 (Fri) afternoon

13:00–14:00	Yiming Hu	Analysis of TianQin Science Objectives
14:15–15:15	Yuta Michimura	Duscussion

4 RESCEU colloquia

- Roxanne Ligi (INAF-Astronomical Observatory of Brera)
  "Detection and characterization of exoplanetary systems: The contribution of high angular resolution"
  April 2, 2018, 11:00-12:00

- Peter Behroozi (University of Arizona)
  "Automated Physics Recovery from Galaxy Observations"
  April 19, 2018, 13:30-14:30

- Kyohei Kawaguchi (ICRR, Univ. of Tokyo)
  "Gravitational-wave templates for inspiralling binary neutron stars"
  May 17, 2018, 13:30-14:30

- Kazuyuki Sugimura (Tohoku University)
  "Accretion onto seed BHs: the impacts of radiation anisotropy and gas angular momentum"
  May 10, 2018, 13:30-14:30

- Kohei Kamada (IBS-CTPU)
  "Cosmological Magnetic Fields: a Frontier in Cosmology and Particle Physics"
  May 21, 2018, 13:00-14:30

- Stéphane Colombi (IAP)
  "Some aspects of Vlasov-Poisson equations"
  May 31, 2018, 13:30-14:30

- Tsuguo Aramaki (SLAC)
  "Hunting for Dark Matter with SuperCDMS, GAPS and GRAMS"
  June 13, 2018, 13:30-14:30

- Shinsuke Takasao (Nagoya Univ.)
  "Accretion from a magnetized disk onto a central star: New accretion mode"
  June 21, 2018, 13:30-14:30

- Magnus Axelsson (Stockholm Univ.)
  "Breaking the spectral degeneracies in black hole binaries using rapid variability"
  July 31, 2018, 13:30-14:30

- Yusuke Tsukamoto (Kagoshima University)
  "Does disk fragmentation by gravitational instability explain formation of the wide orbit planets?"
  October 25, 2018, 13:30-14:30

- Yann Alibert (Univ. of Bern)
  "A hybrid model for giant planet formation"
  October 22, 2018, 10:30-11:30

- Alexei A. Starobinsky (Landau Institute)
  "Stochastic dark energy from inflationary quantum fluctuations"
  November 12, 2018, 15:00-16:00

- Kenta Hotokezaka (Princeton Univ.)
  "Electromagnetic counterparts to GW170817 and astrophysical implications"
  January 21, 2019, 16:00-17:00

- Anna Lisa Varri (Dept. of Astronomy, University of Tokyo)
  "Phase space complexity of star clusters: fresh observables for old and new questions"
  March 07, 2019, 13:30-14:30

- Tilman Troester (University of Edinburgh)
  "Weak gravitational lensing, baryons, and deep learning"
  March 13, 2019, 14:00-15:00

5 Project 1. Evolution of the universe and cosmic structures

5.1 Activity Report

This project aims at clarifying the creation and evolution of the universe and its large scale structures from both 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. 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 FY2018.

5.1.1 Inflationary cosmology

Higgs-R^2 mixed model

The original Higgs inflation model and Starobinsky model of R^2 inflation are two inflation models whose predictions of the spectral index and the tensor-to-scalar ratio occupy the central region of the observed likelihood contours. It has been known that the cutoff scale of the Higgs-R^2 mixed model in the vacuum can be pushed up to the Planck scale and the violent particle production observed in the pure nonminimal coupling model can be treated safely. We found that this violent particle production is not efficient enough to complete the reheating of the Universe, contrary to the case of pure nonminimal coupling model. (Kamada, Yokoyama)

Reheating after k-inflation and G-inflation

If inflation is followed by kination regime as in the cases of k-inflation or G-inflation, the reheating of the universe is achieved by gravitational particle production. We have studied this process in detail and found the condition for sufficient reheating and dark matter formation from conformally coupled massive scalar fields. (Yokoyama)

5.1.2 Cosmological phase transition

We consider the cosmological phase transition, especially the electroweak one, in the Twin Higgs model, which is a possible solution for the naturalness problem in the Standard Model of particle physics. We showed that it is impossible to have the first order phase transitions in these models for the reasonable parameter spaces and we cannot expect for the gravitational wave production that will be detected at DECIGO and other future gravitational waves. In other words, we can rule out the model once we will find the gravitational wave background from the cosmological phase transitions. (Kamada)

5.1.3 Axion dynamics

We have performed a large numerical simulation of formation and evolution of axionic strings, and found a deviation from the scaling solution with a logarithmic increase of the scaling parameter in time. (Yokoyama)

5.1.4 Statistical Computational Astrophysics

We applied a popular deep-learning method called Generative Adversarial Network to denoising a two dimensional field. In particular, we devised a set of networks that can estimate and subtract noises from weak-lensing cosmic convergence maps. We trained the networks by using 60,000 mock lensing maps generated from the outputs of cosmological simulations. The trained networks successfully reconstruct 1-point and 2-point statistics of the original, true lensing signals as well as the real space distributions. We have been exploring improvement of cosmological parameter estimation using denoised maps. (Yoshida)

5.1.5 Effect of Gravitational Lensing on the Distribution of Gravitational Waves from Distant Binary Black Hole Mergers

Next generation gravitational wave experiments allow us to observe binary black hole mergers out to very high redshifts, $z > 20$. The redshift distribution of these black hole mergers is expected to provide an important clue to their origin. However, in gravitational wave observations, redshifts must be inferred from luminosity distance measurements that are affected by gravitational lensing magnifications. We study the expected redshift distribution of binary black hole mergers taking a full account of gravitational lensing effects, and find that highly demagnified images caused by strong lensing produce a high-redshift tail in the observed redshift distribution. Such a demagnified, apparently high-redshift event should be accompanied by a magnified image that is observed typically 10–100 days before the demagnified image. This work highlights the critical important gravitational lensing (de-)magnification on the interpretation of apparently very high redshift gravitational wave events. (Oguri)

5.1.6 High redshift galaxies

We used deep Subaru Hyper Suprime-Cam narrow-band data taken in the CHORUS project to derive the luminosity function of Lyman α emitters (LAEs) at $z = 7.0$. Combining with previous studies in the literature, we found that the Lyman α luminosity density decreases more rapidly than the UV luminosity density from $z \sim 6$ to ~ 8, suggestive of an increase in the neutral fraction of the IGM hydrogen. We also performed radiative numerical simulations of LAEs and found that the dispersion and halo mass dependence of the halo Lyman α optical depth are essential to explain observed luminosity functions of LAEs at $z \gtrsim 6$. We estimated the masses of dark matter haloes hosting ~ 50 $z \sim 6$ quasars with supermassive black hole (SMBH) mass measurements, and found that the black-hole to halo mass ratios of these quasars are higher than those of local galaxies. This indicates that the growth of SMBHs in $z \sim 6$ quasars precedes that of hosting haloes. (Shimasaku)

5.1.7 Faint dwarf spheroidal galaxies

Faint dwarf spheroidal galaxies can be a useful probe to identify the origin of r-process elements, because some of such galaxies have hosted a single neutron star merger (NSM) in their whole histories. If r-process elements are supplied from NSMs, stars formed before the NSM do not have these elements and can be easily distinguished from younger stars formed from gas polluted by the ejecta of the NSM. Since we have identified such a signature in some faint dwarf spheroidal galaxies from already existing observational data, we have been trying to observe as many stars in such galaxies as possible with the Subaru telescope to strengthen the argument in collaboration with researchers working at NAOJ and Tohoku University. Unfortunately, our observation scheduled in May were not performed due to bad weather and volcanic eruptions. Our proposal for the compensation of this lost observation was approved. (Shigeyama)

5.1.8 Optical emission immediately after binary neutron star mergers

Gravitational waves from a binary neutron star merger were detected for the first time and the optical counter part was also detected about 11 hours from the gravitational wave detection. Follow up observations with electromagnetic waves have revealed that a short gamma-ray burst originates from a binary neutron star merger and heavy elements as much as 1% of the solar mass were ejected. As future transient surveys such as Tomo-e will be able to detect emission earlier than this event, we are investigating what kind of information the emission carries. To this end, we calculated the shock breakout from the merging object and found that this results in ejection of matter composed of free-neutrons with a mass of about ? 10^{76} $M_{\odot}$ and discussed the emission from this matter. The results were published in the Astrophysical Journal. We are now try to calculate optical spectra emitted within the first few hours of a merger. (Shigeyama)

5.1.9 Tomo-e Gozen

To search for electro-magnetic counter parts of gravitational wave sources, we have constructed a wide field optical camera equipped with 84 CMOS sensors, which is mounted on 1.0-m Schmidt Telescope in Kiso Observatory at the University of Tokyo. Observations has started in April 2019. This Tomo-e Gozen can detect any types of transient sources ranging from comets in the solar system to afterglows of gamma-ray bursts in the distant universe on timescales of seconds. (Shigeyama)

5.1.10 Supernovae

Observations of the early light from type Ia supernovae

Type Ia supernova is thought to be the explosion of a white dwarf in a binary system. There are two scenarios leading to type Ia supernova. One is the double-degenerate scenario in which the companion is also a white dwarf and eventually coalesces to explode without leaving no compact remnants. The other is the single-degenerate scenario in which the white dwarf accretes matter from a red-giant or main-sequence companion star. In this scenario, there remains the companion after the supernova explosion and the existence of the companion should affect the dynamics of the ejecta of the explosion. We have been investigating effects of the companion on the dynamics and the radiation by 2D numerical simulations taking into account the finite timescale of thermalization between gas and radiation and pointed out the possibility of the enhancement of blue radiation in the early phase. This observation project is a collaboration with M. Doi at IoA, J. Jiang at IPMU , and K. Maeda at Kyoto University. (Shigeyama)

Influence of supernova explosions on the companion stars

Massive stars are usually formed in multiple stellar systems. Thus a supernova explosion can affect the surface layers of nearby stars. We are focusing on the change of the abundance of Li in solar type stars after the explosion of a nearby star because Li is known to exist only in the surface layer where the temperature is lower than 2.6 million K. This effect may account for the diversity of Li abundances observed in metal-poor dwarf stars. From the theoretical point of view, we are investigating the effects of a supernova on the surface layer of low mass stars by numerical simulations. This part is a collaboration with a researcher at Kobe University. At the same time, we are searching binary systems composed of a massive star and a low mass star by performing spectroscopy observations for known massive stars in our galaxy using 1-m class telescopes. To investigate the population of this kind of binary systems in the current universe, we can infer the population of metal-poor counter parts in the ancient universe. As a bi-product, we found a binary blackhole candidate with a long orbital period of ~ 33 (or 73) days (Shigeyama)

Emission of type IIn supernovae

Type IIn supernovae are very bright and could be a useful probe to investigate the activity of star formation in the early universe because this type of supernovae are thought to originate from massive

stars. Though the emission of this supernova is believed to come from collisions between ejecta and thick circumstellar matter, there have been no quantitative models to account for spectra and their temporal evolution. This is due to the difficulty to numerically resolve the structure of the shocked matter. To overcome this difficulty, we take two different approaches. First, we are trying to resolve the structure by assuming the shocked ejecta and the shocked circumstellar matter are in stationary states in the rest frames of the shock waves and separated by a contact surface. We have succeeded in obtaining series of such solutions for about a month from the explosion and constructing light curves of some optical bands. Second, we use Chevalier's self-similar solution for the density and velocity structures in the shocked region. We calculate emission from newly shocked matter at each time and radiative transfer equations based on this solution. We have compare these solutions with previous solutions based on the thin shell approximation and with some existing observational data to test our model. The second part is submitted to the Astrophysical Journal. (Shigeyama)

Eruptive mass loss from a massive star a few years before the core collapse

Sudden Brightening exceeding the Eddington luminosity was observed a few years before some type IIn supernova events. To understand this preceding brightening event, we performed radiation hydrodynamic calculations initiated by injecting some energy at the bottom of the hydrogen-rich envelope of a supergiant with a timescale shorter than the dynamical timescale of the envelope. We found that we can reproduce the observed brightening and that this event ejects about 0.1 $M_\odot$ of matter. We will investigate the relation of this ejected matter with the dense CSM required to reproduce the brightness of type IIn supernovae. (Shigeyama)

5.1.11 Fast radio bursts etc

Totani continued to study fast radio bursts (FRBs), a new mysterious transient phenomenon lasting only a few ms. We have examined that FRBs originate from binary neutron star mergers. A single, non-repeating class of FRBs may occur at the time of merger. We have shown that, using BNS simulation, ejecta formation is a few ms delayed compared with the rise up of rotation speed of the merged neutron star, leaving a time window in which radio signal can be transmitted to an observer. Repeating class of FRBs may originate from a neutron star left after BNS merger, when the total mass is small enough to survive against collapse for a long time. We also constructed a new model of nonthermal afterglow emission from 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. (Totani)

5.1.12 X-ray and γ-ray astrophysics

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 on the study of heavy element distribution in young supernova remnants, high energy particle escape from the shocks of supernova remnants, high energy phenomena on compact stars such as white dwarfs, neutron stars, and black holes. We develops how to parametrize the uniformity of expansion of the supernova remnants. The origin of type Ia SNe is one of the biggest problem, single degenerate (SD) or double degenerate (DD). In the SD case, dense CSM makes the expansion highly asymmetric. With excellent spatial resolution and moderate energy resolution of Chandra X-ray observatory, we make Doppler-shift maps of supernova remnants, and found that we will be able to judge the origin of supernova remnants, SD and DD, with the symmetric parameters. For the future missions, we work on the development of the X-ray recovery mission of Hitomi, XRISM, which will be launched on the Japanese fiscal year 2021. We are now making the performance verification target list. We also develop hard X-ray polarimeter with CMOS sensor and coded aperture for the future small satellite mission. (Bamba)

5.2 Publication List

[1] Shivani Bhandari, et al. (incl. Tomonori Totani): "The SUrvey for Pulsars and Extragalactic Radio Bursts - II. New FRB discoveries and their follow-up", Monthly Notices of the Royal Astronomical Society, **475** (2018) 1427-1446

[2] Ryota Tomaru, Chris Done, Hirokazu Odaka, Shin Watanabe, and Tadayuki Takahashi: "Monte Carlo simulations of the detailed iron absorption line profiles from thermal winds in X-ray binaries", Monthly Notices of the Royal Astronomical Society, **476** (2018) 1776-1784

[3] Hirokazu Odaka, et al.: "Modeling of proton-induced radioactivation background in hard X-ray telescopes: Geant4-based simulation and its demonstration by Hitomi's measurement in a low Earth orbit", Nuclear Instruments and Methods in Physics Research A, **891** (2018) 92-105

[4] Daichi Tsuna, Norita Kawanaka, and Tomonori Totani: "X-ray detectability of accreting isolated black holes in our Galaxy", Monthly Notices of the Royal Astronomical Society, **477** (2018) 791-801

[5] Ken Osato, Nishimichi Takahiro, Masamune Oguri, Masahiro Takada, and Teppei Okumura: "Strong orientation dependence of surface mass density profiles of dark haloes at large scales", Monthly Notices of the Royal Astronomical Society, **477** (2018) 2141-2153

[6] Kojiro Kawana, Ataru Tanikawa, and Naoki Yoshida: "Tidal disruption of a white dwarf by a black hole: the diversity of nucleosynthesis, explosion energy, and the fate of debris streams", Monthly Notices of the Royal Astronomical Society, **477** (2018) 3449-3460

[7] Steven A. Rodney, et al. (incl. Masamune Oguri): "Two Peculiar Fast Transients in a Strongly Lensed Host Galaxy", Nature Astronomy, **2** (2018) 324-333

[8] Patrick L. Kelly, et al. (incl. Masamune Oguri): "Extreme Magnification of an Individual Star at Redshift 1.5 by a Galaxy-Cluster Lens", Nature Astronomy, **2** (2018) 334-342

[9] Shotaro Yamasaki, Tomonori Totani, and Kenta Kiuchi: "Repeating and Non-repeating Fast Radio Bursts from Binary Neutron Star Mergers", Publications of the Astronomical Society of Japan, **70** (2018) 39

[10] Hitomi Collaboration (incl. Aya Bamba, Hirokazu Odaka): "Hitomi X-ray Observation of the Pulsar Wind Nebula G21.5−0.9", Publications of the Astronomical Society of Japan, **70** (2018) 38

[11] H.E.S.S. Collaboration (incl. Aya Bamba): "A search for new supernova remnant shells in the Galactic plane with H.E.S.S.", Astronomy & Astrophysics, **612** (2018) A8

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5.3 International Conference Talks

5.3.1 Contributed talks

[107] Yuuki Wada, et al.: "A gamma-ray glow terminated by leader development of an inter-cloud discharge in Japanese winter thunderstorm", EGU General Assembly (Vienna, Austria, April 7-12 , 2018)

[108] Ken Osato, Takahiro Nishimichi, Masamune Oguri, Masahiro Takada, and Teppei Okumura: "Strong orientation dependence of surface mass density profiles of dark haloes at large scales", Statistical challenges for large-scale structure in the era of LSST (Oxford, UK, April 18-20, 2018)

[109] Kojiro Kawana: "A Variety of Tidal Disruptions Events of a WD by a BH", Jet and Shock Breakouts in Cosmic Transients (Kyoto, Japan, May 14-18, 2018)

[110] Conor M. B. Omand: "Dust Formation and Emission from Pulsar-Driven Supernovae", Jets and Shock Breakouts in Cosmic Transients (Kyoto, Japan, May 14-18, 2018)

[111] Daichi Tsuna, Ayako Ishii, Kazumi Kashiyama, and Toshikazu Shigeyama: "Multi-wavelength Detectability of Mass Ejection in Failed Supernovae from Blue Supergiants and Wolf-Rayet Stars", Jets and Shock Breakouts in Cosmic Transients (Kyoto, Japan, May 14-18, 2018)

[112] Takahiro Nishimichi: "Dark Quest I. Emulators for the clustering of halos/galaxies", The Nonlinear Universe 2018 (Smartno, Slovenia, July 15-21, 2018)

[113] Ken Osato, Takahiro Nishimichi, Francis Bernardeau, and Atsushi Taruya: "Blind test of perturbation theories with N-body simulations", Summer School on Large-Scale Structure (Berlin, Germany, July 23-27, 2018)

[114] Conor M. B. Omand: "Dust Formation and Emission from Pulsar-Driven Supernovae", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[115] Riouhei Nakatani: "Radiation Hydrodynamics Simulations of Photoevaporation of Protoplanetary Disks: Metallicity Dependence of UV and X-ray Photoevaporation", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[116] Toyokazu Sekiguchi: "Long-term dynamics of axion strings", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[117] Yi-Peng Wu: "Search for heavy physics in the cosmological collider", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[118] Hiroaki W. H. Tahara: "Self-anisotropizing universe in Horndeski theory", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[119] Daichi Tsuna, Ayako Ishii, Kazumi Kashiyama, and Toshikazu Shigeyama: "Detectability of Mass Ejection from Failed Supernovae", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[120] Natsuki H. Hayatsu: "The Star-Formation History of the Early Universe as Revealed by Blind Searches for Far-infrared Emission Lines", XXXth International Astronomical Union General Assembly (Vienna, Austria, August 20-31, 2018)

[121] Takuma Suda, et al.: "What are the implications of stellar chemical abundances in dwarf galaxies?", IAU Symposium 344: Dwarf Galaxies: From the Deep Universe to the Present (Vienna, Austria, Auguest 20-24, 2018)

[122] Jun'ichi Yokoyama: "Gravitational wave data analysis with the independent component analysis", KAGRA data analysis workshop (Tokyama, Japan, August 23, 2018)

[123] Minxi He: "Inflation in the Mixed Higgs-R^2 Model", COSMO-18 (Daejeon, Korea, August 27-31, 2018)

[124] Yi-Peng Wu: "Search for hybrid inflation with the cosmological collider", COSMO-18 (Daejeon, Korea, August 27-31, 2018)

[125] Naritaka Oshita: "Inflationary universes born out of the highly inhomogeneous initial condition", COSMO-18 (Daejeon, Korea, August 27-31, 2018)

[126] Hiroaki W. H. Tahara: "Self-anisotropizing universe in Horndeski theory", COSMO-18 (Daejeon, Korea, August 27-31, 2018)

[127] Toyokazu Sekiguchi: "Simulation of axion electrodynamics and its cosmological applications", Invisibles 2018 (Karlsruhe, Germany, September 3-7, 2018)

[128] Tomonori Totani: "Lethal radiation from nearby supernovae helps to explain the small cosmological constant", 8th International Workshop on Astronomy and Relativistic Astrophysics (Ollantaytambo, Peru, September 9-15, 2018)

[129] Yi-Peng Wu: "Signature of heavy physics in the primordial non-Gaussianity", GRAVITY@PRAGUE 2018 (Prague, Czech Republic, September 10-14, 2018)

[130] Kohei Kamada: "Primordial Hypermagnetic Fields with Helicity and Baryon Asymmetry of the Universe", Quantum Anomalies and Chiral Magnetic Phenomena (Stockholm, Sweden, September 17 - October 12, 2018)

[131] Kazuhiro D. Kanagawa, Hidekazu Tanaka, and Ewa Szuszkiewicz: "Radial migration of a giant planet in a protoplanetary disk", Japanese-German meeting on Exoplanets and Planet Formation 2018 (Edesheim, Germany, September 24-28, 2018)

[132] Masamune Oguri: "Cluster mass distributions", Chile-Japan Academic Forum 2018: Astronomy and Astronomical Instrumentation (Nikko, Japan, September 26-27, 2018)

[133] Akira Harada: "The Neutrino Distributions in the Rotating Core-Collapse Superanova", Deciphering multidimensional nature of core-collapse Supernovae via Gravitational-Wave and neutrino signatures (Toyama, Japan, October 8-10, 2018)

[134] Ken Osato, Samuel Flnder, Daisuke Nagai, Masato Shirasaki, and Naoki Yoshida: "Investigating Cluster Astrophysics and Cosmology with Cross-Correlation of Thermal SZ Effect and Weak Lensing", ICM Physics and Modeling (Munich, Germany, October 8-10, 2018)

[135] Hiromasa Suzuki, et al.: "A Study on Homogeneous Recombining Plasma of G359.1−0.5: the GeV/VHE gamma-ray SNR Interacting with Molecular Clouds", SNR workshop 2018 (Nagoya, Japan, October 9-10, 2018)

[136] Tomoaki Kasuga, et al.: "Asymmetric Expansion of the Fe Ejecta in Kepler's SNR", SNR workshop 2018 (Nagoya, Japan, October 9-10, 2018)

[137] Toyokazu Sekiguchi: "Long-term dynamics in axion string networks", 10th symposium on Discovery, Fusion, Creation of New Knowledge by Multidisciplinary Computational Sciences (Tsukuba, Japan, October 15-16, 2018)

[138] Ken Osato, Daisuke Nagai, and Masato Shirasaki: "Modeling ICM profile with Illustris simulations", IllustrisTNG Science Meeting (Munich, Germany, October 15-17, 2018)

[139] Taira Oogi: "Clustering of optical and X-ray AGNs in a semi-analytic model", Formation and evolution of SMBHs revealed by 'Wide field', 'Multi-wavelength', and 'Transient' surveys with HSC (Sendai, Japan, November 2-3, 2018)

[140] Taira Oogi: "Modeling galaxy quenching and spatial distributions of star-forming and quenched galaxies", The 8th KIAS Workshop on Cosmology and Structure Formation (Seoul, Korea, November 4-9, 2018)

[141] Toyokazu Sekiguchi: "Long-term dynamics of axion strings", The 28th Workshop on General Relativity and Gravitation in Japan (Tokyo, Japan, November 5-9, 2018)

[142] Hiroaki W. H. Tahara: "Self-anisotropizing universe in Horndeski theory", The 28th Workshop on General Relativity and Gravitation in Japan (Tokyo, Japan, November 5-9, 2018)

[143] Yi-Peng Wu: "Higgs as heavy-lifted physics during inflation", The 28th Workshop on General Relativity and Gravitation in Japan (Tokyo, Japan, November 5-9, 2018)

[144] Minxi He: "Reheating in the Mixed Higgs-R^2 Model", The 28th Workshop on General Relativity and Gravitation in Japan (Tokyo, Japan, November 5-9, 2018)

[145] Hiromasa Suzuki, et al.: "A study on escaping of cosmic rays from supernova remnant shocks through observations on thermal X-ray plasma", Particle Acceleration and Transport: from the Sun to Extragalactic Sources (Calabria, Itary, November 12-16, 2018)

[146] Kana Moriwaki: "The distribution and physical properties of high-redshift [OIII] emitters in a cosmological hydrodynamics simulation", IAU341 PanModel2018 Challenges in Panchromatic Galaxy Modelling with Next Generation Facilities (Osaka, Japan, November 12-16, 2018)

[147] Minxi He: "Reheating in the Mixed Higgs-R^2 Model", CosPA2018, International Symposium on Cosmology and Particle Astrophysics (Yangzhou, China, November 19-23, 2018)

[148] Soichiro Hashiba: "Non-perturbative method for calculating gravitational particle creation", CosPA2018, International Symposium on Cosmology and Particle Astrophysics (Yangzhou, China, November 19-23, 2018)

[149] Hiroaki W. H. Tahara: "Self-anisotropizing universe in Horndeski theory", CosPA2018, International Symposium on Cosmology and Particle Astrophysics (Yangzhou, China, November 19-23, 2018)

[150] Tilman Hartwig: "Carbon-enhanced metal-poor stars as a consequence of inhomogeneous metal mixing", Stellar Archaeology as a Time Machine to the Early Universe, Japan (Kashiwa, Japan, December 3-7, 2018)

[151] Takuma Suda, Shimako Yamada, and Masayuki Y. Fujimoto: "s-Process Nucleosynthesis in the Progenitors of Carbon-Enhanced Metal-Poor Stars", Stellar Archaeology as a Time Machine to the Early Universe, Japan (Kashiwa, Japan, December 3-7, 2018)

[152] Junya Kume, et al.: "Independent component analysis with iKAGRA data: continuous wave signals", 21st KAGRA Face-to-Face Meeting (Tokyo, Japan, December 5-6, 2018)

[153] Toyokazu Sekiguchi, et al.: "Independent component analysis with iKAGRA data: burst signals", 21st KAGRA Face-to-Face Meeting (Tokyo, Japan, December 5-6, 2018)

[154] Naoki Yoshida: "Big Data Cosmology with Subaru HSC", 4th CREST International Symposium on Big Data Application (Tokyo, Japan, January 14-15, 2019)

[155] Kojiro Kawana: "A Variety of Tidal Disruptions Events of a White Dwarf by a Black Hole", 10th DTA symposium "Stellar deaths and their diversity" (Tokyo, Japan, January 21-23, 2019)

[156] Conor M. B. Omand: "Dust Formation and Emission from Pulsar-Aided Supernova Remnants", 10th DTA symposium "Stellar deaths and their diversity" (Tokyo, Japan, January 21-23, 2019)

[157] Kohei Kamada: "On the preheating in a scale invariant UV extension of Higgs inflation", Scale invariance in particle physics and cosmology (Geneva, Switzerland, January 28 - February 1, 2019)

[158] Masamune Oguri: "Shapes and alignments of clusters", 2019 BUFFALO Collaboration Meeting (Las Vegas, USA, February 5-8, 2019)

[159] Kana Moriwaki: "The distribution and physical properties of high-redshift [OIII] emitters in a cosmological hydrodynamics simulation", New Frontiers of Submillimeter Astronomy (Nagano, Japan, February 17-19, 2019)

[160] Toyokazu Sekiguchi: "Probing dark energy with 21cm line observations", JSPS- FAPESP workshop on Dark Energy, Dark Matter, and Galaxies (Sao Paulo, Brazil, February 18-20, 2019)

[161] Naoki Yoshida: "Statistical Computational Cosmology with Big Astronomical Data", 1st RCCS Symposium (Kobe, February 19, 2019)

[162] Tilman Hartwig: "Carbon-enhanced metal-poor stars as a consequence of inhomogeneous metal mixing", Into the Starlight: The end of the Cosmic Dark Ages (Aspen, USA, March 3-9, 2019)

[163] Soichiro Hashiba: "Gravitational particle creation for dark matter and reheating", Accelerating Universe in the Dark (Kyoto, Japan, March 4-8, 2019)

[164] Taira Oogi: "Modelling galaxy quenching and spatial distributions of star-forming and quenched galaxies", Panchromatic Panoramic Studies of Galaxy Clusters: from HSC to PFS and ULTIMATE (Taipei, Taiwan, March 11-13, 2019)

[165] Ken Osato, Hironao Miyatake, Daisuke Nagai, Masato Shirasaki, and Naoki Yoshida: "Cosmology and Cluster Astrophysics with WL and tSZ", Panchromatic Panoramic Studies of Galaxy Clusters: from HSC to PFS and ULTIMATE (Taipei, Taiwan, March 11-13, 2019)

[166] Takahiro Nishimichi: "Statistical Computational Cosmology with Subaru HSC", CREST/PRESTO Big Data Areas Joint PI Meeting with NSF/DATAIA Researchers (Kyoto, Japan, March 12, 2019)

[167] Tilman Hartwig: "Observing the First Stars", Extremely Big Eyes on the Early Universe (Kashiwa, Japan, March 25-29, 2019)

[168] Kazumi Kashiyama: "The birth and growth of supermassive black holes in the early universe", Space Gravitational Wave Detection (Tokyo, Japan, March 27-29, 2019)

5.3.2 Invited talks

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

[170] Ayako Ishii, Toshikazu Shigeyama, and Masaomi Tanaka: "Early Emission in Shock Breakout of Binary Neutron Star Merger", Jets and Shock Breakouts in Cosmic Transients (Kyoto, Japan, May 14-18, 2018)

[171] Masamune Oguri: "Gravitational lensing with Subaru Hyper Suprime-Cam survey", Studying the Universe with GAlaxy suRveys – Revealing the Unlimited in ShangHai (Shanghai, China, June 11-15, 2018)

[172] Naoki Yoshida: "Formation of the First Galaxies and Blackholes", Rise and Shine 2018 (Strasbourg, France, June 18-22, 2018)

[173] Jun'ichi Yokoyama: "Reheating and spontaneous cogenesis after G-inflation", Joint Canada Asia Pacific Conference on General Relativity and Relativistic Astrophysics, (Edmonton, Canada, June 25-29, 2018)

[174] Yuuki Wada, et al.: "X-ray estimates of white dwarf masses in magnetic cataclysmic variables", 15th Marcel Grossmann Meeting (Rome, Italy, July 1-7, 2018)

[175] Jun'ichi Yokoyama: "Self-anisotropizing inflationary universe in Horndeski theory and beyond", 7th International Conference on New Frontiers in Physics (Crete, Greece, July 4-12, 2018)

[176] Jun'ichi Yokoyama: "Approaches to inflationary cosmology", Summer School of Democritus Institute (Greece, July 6, 2018)

[177] Jun'ichi Yokoyama: "Cosmology of the Higgs field", 5th Korea-Japan workshop on dark energy (Daejeon, Korea, August 6-10, 2018)

[178] Masamune Oguri: "Cluster mass distributions", The Universe as a telescope: probing the cosmos at all scales with strong lensing (Milan, Italy, September 3-7, 2018)

[179] Yuuki Wada, et al.: "Recent Updates from Mapping Observation of High-energy phenomena In Japanese Winter Thunderstorms", Thunderstorms and Elementary Particle Acceleration (TEPA) 2018 (Aragatsotn, Armenia, September 17-20, 2018)

[180] Naoki Yoshida: "Formation of the First Galaxies and Blackholes", IGM2018: Revealing Cosmology and Reionization History with the Intergalactic Medium (Kashiwa, Japan, September 18-21, 2018)

[181] Tilman Hartwig: "A novel formation scenario for carbon-enhanced metal-poor stars", Taiwanese Theoretical Astrophysics Workshop, Taiwan (Taipei, Taiwan, September 25-27, 2018)

[182] Kazumi Kashiyama: "Ultra-Long Gamma-Ray Bursts and Tidal Disruption Events from Intermediate-Mass Black Holes in Collapsing Star Clusters", Taiwanese Theoretical Astrophysics Workshop (Taipei, Taiwan, September 25-27, 2018)

[183] Aya Bamba: "X-ray studies of SNRs and relevant sources in Large Magellanic Clouds", SNR workshop 2018 (Nagoya, Japan, October 9-10, 2018)

[184] Tomonori Totani: "Fast Radio Burst and Non-thermal Afterglow from Binary Neutron Star Mergers", The extreme Universe viewed in very-high-energy gamma rays 2018 (La Palma, Spain, October 12, 2018)

[185] Takahiro Nishimichi: "Dark Quest I.: A New Simulation Suite for Halo Clustering at 100+1 wCDM Models", The 4th CosKASI-ICG-NAOC-YITP Joint Workshop on Frontiers of Cosmology (Beijing, China, October 29 - November 2, 2018)

[186] Aya Bamba: "Constraining the energetic particle content of Supernova Remnants through X-ray observations", Particle Acceleration and Transport: from the Sun to Extragalactic Sources (Calabria, Italy, November 12-16, 2018)

[187] Hirokazu Odaka: "Monte Carlo Simulations using Geant4 for Hitomi and Suzaku", New eyes on X-ray astrophysical objects with Japanese and Chinese observatories (Sagamihara, Japan, 19-21 November, 2018)

[188] Jun'ichi Yokoyama: "Micro black hole remnant and Planckian interacting dark matter", CosPA2018, International Symposium on Cosmology and Particle Astrophysics (Yangzhou, China, November 19-23, 2018)

[189] Naoki Yoshida: "Conference Summary: Formation of the First Stars and Galaxies", Stellar Archeology as a Time Machine to the First Stars (Kashiwa, Japan, December 3-7, 2018)

[190] Yi-Peng Wu: "Inflationary particle production and non-Gaussianity", 5th International Workshop on "Dark Matter, Dark Energy and Matter-Antimatter Asymmetry" (Hsinchu and Kaohsiung, Taiwan, December 28-31, 2018)

[191] Naoki Yoshida: "Cosmology with Big Astronomical Data", 4th International Symposium on Big-Data Analytics in Science and Engineering (Aizu, Japan, February 4, 2019)

[192] Tomonori Totani: "VHE gamma-ray and neutrino emission from star forming galaxies / Some topics on fast radio bursts", The 10th International workshop on Very High Energy Particle Astronomy (Kashiwa, Japan, February 18-20, 2019)

[193] Kazumi Kashiyama: "Detectability of Small-Scale Dark Matter Clumps with Pulsar Timing Arrays", JSPS-FAPESP workshop on Dark Energy, Dark Matter, and Galaxies (Sao Paulo, Brazil, February 18-20, 2019)

[194] Masamune Oguri: "An optically selected HSC cluster catalog", Panchromatic Panoramic Studies of Galaxy Clusters: from HSC to PFS and ULTIMATE (Taipei, Taiwan, March 11-13, 2019)

6 Project 2. Gravitational-wave astrophysics and experimental gravity

6.1 Activity Report

6.1.1 Cannon group

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 LIGO Scientific Collaboration (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. During this past academic year the Advanced LIGO and Advanced Virgo antennas began their third observational data-taking run, "O3". 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. In the next academic year year we hope to see KAGRA join the international network of gravitational-wave telescopes. Members of our group are active in all aspects of observational gravitational-wave astronomy, the following are some highlights from FY2017.

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 the release of the first catalogue of gravitational-wave signals, GWTC-1 [arXiv:1811.12907]. The GstLAL detection system developed by our group contributed the bulk of the discoveries to that list. During O3, our group has made significant contributions to several major discoveries of the LSC and Virgo Collaboration. A new neutron star merger was discovered, S190425z, and just as happened in O2 the GstLAL detection system developed by our group was the only system to identify it. Unfortunately not all gravitational-wave detectors were operating, so the location of the source could not be determined precisely, and attempts to identify an optical counterpart have not been successful. We

are hopeful that future discoveries will repeat the experience of GW170817. We have also identified what might be the first neutron star-black hole merger, S190426c.

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.

Other Exotica

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 working to significantly improve the sensitivity and performance of the system to make it easier to use and more effective in the future.

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 completed a search for gravitational waves generated by this mechanism using stochastic gravitational-wave detection techniques.

People and Things

During the 2018 through 2019 academic year, two of our Master's students, Mr. Hiroaki Ohta and Mr. Daichi Tsuna, successfully defended their theses and were admitted to the doctoral program to remain with our group. We were joined by two new Master's students, Mr. Chi-Wai Chan and Ms. Minori Shikauchi, one new postdoctoral fellow, Dr. Heather Fong, and one new assistant professor, Dr. Atsushi Nishizawa who joined our group just at the end of the 2018/19 academic year. Our group successfully renewed its funding thanks to the generous support of JSPS. Two doctoral students, Mr. Souichiro Morisaki and Mr. Leo Tsukada, obtained independent funding to support extended visits to research groups in Cardiff University, and the California Institute of Technology, respectively.

Our group enjoyed substantial international conference participation in the 2018–2019 academic year. Group members attended a total of 40 international meetings, giving invited talks at 9.

6.1.2 Affiliates

Masaki Ando

We are working on KAGRA, a gravitational-wave antenna at Kamioka, Gifu prefecture. 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. We are planning to start observation run in the end of 2019. 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.

Mamoru Doi

The Tomo-e Gozen Camera is a new CMOS camera developed for the 105 cm Kiso Schdmit telescope. In total 84 2k × 1k CMOS sensors with large pixel format (19μm/pixel) will cover 20 deg^2, and the dedicated electronics can achieve two frames per second with low readout noise ($\sim 2e^-$). In FY2018 we installed 63 sensors at the prime focus of the Kiso Schmidt telescope, and carried out commissioning observations.

The wide field of view and the fast readout speed of Tomo-e Gozen enable us to quickly search for optical counterparts of GW events in their large localization errors (typically a few 100 deg^2). During an observing run of the gravitational wave detectors which continues for about a year, GW event alerts may arrive anytime 24 hours a day. To dynamically perform follow-up observations reacting those alerts, we have developed an automated observation system which starts follow-up observations triggered by electronic alerts. Images obtained in the follow-up observations are automatically processed by a pipeline software, which performs image subtractions with reference images and find transient events. Although the gravitational wave detectors have not detected any GW event during the engineering runs conducted in FY2018 (ER13 in December 2018 and ER14 in March 2019), the functionality of the automated observation system has been confirmed by test observations using mock alerts.

The Research Center for the Early Universe supported this project with the purchase of 264 TBytes of storage and partial salary for a project assistance professor.

6.2 Publication List

[1] Masao Hayashi, Ken-ichi Tadaki, Tadayuki Kodama, Kotaro Kohno, et al.: "Molecular Gas Reservoirs in Cluster Galaxies at $z = 1.46$", The Astrophysical Journal, **856** (2018) 118

[2] Takuma Izumi, et al. (incl. Kotaro Kohno): "Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs). III. Star formation properties of the host galaxies at $z > 6$ studied with ALMA", Publications of the Astronomical Society of Japan, **70** (2018) 36

[3] B. P. Abbott, et al. (KAGRA Collaboration, LIGO Scientific Collaboration, and Virgo Collaboration, incl. Masaki Ando, Kipp Cannon, Jun'ichi Yokoyama, et al.): "Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA", Living Reviews in Relativity, **21** (2018) 3

[4] Tomofumi Shimoda, Naoki Aritomi, Ayaka Shoda, Yuta Michimura and Masaki Ando: "Seismic cross-coupling noise in torsion pendulums", Physical Review D, **97** (2018) 104003

[5] Kentaro Komori, Yutaro Enomoto, Hiroki Takeda, Yuta Michimura, Kentaro Somiya, Masaki Ando, and Stefan W. Ballmer: "Direct approach for the fluctuation-dissipation theorem under nonequilibrium steady-state conditions", Physical Review D, **97** (2018) 102001

[6] Masao Sako, et al. (incl. Mamoru Doi): "The Data Release of the Sloan Digital Sky Survey-II Supernova Survey", Publications of the Astronomical Society of the Pacific, **130** (2018) 064002

[7] Hanindyo Kuncarayakti, Joseph P. Anderson, Lluís Galbany, Keiichi Maeda, Mario Hamuy, Greg Aldering, Nobuo Arimoto, Mamoru Doi, Tomoki Morokuma, and Tomonori Usuda: "Constraints on core-collapse supernova progenitors from explosion site integral field spectroscopy", Astronomy & Astrophysics, **613** (2018) A35

[8] Hideki Umehata, et al. (incl. Kotaro Kohno): "ALMA deep field in SSA22: Survey design and source catalog of a 20 arcmin^2 survey at 1.1 mm", Publications of the Astronomical Society of Japan, **70** (2018) 65

[9] Yuta Michimura, Kentaro Komori, Atsushi Nishizawa, Hiroki Takeda, Koji Nagano, Yutaro Enomoto, Kazuhiro Hayama, Kentaro Somiya, and Masaki Ando: "Particle swarm optimization of the sensitivity of a cryogenic gravitational wave detector", Physical Review D, **97** (2018) 122003

[10] Qing-Hua Tan, et al. (incl. Kotaro Kohno): "The MALATANG Survey: The $L_{\rm GAS}$-$L_{\rm IR}$ Correlation on Subkiloparsec Scale in Six Nearby Star-forming Galaxies as Traced by HCN J = 4–3 and HCO$^+$ J = 4–3", The Astrophysical Journal, **860** (2018) 165

[11] Seiji Fujimoto, Masami Ouchi, Kotaro Kohno, et al.: "ALMA 26 Arcmin^2 Survey of GOODS-S at One Millimeter (ASAGAO): Average Morphology of High-z Dusty Star-forming Galaxies in an Exponential Disk ($n \simeq 1$)", The Astrophysical Journal, **861** (2018) 7

[12] Milagros Zeballos, et al. (incl. Kotaro Kohno): "AzTEC 1.1 mm observations of high-z protocluster environments: SMG overdensities and misalignment between AGN jets and SMG distribution", Monthly Notices of the Royal Astronomical Society, **479** (2018) 4577

[13] Yoshiki Matsuoka, et al. (incl. Kotaro Kohno): "Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs). IV. Discovery of 41 Quasars and Luminous Galaxies at $5.7 < z < 6.9$", The Astrophysical Journal Supplement Series, **237** (2018) 5

[14] Keiichi Maeda, Ji-an Jiang, Toshikazu Shigeyama, and Mamoru Doi: "Type Ia Supernovae in the First Few Days: Signatures of Helium Detonation versus Interaction", The Astrophysical Journal, **861** (2018) 78

[15] Hiroki Takeda, Atsushi Nishizawa, Yuta Michimura, Koji Nagano, Kentaro Komori, Masaki Ando, and Kazuhiro Hayama: "Polarization test of gravitational waves from compact binary coalescences", Physical Review D, **98** (2018) 022008

[16] Peter R. Roelfsema, et al. (incl. Kotaro Kohno): "SPICA-A Large Cryogenic Infrared Space Telescope: Unveiling the Obscured Universe", Publications of the Astronomical Society of Australia, **35** (2018) e030

[17] Ken-ichi Tadaki, et al. (incl. Kotaro Kohno): "The gravitationally unstable gas disk of a starburst galaxy 12 billion years ago", Nature, **560** (2018) 613

[18] Yuta Kato, et al. (incl. Kotaro Kohno): "A high dust emissivity index β for a CO-faint galaxy in a filamentary Lyα nebula at $z = 3.1$", Publications of the Astronomical Society of Japan, **70** (2018) L6

[19] Ji-an Jiang, Mamoru Doi, Keiichi Maeda, and Toshikazu Shigeyama: "Surface Radioactivity or Interactions? Multiple Origins of Early-excess Type Ia Supernovae and Associated Subclasses", The Astrophysical Journal, **865** (2018) 149

[20] Shutaro Ueda, et al. (incl. Kotaro Kohno): "A Cool Core Disturbed: Observational Evidence for the Coexistence of Subsonic Sloshing Gas and Stripped Shock-Heated Gas Around the Core of RX J1347.5−1145", The Astrophysical Journal, **866** (2018) 48

[21] B. P. Abbott, et al. (The LIGO Scientific Collaporation and the Virgo Collaboration, incl. Kipp Cannon, et al.): "GW170817: Measurements of Neutron Star Radii and Equation of State", Physical Review Letters, **121** (2018) 161101

[22] Ippei Obata, Tomohiro Fujita, and Yuta Michimura: "Optical Ring Cavity Search for Axion Dark Matter", Physical Review Letters, **121** (2018) 161301

[23] Takuma Izumi, Keiichi Wada, Ryosuke Fukushige, Sota Hamamura, and Kotaro Kohno: "Circumnuclear Multiphase Gas in the Circinus Galaxy. II. The Molecular and Atomic Obscuring Structures Revealed with ALMA", The Astrophysical Journal, **867** (2018) 48

[24] Bunyo Hatsukade, Kotaro Kohno, et al.: "ALMA twenty-six arcmin^2 survey of GOODS-S at one millimeter (ASAGAO): Source catalog and number counts" Publications of the Astronomical Society of Japan, **70** (2018) 105

[25] Tatsuya Takekoshi, et al. (incl. Kotaro Kohno): "The Dust-selected Molecular Clouds in the Northeast Region of the Small Magellanic Cloud", The Astrophysical Journal, **867** (2018) 117

[26] Tao Wang, et al. (incl. Kotaro Kohno): "Revealing the Environmental Dependence of Molecular Gas Content in a Distant X-Ray Cluster at $z = 2.51$", The Astrophysical Journal, **867** (2018) L29

[27] B. P. Abbott, et al. (The LIGO Scientific Collaporation and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Search for Subsolar-Mass Ultracompact Binaries in Advanced LIGO's First Observing Run", Physical Review Letters, **121** (2018) 231103

[28] Yoshiki Matsuoka, et al. (incl. Kotaro Kohno): "Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs). V. Quasar Luminosity Function and Contribution to Cosmic Reionization at $z = 6$", The Astrophysical Journal, **869** (2018) 150

[29] Eiichi Egami, et al. (incl. Kotaro Kohno): "Probing the high-redshift universe with SPICA: Toward the epoch of reionisation and beyond", Publications of the Astronomical Society of Australia, **35** (2018) e048

[30] B. P. Abbott, et al. (The LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Properties of Binary Neutron Star Merger GW170817", Physical Review X, **9** (2019) 011001

[31] KAGRA collaboration (incl. Masaki Ando, Kipp Cannon, Jun'ichi Yokoyama, et al.): "KAGRA: 2.5 Generation Interferometric Gravitational Wave Detector", Nature Astronomy, **3** (2019) 35-40

[32] A. Albert, et al. (ANTARES and IceCube and LIGO Scientific Collaboration and Virgo Collaboration, incl. Kipp Cannon, et al.): "Search for multimessenger sources of gravitational waves and high-energy neutrinos with advanced LIGO during its first observing run, ANTARES, and IceCube", The Astrophysical Journal, **870** (2019) 134

[33] E. Burns, et al. (Fermi Gamma-ray Burst Monitor Team, the LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "A Fermi Gamma-Ray Burst Monitor Search for Electromagnetic Signals Coincident with Gravitational-wave Candidates in Advanced LIGO's First Observing Run" The Astrophysical Journal, **871** (2019) 90

[34] Misaki Mizumoto, Takuma Izumi, and Kotaro Kohno: "Kinetic Energy Transfer from X-Ray Ultrafast Outflows to Millimeter/Submillimeter Cold Molecular Outflows in Seyfert Galaxies", The Astrophysical Journal, **871** (2019) 156

[35] Ryo Ando, Kotaro Kohno, et al.: "The Excitation State of Galactic Diffuse Molecular Gas, Investigated with ALMA Observations of Multi-transition Absorption Lines", The Astrophysical Journal, **871** (2019) 256

[36] Yoshiki Matsuoka, et al. (incl. Kotaro Kohno): "Discovery of the First Low-Luminosity Quasar at $z > 7$", The Astrophysical Journal, **872** (2019) L2

[37] B. P. Abbott, et al. (The LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Constraining the p-Mode-g-Mode Tidal Instability with GW170817", Physical Review Letters, **122** (2019) 061104

[38] Nobuyuki Matsumoto, Seth B. Cataño-Lopez, Masakazu Sugawara, Seiya Suzuki, Naofumi Abe, Kentaro Komori, Yuta Michimura, Yoichi Aso, and Keiichi Edamatsu: "Demonstration of Displacement Sensing of a mg-Scale Pendulum for mm- and mg-Scale Gravity Measurements", Physical Review Letters, **122** (2019) 071101

[39] Yoichi Tamura, et al. (incl. Kotaro Kohno): "Detection of the Far-infrared [O III] and Dust Emission in a Galaxy at Redshift 8.312: Early Metal Enrichment in the Heart of the Reionization Era", The Astrophysical Journal, **874** (2019) 27

[40] B. P. Abbott, et al. (The LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Search for transient gravitational-wave signals associated with magnetar bursts during Advanced LIGO's second observing run", The Astrophysical Journal, **874** (2019) 163

[41] KAGRA Collaboration (incl. Masaki Ando, Kipp Cannon, Jun'ichi Yokoyama, et al.): "Vibration isolation system with a compact damping system for power recycling mirrors of KAGRA", Classical and Quantum Gravity, **36** (2019) 095015

[42] B. P. Abbott, et al. (The LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Searches for continuous gravitational waves from 15 supernova remnants and Fomalhaut b with Advanced LIGO", The Astrophysical Journal, **875** (2019) 122

[43] B. P. Abbott, et al. (The LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Low-latency gravitational wave alerts for multi-messenger astronomy during the second Advanced LIGO and Virgo observing run", The Astrophysical Journal, **875** (2019) 161

[44] B. P. Abbott, et al. (The LIGO Scientific Collaboration and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Search for gravitational waves from a long-lived remnant of the binary neutron star merger GW170817", The Astrophysical Journal, **875** (2019) 160

[45] M. Soares-Santos, et al. (DES Collaboration and LIGO Scientific Collaboration and Virgo Collaboration, incl. Kipp Cannon, et al.): "First Measurement of the Hubble Constant from a Dark Standard Siren using the Dark Energy Survey Galaxies and the LIGO/Virgo Binary-Black-hole Merger GW170814", The Astrophysical Journal, **876** (2019) L7

[46] B. P. Abbott, et al. (The LIGO Scientific Collaporation and the Virgo Collaboration, incl. Kipp Cannon, et al.): "All-sky search for long-duration gravitational-wave transients in the second Advanced LIGO observing run", Physical Review D, **99** (2019) 104033

[47] Ryan Magee, Heather Fong, Sarah Caudill, Cody Messick, Kipp Cannon, Patrick Godwin, Chad Hanna, Shasvath Kapadia, Duncan Meacher, Siddharth R. Mohite, Debnandini Mukherjee, Alexander Pace, Surabhi Sachdev, Minori Shikauchi, and Leo Singer: "Sub-threshold binary neutron star search in Advanced LIGO's first observing run", The Astrophysical Journal, **878** (2019) L17

[48] B. P. Abbott, et al. (The LIGO Scientific Collaporation and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Searches for gravitational waves from known pulsars at two harmonics in 2015–2017 LIGO data", The Astrophysical Journal, **879** (2019) 10

[49] B. P. Abbott, et al. (The LIGO Scientific Collaporation and the Virgo Collaboration, incl. Kipp Cannon, et al.): "Narrow-band search for gravitational waves from known pulsars using the second LIGO observing run, 2019", Physical Review D, **91** (2019) 022004

6.3 International Conference Talks

6.3.1 Contributed talks

[50] Hiroki Takeda, et al.: "Parameter estimation with inspiral waveforms of compact binary coalescences including nontensorial gravitational waves polarizations", 19th KAGRA Face-to-Face meeting (Osaka, Japan, May 18-20, 2018)

[51] Satoru Takano, et al.: "TOBA: TOrsion Bar Antenna, The Current Status and Future Plans", 19th KAGRA Face-to-Face meeting (Osaka, Japan, May 18-20, 2018)

[52] Koji Nagano on behalf of KAGRA Detchar subgroup: "Results of the PEM injection during bKAGRA phase 1", 19th KAGRA Face-to-Face meeting (Osaka, Japan, May 18-20, 2018)

[53] Masaki Ando: "KAGRA Roadmap and Configuration", 19th KAGRA Face-to-Face meeting (Osaka, Japan, May 18-20, 2018)

[54] Koji Nagano on behalf of the KAGRA Collaboration: "Environmental monitors and injection test in bKAGRA phase1", The 4th KAGRA International Workshop (Seoul, Korea, June 29-30, 2018)

[55] Yuta Michimura: "Optimization of the KAGRA sensitivity", The 4th KAGRA International Workshop (Seoul, Korea, June 29-30, 2018)

[56] Hiroki Takeda, et al.: "Polarization test of gravitational waves from compact binary coalescences", The 15th Marcel Grossman Meeting (Rome, Italy, July 1-7, 2018)

[57] Koji Nagano, et al.: "Constructing Test Bench for Integration Tests of Components Developed for DECIGO and B-DECIGO", The 15th Marcel Grossman Meeting (Rome, Italy, July 1-7, 2018)

[58] Yuta Michimura, et al.: "Prospects for improving the sensitivity of KAGRA gravitational wave detector", The 15th Marcel Grossman Meeting (Rome, Italy, July 1-7, 2018)

[59] Soichiro Morisaki and Teruaki Suyama: "Search for ultralight scalar field dark matter with gravitational wave observatories", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[60] Ching Pin, Ooi: "Mechanical loss of crystal fibres for torsion pendulum experiments", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[61] Yuta Michimura, et al.: "bKAGRA Phase 1 Paper Status", 20th KAGRA Face-to-Face Meeting (Toyama, Japan, August 24-26, 2018)

[62] Yutaro Enomoto for MIF subgroup: "MIF status", 20th KAGRA Face-to-Face Meeting (Toyama, Japan, August 28-30 2018)

[63] Kotaro Kohno: "New science capabilities with DESHIMA/MOSAIC on LMT 50m", Guillermo Haro 2018 workshop (Tonantzintla, Mexico, September 3-14, 2018)

[64] Kotaro Kohno: "ALMA deep surveys on CANDLES fields", The Universe by the Light of CANDELS: Past and Future (Amherst, USA, October 22-24, 2018)

[65] Hiroki Takeda, et al.: "Probing nontensorial polarization of inspiral gravitational waves with the third-generation detectors", The 28th Workshop on General Relativity and Gravitation in Japan (Tokyo, Japan, November 5-9, 2018)

[66] Kotaro Kohno: "Characterization of dusty galaxies uncovered by ALMA 26 arcmin2 survey of GOODS-S at one-millimeter (ASAGAO)", IAU Symposium 341, PanModel2018: Challenges in Panchromatic Galaxy Modelling with Next Generation Facilities (Osaka, Japan, November 12-16, 2018)

[67] Leo Tsukada, Thomas Callister, Andrew Matas, and Patrick Meyers: "A first search for stochastic gravitational wave background from ultra-light bosons", Gravitational Wave Physics and Astronomy Workshop (College Park, USA, December 1-4, 2018)

[68] Daichi Tsuna, et al.: "Current Status of the Search for Cosmic Strings in the Advanced LIGO and Advanced Virgo's Second Observing Run", Gravitational Wave Physics and Astronomy Workshop (College Park, USA, December 1-4, 2018)

[69] Tomofumi Shimoda, et al.: "R&D of Newtonian noise measurement", KAGRA satellite meeting (Tokyo, Japan, December 4, 2018)

[70] Yuta Michimura, et al.: "Summary of Past Discussions on KAGRA Upgrade", 21st KAGRA Face-to-Face Meeting (Tokyo, Japan, December 5-6, 2018)

[71] Yuta Michimura, et al.: "Final Draft of bKAGRA Phase 1 Paper", 21st KAGRA Face-to-Face Meeting (Tokyo, Japan, December 5-6, 2018)

[72] Heather Fong: "Latest results from Advanced LIGO and Virgo and outlook for next observing run", 2019 Testing Gravity Meeting (Vancouver, Canada, January 23-26, 2019)

[73] Satoru Takano, et al.: "Newtonian Noise Measurement by Torsion Bar Antenna", The 1st Kagra-Virgo-3G Detectors Workshop (Perugia, Italy, February 16, 2019)

[74] Atsushi Nishizawa: "Cosmological test of gravity with gravitational waves", The 4th KMI International Symposium (Nagoya, Japan, February 18-20, 2019)

[75] Soichiro Morisaki, Leo Singer, and Vivien Raymond: "Automatic PE follow-up", Face2Face meeting for CBC Parameter Estimation group (Monash, Australia, February 18-22, 2019)

[76] Kotaro Kohno: "Galaxy surveys using Large Submillimeter Telescope", Accelerating Universe in the Dark (Kyoto, Japan, March 4-8, 2019)

[77] Soichiro Morisaki, Leo Singer, and Vivien Raymond: "Automatic PE follow-up with GWCelery", LIGO-VIRGO Collaboration Meeting (Lake Geneva, USA, March 18-21, 2019)

[78] Takuya Kawasaki: "Optical Levitation to Realise a Macroscopic Quantum System", The 1st QFilter Workshop (Paris, France, Mar 19, 2019)

[79] Yuta Michimura: "Brief Overview of QFilter Project", The 1st QFilter Workshop (Paris, France, Mar 19, 2019)

[80] Yuta Michimura: "Optical Levitation of a Mirror for Realizing Macroscopic Entanglement", The 1st QFilter Workshop (Paris, France, Mar 19, 2019)

6.3.2 Invited talks

[81] Tomofumi Shimoda, et al.: "Status of Torsion-bar Antenna Development", Gravitational Wave Advanced Detector Workshop 2018 (Alaska, USA, May 12-17, 2018)

[82] Yutaro Enomoto and Kiwamu Izumi for the KAGRA Collaboration: "KAGRA: Status and Near Term Plans", Gravitational Wave Advanced Detector Workshop 2018 (Alaska, USA, May 12-17, 2018)

[83] Kentaro Komori, et al.: "Towards observation of quantum radiation pressure fluctuation acting on a torsion pendulum", Gravitational Wave Advanced Detector Workshop 2018 (Alaska, USA, May 12-17, 2018)

[84] Yuta Michimura: "Sensitivity Optimization of Cryogenic Gravitational Wave Detectors", Gravitational Wave Advanced Detector Workshop 2018 (Alaska, USA, May 12-17, 2018)

[85] Kotaro Kohno: "Radio to (sub)millimeter observations of astrophysical plasmas", 12th International Conference on High Energy Density Laboratory Astrophysics (Kurashiki, Japan, May 27 - June 1, 2018)

[86] Mamoru Doi, et al.: "The University of Tokyo Atacama Observatory 6.5m telescope: project overview and current status", SPIE Astronomical Telescopes + Instrumentation (Austin, USA, June 10-15, 2018)

[87] Masaki Ando: "DECIGO : Gravitational-Wave Observation from Space", The 15th Marcel Grossman Meeting (Rome, Italy, July 1-7, 2018)

[88] Masaki Ando, et al.: "TOBA: Torsion-Bar Gravitational-Wave Antenna", The 15th Marcel Grossman Meeting (Rome, Italy, July 1-7, 2018)

[89] Kotaro Kohno: "NOEMA/IRAM 30m-ALMA synergies on the study of galaxies", NOEMA/30m workshop (Mitaka, Japan, July 24-25, 2018)

[90] Kotaro Kohno: "ALMA deep surveys of blank fields and lensing clusters", Chile-Japan Academic Forum 2018 (Nikko, Japan, September 26-27, 2018)

[91] Kotaro Kohno: "Exploring the formation and evolution of galaxies in the early universe by exploiting the superconducting astrophotonics", International Colloquium of Mexcian and Japanese Studies (Mexico City, Mexico, October 16-17, 2018)

[92] Masaki Ando: "Recent results of gravitational wave", Higgs Couplings 2018 (Ryogoku, Japan, November 26-30, 2018)

[93] Yuta Michimura on behalf of the KAGRA Collaboration: "Status of KAGRA: Recent progress towards O3 and future plans", Conference on Multi-messenger Astronomy in the Era of LIGO-India (Khandala, India, January 15-18, 2019)

[94] Kotaro Kohno: "Large Submillimeter Telescope: an overview", International Workshop on Submillimeter Astronomy (Nanjing, China, February 21-23, 2019)

[95] Atsushi Nishizawa: "Testing gravity at cosmological distance with GWs", Space Gravitational Wave Detection (Tokyo, Japan, March 27-29, 2019)

[96] Heather Fong: "Source-dependent ranking statistic for compact binary coalescences", Leonard E Parker Center for Gravitation (Milwaukee, USA, March 28, 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 Application of asteroseismology to explore the spin-orbit architecture of exoplanetary systems

A significant fraction of exoplanetary systems is known to exhibit spin-orbit misalignments. This surprising fact has been mainly revealed by a spectroscopic method, known as the Rossiter-McLaughlin effect for transiting planetary systems. This method measures the projected angle between the stellar spin and the planetary orbital axes, but is insensitive to the obliquity of the stellar spin with respect to the observer. Asteroseismology offers a unique method to infer the stellar obliquity in a complementary fashion.

We analyze and measure the stellar inclination of 94 *Kepler* main-sequence solar-like stars, among which 33 are planetary hosts. Among the 33 stars, we found that the stellar inclination of Kepler-408 is 42^{+5}_{-4} degrees, and thus Kepler-408b is, by far, the smallest planet known to have a significantly misaligned orbit.

We also measure the rotation periods of 19 stars in the *Kepler* transiting planetary systems, $P_{\rm rot,astero}$ from asteroseismology and $P_{\rm rot,phot}$ from photometric variation of their lightcurve. Two stars exhibit two clear peaks in the Lomb-Scargle periodogram, neither of which agrees with the seismic rotation period. Other four systems do not show any clear peak, whose stellar rotation period is impossible to estimate reliably from the photometric variation. For the remaining 13 systems, $P_{\rm rot,astero}$ and $P_{\rm rot,phot}$ agree within 30%. Interestingly, three out of the 13 systems are in the spin-orbit resonant state in which $P_{\rm orb,b}/P_{\rm rot,astero} \approx 1$ with $P_{\rm orb,b}$ being the orbital period of the inner-most planet of each system. While further analysis of stars with reliable rotation periods is required to examine the statistical significance, the spin-orbit resonance between the star and planets, if confirmed, have important implications for the star-planet tidal interaction, in addition to the origin of the spin-orbit (mis-)alignment of transiting planetary systems.

7.1.2 Solar System Explorations

We are engaged in missions for both small and large bodies in the solar system. In FY2018, however, we were focused on small-body mission activities because Hayabusa2 arrived at the target asteroid Ryugu in the beginning of FY2018.

We conducted a variety of observations and analyses for images obtained with a multi-band telescopic camera and panchromatic wide-angle cameras on Hayabusa2 in FY2018. The observed spectral characteristics of Ryugu turned out to be consistent with the dynamically most probable source asteroid families for Ryugu: Eulalia and Polana families. They are among the most widely dispersed C-complex families in the inner main belt, which can deliver fragments at very high flux rate to the resonance zones (ν6 and 3:1), the dominant sources of near-Earth objects (NEO's).

Furthermore, a very high abundance (about twice Itokawa) of boulders are seen on Ryugu. Many lines of evidence for mass wasting observed on Ryugu indicates that its surface is mechanically unconsolidated,

allowing boulders to move easily. The morphologies of impact craters on Ryugu are consistent with gravity-regime formation, in which impact events produce large ejecta masses. These three lines of evidence suggests that large mass of boulders and pebbles should be ejected from Ryugu to space over time.

Consequently, a large number of macroscopic objects of Ryugu-like materials should arrive at Earth, implying that there should be counterparts in our meteorite collection. One of such candidates is moderately dehydrated carbonaceous chondrites, which exhibit very low albedo and flat spectra. They are also found with high abundance in Antarctica, which has sampled the long-term average flux of infalling meteorites on Earth. Another is interplanetary dust particles (IDPs), which also exhibit low albedos and account for large influx of extraterrestrial material to Earth.

Although a decisive conclusion may not be obtained before Ryugu samples returned to Earth are analyzed, currently available observational evidence, such as high boulder abundance on Ryugu, favors that its composition may be similar to moderately dehydrated carbonaceous chondrites. This would further suggest that Ryugu's relatively low abundance of hydrated minerals may be due to partial dehydration on Ryugu's parent body.

7.1.3 Transiting Planets near the Snow Line from 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 [64]. 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.

7.1.4 Exo Jasmine

The M-class IR satellite for astrometry in Japan, JASMINE, plans to observe the galactic bulge. This FY, we started a scientific project, Exo JASMINE, which plans to survey transiting planets around late M-type stars during about half of the observation period when JASMINE cannot observe the budge. We aim to detect habitable transiting planets around such stars, which should be the best targets for characterization by ground-based large telescopes such as TMT and the space observatory such as JWST and Ariel.

7.1.5 Self-lensing Discovery of an unusually small white dwarf in an wide orbit around a Sun-like-star

A self-lensing binary (SLB) is the periodic magnification of a star due to gravitational lensing by a compact star companion, which was predicted by Kip Thorne in 1969. After the serendipitous detection of the first SLB, we performed a systematic survey of SLBs in the Kepler data in international collaboration with Harvard-Smithsonian Center for Astrophysics et al. Using GPU computing, we found four of the five known SLBs. We discovered that these SLBs, which are a white dwarf and a normal star binary, have features similar to field blue stragglers (FBS). But, we found that the white dwarf mass of one of them, KIC 8145411, is only 0.2 solar mass despite its wide nearly circular orbit (1.28 au) (Masuda, Kawahara et al. in press). It is difficult to explain KIC 8145411 using the current binary formation theory. The SLB-FBS connection that we found will provide an excellent test for models of interacting binaries.

7.1.6 LOTUS

Known exoplanets near the snow line are located too far to measure their nature even for its mass. Nearby targets are crucial for further study by ground-based large telescopes or the space observatory.

To find such nearby systems, We are developing the nanosatellite mission, LOTUS (long-period transiting exoplanet surveyor), in collaboration with the University of Tokyo (Nakasuka lab), NAOJ, and Princeton University. LOTUS has a very wide (33 deg × 33 deg) 7.5 cm telescope in a nanosatellite bus system (20 kg) and plans to observe north and south poles continuously.

7.1.7 Physical and Chemical Evolution of a Disk/Envelope System of Solar-Type Protostars

Physical and chemical evolution during formation processes of solar-type protostars has been studied with Atacama Large Millimeter/submillimeter Array (ALMA). A protostellar disk is a birthplace of a planetary system, and observations of its physical and chemical structure are of fundamental importance in understandings of the diversity of planetary system. By taking advantage of unprecedented spatial resolution and sensitivity of ALMA, we are observing nearby protostellar sources in various molecular lines. Highlights for the last year are summarized as follows.

Okoda et al. (2018) have detected the Keplerian motion around the low-mass protostar, IRAS 15398-3359, in Lupus by a high angular resolution observation of the SO line with ALMA. Based on this result, this protostar has been found to have a very low mass (0.007 solar mass). Since this source is deeply embedded in a parent core, the very low mass means the extreme youth of the protostar (∼1000 years). Nevertheless, it has already harbored a Keplerian disk with a size of 40 au in radius. This result provides us with the first observational evidence of "co-evolution" of a protostar and a disk in the earliest phase of star formation.

It is known that the chemical composition of the protostellar source has significant diversity. So far, the chemical diversity is classified by the relative abundances of saturated and unsaturated organic molecules. Oya et al. (2019) have found another type of the diversity in the protostellar source, Elias 29, in Ophiuchus. In this source, SO and SO_2 are very abundant, whereas both saturated and unsaturated organic molecules are deficient. Thus, the sulfur chemistry appears as a new "axis" of the chemical diversity.

For thorough understandings of the physical and chemical evolution, systematic observations of more protostellar sources are needed. With this in mind, we are now conducting the ALMA large program, FAUST, in which we aim at revealing the chemical composition of 13 representative protostellar sources.

7.2 Publication List

[1] Yu Chang, Kazuhisa Goto, Yasuhito Sekine, and Eiichi Tajika: "Depositional processes of impactites from the YAX-1 drill core in the Chicxulub impact structure inferred from vertical profiles of PDF orientations and grain size distributions of shocked quartz", Meteoritics & Planetary Science, **53** (2018) 1323-1340

[2] Masato Ishizuka, Takayuki Kotani, Jun Nishikawa, Takashi Kurokawa, Takahiro Mori, Tsukasa Kokubo, and Motohide Tamura: "Fiber Mode Scrambler for the Subaru Infrared Doppler Instrument (IRD)", Publications of the Astronomical Society of the Pacific, **130** (2018) 065003

[3] Ryo Kandori, Motohide Tamura, Tetsuya Nagata, Kohji Tomisaka, Nobuhiko Kusakabe, Yasushi Nakajima, Jungmi Kwon, and Takahiro Nagayama: "Distortion of Magnetic Fields in a Starless Core. III. Polarization-Extinction Relationship in FeSt 1-457", The Astrophysical Journal, **857** (2018) 100

[4] Masataka Aizawa, Kento Masuda, Hajime Kawahara, and Yasushi Suto: "Systematic Search for Rings around Kepler Planet Candidates: Constraints on Ring Size and Occurrence Rate", The Astronomical Journal, **155** (2018) 206

[5] Masahiro Ikoma, Linda Elkins-Tanton, Keiko Hamano, and Jenny Suckale: "Water Partitioning in Planetary Embryos and Protoplanets with Magma Oceans", Space Science Reviews, **214** (2018) 76

[6] Zachary C. Long, et al. (incl. Motohide Tamura): "Differences in the Gas and Dust Distribution in the Transitional Disk of a Sun-like Young Star, PDS 70", The Astrophysical Journal, **858** (2018) 112

[7] Jungmi Kwon, et al. (incl. Motohide Tamura): "A First Look at BISTRO Observations of the ρ Oph-A core", The Astrophysical Journal, **859** (2018) 4

[8] Shoya Kamiaka, Othman Benomar, and Yasushi Suto: "Reliability of stellar inclination estimated from asteroseismology: analytical criteria, mock simulations, and Kepler data analysis", Monthly Notices of the Royal Astronomical Society, **479** (2018) 391-405

[9] Jungmi Kwon, Takao Nakagawa, Motohide Tamura, James H. Hough, Ryo Kandori, Minho Choi, Miju Kang, Jungyeon Cho, Yasushi Nakajima, and Tetsuya Nagata: "Near-infrared Polarimetry of the Outflow Source AFGL 6366S: Detection of Circular Polarization", The Astronomical Journal, **156** (2018) 1

[10] Kazuhiro D. Kanagawa, Hidekazu Tanaka, and Ewa Szuszkiewicz: "Radial Migration of Gap-opening Planets in Protoplanetary Disks. I. The Case of a Single Planet", The Astrophysical Journal, **861** (2018) 140

[11] Ruobing Dong, et al. (incl. Motohide Tamura): "The Eccentric Cavity, Triple Rings, Two-armed Spirals, and Double Clumps of the MWC 758 Disk", The Astrophysical Journal, **860** (2018) 124

[12] Shogo Nishiyama, et al. (incl. Motohide Tamura): "Radial velocity measurements of an orbiting star around Sgr A*", Publications of the Astronomical Society of Japan, **70** (2018) 74

[13] Archana Soam, et al. (incl. Motohide Tamura): "Magnetic Fields toward Ophiuchus-B Derived from SCUBA-2 Polarization Measurements", The Astrophysical Journal, **861** (2018) 65

[14] Yi Yang, et al. (incl. Motohide Tamura): "High-contrast Polarimetry Observation of the T Tau Circumstellar Environment", The Astrophysical Journal, **861** (2018) 133

[15] Taichi Uyama, et al. (incl. Motohide Tamura): "Subaru/HiCIAO HK_s Imaging of LKHa 330: Multi-band Detection of the Gap and Spiral-like Structures", The Astronomical Journal, **156** (2018) 53

[16] John H. Livingston, et al. (incl. Motohide Tamura): "44 Validated Planets from K2 Campaign 10", The Astronomical Journal, **156** (2018) 78

[17] Yoko Oya, Nami Sakai, Yoshimasa Watanabe, Ana López-Sepulcre, Cecilia Ceccarelli, Bertrand Lefloch, and Satoshi Yamamoto: "Sub-arcsecond Kinematic Structure of the Outflow in the Vicinity of the Protostar in L483", The Astrophysical Journal, **863** (2018) 72

[18] Marshall C. Johnson, et al. (incl. Motohide Tamura): "K2-260 b: a hot Jupiter transiting an F star, and K2-261 b: a warm Saturn around a bright G star", Monthly Notices of the Royal Astronomical Society, **481** (2018) 596

[19] Michihiro Takami, et al. (incl. Motohide Tamura): "Near-infrared High-resolution Imaging Polarimetry of FU Ori-type Objects: Toward a Unified Scheme for Low-mass Protostellar Evolution", The Astrophysical Journal, **864** (2018) 20

[20] Shigeru Ida, Hidekazu Tanaka, Anders Johansen, Kazuhiro D. Kanagawa, and Takayuki Tanigawa: "Slowing Down Type II Migration of Gas Giants to Match Observational Data", The Astrophysical Journal, **864** (2018) 77

[21] Yuki Okoda, Yoko Oya, Nami Sakai, Yoshimasa Watanabe, Jes K. Jørgensen, Ewine F.van Dishoeck, and Satoshi Yamamoto: "The Co-evolution of Disks and Stars in Embedded Stages: The Case of the Very-low-mass Protostar IRAS 15398–3359", The Astrophysical Journal, **864** (2018) L25

[22] Giovanna Tinetti, et al. (incl. Masahiro Ikoma): "A Chemical Survey of Exoplanets with ARIEL", Experimental Astronomy, **46** (2018) 135-209

[23] Yasuhito Hasegawa, Goeffrey Bryden, Masahiro Ikoma, Gautam Vasisht, and Mark Swain: "The Origin of Heavy Element Content Trend in Giant Planets via Core Accretion", The Astrophysical Journal, **865** (2018) 32

[24] Yoshifusa Ita, et al. (incl. Motohide Tamura): "A near-infrared variable star survey in the Magellanic Clouds: the Small Magellanic Cloud data", Monthly Notices of the Royal Astronomical Society, **481** (2018) 4206

[25] Ryo Kandori, Kohji Tomisaka, Motohide Tamura, Masao Saito, Nobuhiko Kusakabe, Yasushi Nakajima, Jungmi Kwon, Takahiro Nagayama, Tetsuya Nagata, and Ken'ichi Tatematsu: "Distortion of Magnetic Fields in a Starless Core. IV. Magnetic Field Scaling on Density and Mass-to-flux Ratio Distribution in FeSt 1-457", The Astrophysical Journal, **865** (2018) 121

[26] Alexander Tavrov, et al. (incl. Masahiro Ikoma): "Stellar Imaging Coronagraph and Exoplanet Coronal Spectrometer – Two Additional Instruments for Exoplanet Exploration Onboard the WSO-UV 1.7 Meter Orbital Telescope", Journal of Astronomical Telescopes, Instruments, and Systems, **4** (2018) 4

[27] Kazumi Ozaki, Christopher T. Reinhard, and Eiichi Tajika: "A sluggish mid-Proterozoic biosphere and its effect on Earth's redox balance", Geobiology, **17** (2019) 3-11

[28] Toshiyuki Mizuki, et al. (incl. Motohide Tamura): "Orbital Characterization of GJ1108A System, and Comparison of Dynamical Mass with Model-derived Mass for Resolved Binaries", The Astrophysical Journal, **865** (2018) 152

[29] Alessandro Morbidelli, Shun-Ichiro Karato, Masahiro Ikoma, et al.: "Editorial: Topical Collection on the Delivery of Water to Protoplanets, Planets, and Satellites", Space Science Reviews, **214** (2018) 110

[30] Yuhiko Aoyama, Masahiro Ikoma, and Takayuki Tanigawa: "Theoretical Model of Hydrogen Line Emission from Accreting Gas Giants", The Astrophysical Journal, **866** (2018) 84

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[58] Seiji Sugita, et al.: "The geomorphology, color, and thermal properties of Ryugu: Implications for parent-body processes", Science, **364** (2019) 252-252

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[60] Kohei Kitazato, et al. (incl. Seiji Sugita, et al.): "The surface composition of asteroid 162173 Ryugu from Hayabusa2 near-infrared spectroscopy", Science, **364** (2019) 272-275

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[62] Shintaro Kadoya and Eiichi Tajika: "Outer limits of the habitable zone in terms of climate mode and climate evolution of Earth-like planets", The Astrophysical Journal, **875** (2019) 7

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[64] Hajime Kawahara and Kento Masuda: "Transiting Planets near the Snow Line from Kepler. I. Catalog", The Astronomical Journal, **157** (2019) 218

7.3 International Conference Talks

7.3.1 Contributed talks

[65] Yoko Oya: "Three Cases of Chemical Differentiation in Disk-Forming Regions of Low-Mass Protostellar Sources", The Early Phase of Star Formation 2018 (Ringberg, Germany, May 13-18, 2018)

[66] Takashi Nakagawa, Eiichi Tajika, and Shintaro Kadoya: "On the climate and magnetic evolution of Earth-like planets", JpGU Meetng 2018 (Makuhari, Japan, May 20-25, 2018)

[67] Ayumi Akiyama, Mariko Harada, Ryutaro Furukawa, Shin-ichi Yokobori, Eiichi Tajika, and Akihiko Yamagishi: "Evolution of antioxidant enzymes in cyanobacteria and its relationships to the rise of atmospheric oxygens", JpGU Meetng 2018 (Makuhari, Japan, May 20-25, 2018)

[68] Shogo Kirino, Eiichi Tajika, and Peng K. Hong: "Re-examination of bistability of atmospheric oxygen level", JpGU Meetng 2018 (Makuhari, Japan, May 20-25, 2018)

[69] Takashi Nakagawa, Shintaro Kadoya, and Eiichi Tajika: "Global-scale water-carbon cycle in mantle dynamics and its implication to climate evolution", Gordon Research Conference (Smithfield, USA, June 17-22, 2018)

[70] Yoko Oya: "Unified Picture of Chemical Differentiation in Disk-Forming Regions of Low-Mass Protostellar Sources", Astrochemistry Workshop (Tokyo, Japan, June 25-26, 2018)

[71] Kazuhiro D. Kanagawa, Hidekazu Tanaka, and Ewa Szuszkiewicz: "Radial migration of a giant planet in a protoplanetary disk", Exoplanet II (Cambridge, UK, July 2-6, 2018)

[72] Muneaki Imai, Nami Sakai, Yoko Oya, Ana López-Sepulcre, Yoshimasa Watanabe, Cecilia Ceccarelli, Bertrand Lefloch, Emmanuel Caux, Charlotte Vastel, Claudine Kahane, Takeshi Sakai, Tomoya Hirota, and Satoshi Yamamoto: "Chemical Characteristics of Prototypical Isolated Protostar in B335", NOEMA/30m Workshop (Tokyo, Japan, July 24-25, 2018)

[73] Masataka Aizawa, Kento Masuda, Hajime Kawahara, and Yasushi Suto: "Search for exoplanetary rings via transit method", RESCEU Summer School (Hakodate, Japan, July 27-30, 2018)

[74] Yuki Okoda, Yoko Oya, Nami Sakai, Yoshimasa Watanabe, Jes K. Jørgensen, Ewine F.van Dishoeck, and Satoshi Yamamoto: "High resolution observations of forming disks; Very-Low-Mass Protostellar case", JCMT team meeting (Tokyo, Japan, August 1-2, 2018)

[75] Yoko Oya: "Unified Picture of Chemical Differentiation in Disk-Forming Regions of Low-Mass Protostellar Sources", IAU Symposium 345: Origins: From the Protosun to the First Steps of Life (Vienna, Austria, August 20-23, 2018)

[76] Masahiro Ikoma, Yuichi Ito, Yui Kawashima, Naoya Osada, and Shingo Kameda: "Theoretical Spectra of Highly-irradiated Atmospheres of Transiting Exoplanets", The 9th Solar System Symposium (Moscow, Russia, October 8-12, 2018)

[77] Yuichiro Cho, et al.: "Morphological features of craters on asteroid Ryugu", DPS meeting #50 (Knoxville, USA, October 21-26, 2018)

[78] Eri Tatsumi, et al.: "Hayabusa2's first results on the visible spectroscopic properties of 162173 Ryugu", DPS meeting #50 (Knoxville, USA, October 21-26, 2018)

[79] Yoko Oya, Nami Sakai, Ana López-Sepulcre, Cecilia Ceccarelli, Bertrand Lefloch, and Satoshi Yamamoto: "Elias 29: a Class I Low-Mass Protostellar Source Rich in S-bearing Species", Workshop on Interstellar Matter 2016 (Sapporo, Japan, November 14-16, 2018)

[80] Muneaki Imai, Nami Sakai, Yoko Oya, Ana López-Sepulcre, Yoshimasa Watanabe, and Satoshi Yamamoto: "Innermost Envelope Structure of B335 Traced by Complex Organic Molecules", Workshop on Interstellar Matter 2016 (Sapporo, Japan, November 14-16, 2018)

[81] Yuichiro Cho, et al.: "Distribution and morphology of craters on asteroid Ryugu", American Geophysical Union 2018 Fall Meeting (Washington, D.C., USA, December 10-14, 2018)

[82] Eri Tatsumi, et al.: "Visible Spectrophotometry of 162173 Ryugu", American Geophysical Union 2018 Fall Meeting (Washington, D.C., USA, December 10-14, 2018)

[83] Kosuke Goto, Maria L. Tejada, Eiichi Tajika, and Katsuhiko Suzuki: "Enhanced magmatism triggered the middle Miocene Climatic Optimum: Insights from osmium isotopes and a carbon cycle model", American Geophysical Union 2018 Fall Meeting (Washington, D.C., USA, December 10-14, 2018)

[84] Takashi Nakagawa, Shintaro Kadoya, and Eiichi Tajika: "Climate evolution of the Earth-like planets with plate motion in a whole Earth System evolution model", American Geophysical Union 2018 Fall Meeting (Washington, D.C., USA, December 10-14, 2018).

[85] Seiji Sugita, et al.: "The Evolution of Ryugu's Parent Body Constrained by Hayabusa2 Imaging Observations", The 50th Lunar and Planetary Science Conference (Woodlands, Texas, March 18-22, 2019)

[86] Eri Tatsumi, et al.: "Visible Color Variation of Boulders on 162173 Ryugu", The 50th Lunar and Planetary Science Conference (Woodlands, Texas, March 18-22, 2019)

7.3.2 Invited talks

[87] Seiji Sugita, et al.: "Comparison of visible spectra between Ryugu and low-albedo asteroid families in the inner main belt", Japan Geoscience Union 2018 Meeting (Makuhari, Japan, May 20-24, 2018)

[88] Masataka Aizawa: "Detection of exoplanetary rings", Asia Oceania Geosciences Society (Honolulu, USA, June 3-8, 2018)

[89] Masahiro Ikoma: "Theoretical Prediction for Atmospheric Spectra of Highly Irradiated Low-mass Exoplanets", ExoMol Conference on Spectroscopy of Exoplanets (London, UK, July 8-11, 2018)

[90] Masahiro Ikoma: "Formation of Planetary Envelopes and Atmospheres: Role of Vaporized Icy Material", COSPAR 2018 (Pasadena, CA, USA, July 14-22, 2018)

[91] Seiji Sugita, et al.: "The first detailed visible multi-band imaging observations of asteroid Ryugu", DPS meeting #50 (Knoxville, USA, October 21-26, 2018)

[92] Seiji Sugita, et al.: "The geologic properties of asteroid Ryugu revealed by Hayabusa2 visible multi-band imaging observations at multi-scales", Geological Society of America Annual Meeting 2018 (Indianapolis, USA, November 4-7, 2018)

[93] Yasushi Suto: "GCM simulation of a second earth: cloud pattern and the obliquity determination from future direct imaging", The 8th KIAS workshop on cosmology and structure formation (Seoul, Korea, November 4-9, 2018)

[94] Masahiro Ikoma: "Formation and Evolution of Atmospheres of Low-mass Planets around Low-temperature Star", Colloquium at Department of Physics an Astronomy (London, UK, December 4, 2018)

[95] Seiji Sugita, et al.: "The first detailed visible multi-band imaging observations of asteroid Ryugu", Hayabusa Symposium 2018 (Sagamihara, Japan, December 4-7, 2018)

[96] Seiji Sugita, et al.: "ONC Observations and Science Results", Misasa International Symposium MISASA VII "Sample return and Astrobiology" (Yonago, Japan, December 19-21, 2018)

[97] Masahiro Ikoma: "Theoretical and Observational Studies on Exoplanet Atmospheres: Current Understanding and Future Perspective", The 20th Symposium on Planetary Sciences (Sendai, Japan, February 18-21, 2019)