RESCEU

RESEARCH CENTER FOR THE EARLY UNIVERSE
THE UNIVERSITY OF TOKYO
RESCEU

Introduction

The Research Center for the Early Universe (RESCEU) at The University of Tokyo's School of Science was founded in April, 1999, by ordinance of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The research center is the successor of the center with the same name, founded in 1995, based on the MEXT program “Basic Research for COE (Center of Excellence) Development”.

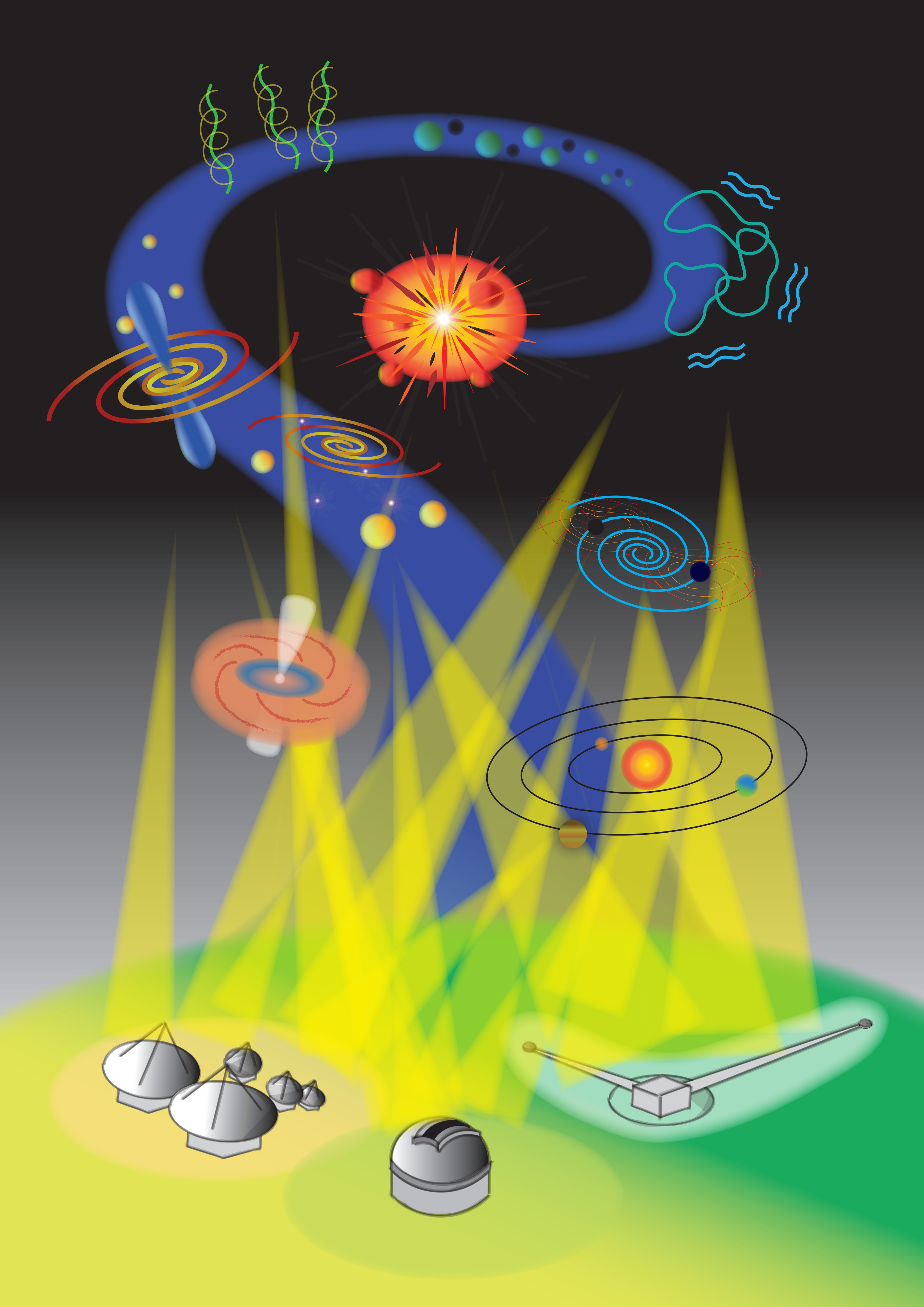
The research center began with a professor, an associate professor, and two assistant professors, and now has gown to three professors, an associate professor, and four assistant professors, as well as several research associates, many postdocs and graduate students. Moreover, with the participation of researchers from the Departments of Physics, Astronomy, and Earth and Planetary Science as RESCEU collaborators, we serve as a hub for research in astrophysics in the School of Science. Astrophysics is a rapidly developing area in basic science. In response to the progress, we are organized into three main research themes to explore the new horizons of our knowledge and continue to achieve many state-of-the-art research accomplishments.

The birth and evolution of the Universe is an important problem at the heart of research in astrophysics, and has been a research theme of RESCEU from its beginning. We propose theoretical models of the birth and origin of the Universe by combining the latest research results in particle physics and gravitational theory. We also perform the multi-wave cosmological observations. Moreover, we explore the evolution of structures in the Universe using numerical simulations, taking the observational results as initial conditions.

The direct detection of gravitational waves by LIGO in the USA in 2015 was a breakthrough in the history of physics. It immediately gave the birth to the research area of gravitational-wave astrophysics, which is now developing rapidly. The research group at RESCEU made essential contributions to the detection of gravitational waves from black holes and neutron stars in collaboration with gravitational wave research groups around the world. We expect to play important roles in the data analysis and interpretation for the forthcoming KAGRA experiment in Japan.

Extrasolar planets, or exoplanets, first found in the 1990s are now established as a new area in astronomy. This field includes research into the origin of the solar system, the co-evolution of the stars and planets, as well as astrobiology. RESCEU leads the project on the observation of exoplanets using the Subaru telescope. A wide range of other research is conducted at RESCEU, such as the radio observation of protoplanetary discs, precise analysis of light curve data of exoplanetary systems, and the exploration of the origin of the solar system with space missions.

Evolution of the universe and cosmic structures, gravitational-wave astrophysics and experimental gravity, and formation and characterization of planetary systems: through these three main projects of RESCEU, we engage in research with a comprehensive point of view in collaboration with those not only in The University of Tokyo but also many other institutes in Japan and around the world.

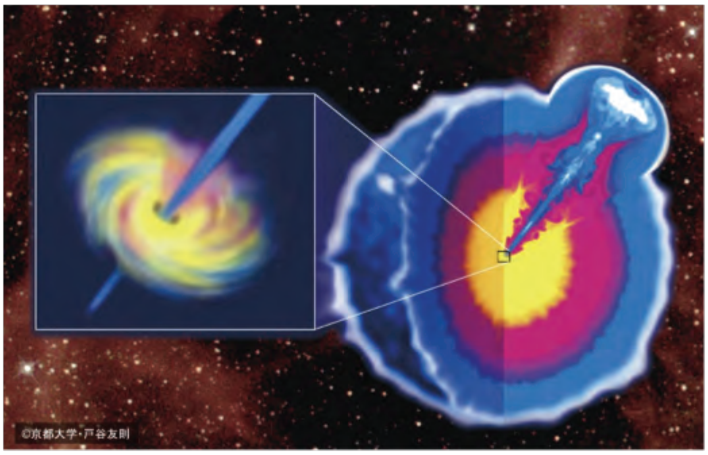


Project 1

Evolution of the Universe and cosmic structures

How was the Universe born? How did it evolve? This project conducts research with the aid of the latest theories and observations to answer these fundamental questions. Inflation, proposed to resolve fundamental problems in the Big Bang cosmology, predicts tiny primordial density fluctuations, which act as the initial conditions for large-scale structure of the present Universe. Starting with these predictions, we conduct theoretical as well as observational research, performing precise numerical simulations from the star formation in the early Universe up to large-scale structure formation.

We use observations to unveil the nature of the hierarchical structure of the Universe, mapping the distribution of dark matter with wide-field photometric and spectroscopic surveys by the Subaru telescope. In particular, a record of cosmic expansion, which weakens the efficiency of structure formation in the Universe through the gravitational interaction, is imprinted in the time evolution of the dark matter distribution. New research to explore the nature of dark energy, which accelerates the expansion of the Universe, by mapping the dark matter distribution with the Subaru telescope is now in progress.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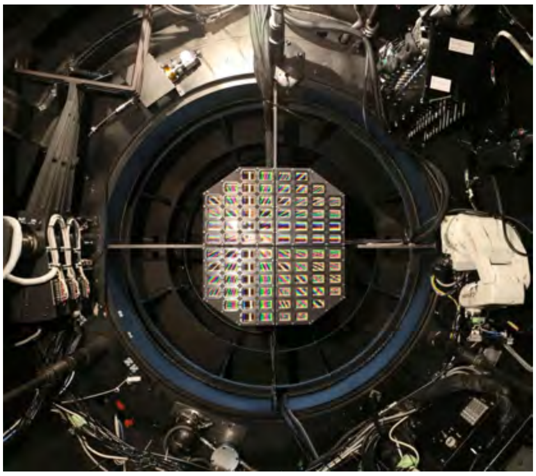
Artist's depiction of the jet during gamma-ray burst

In addition to the evolution of these structures, the chemical evolution of galaxies is also an important tool for tracing the history of the Universe. Elements heavier than helium are generated by nuclear fusion and stored inside stars. They are spread over interstellar distances by extreme astronomical phenomena such as supernovae or gamma-ray bursts. The debris collapses to form a new generation of stars that experience further supernovae or gamma-ray bursts. Chemical evolution of galaxies proceeds accordingly. Among them, the gamma-ray burst is regarded as the strongest explosive phenomenon in the Universe. They are classified as longer ones whose durations are a few to a few tens of seconds, and shorter ones whose durations are less than 2 seconds. The former is likely explained by the jet from the black hole produced in the extreme supernova and the latter is likely explained by the merger of pairs of neutron stars (BNSs).



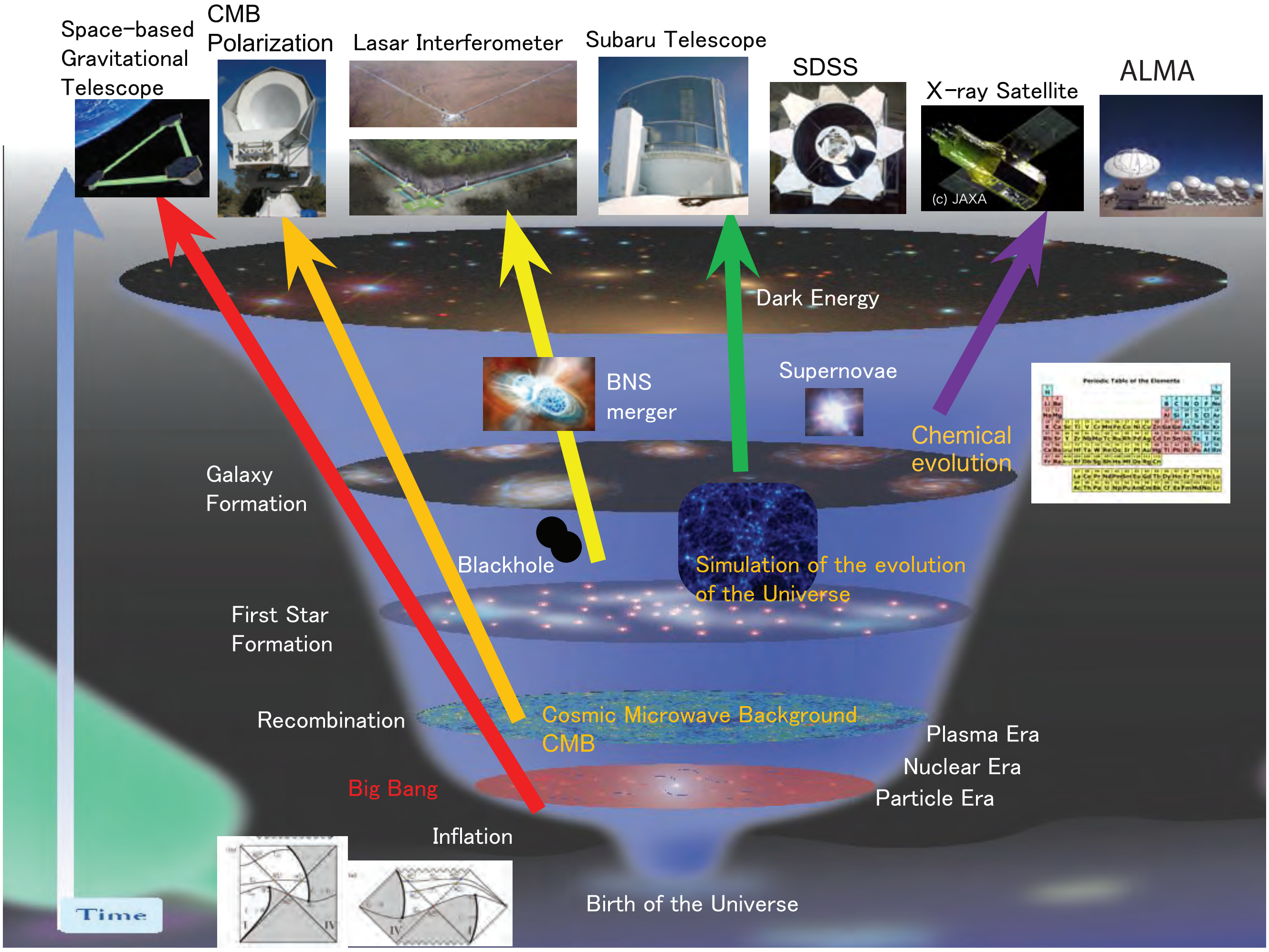
Fast wide-field camera Tomo-e Gozen

We perform observations of X-ray, gamma-ray, and gravitational waves from these violently fluctuating astrophysical objects. In particular, we have constructed a very fast wide-field camera, Tomo-e Gozen, an array of 84 CMOS detectors for the Kiso Schmidt

Telescope, in order to perform optical observations of these violently fluctuating astrophysical objects with a time resolution never done before. We study comprehensively the chemical evolution of galaxies with the combination of the data from these observations and theoretical models.

Primordial inflation is now strongly supported by precise measurements of the cosmic microwave background (CMB). However, it is difficult to explain it together with other phenomena in the early Universe using general relativity and the Standard Model of particle physics (SM). We propose models for inflation, dark matter, and the generation of matter-antimatter asymmetry using well-motivated models of physics beyond the SM and general relativity.

Moreover, it is essential to test predictions of theoretical inflationary cosmology observationally. We investigate the implications of a forthcoming CMB B-mode detection. We also examine future space-based gravitational-wave telescopes with our Project 2, so that we will eventually unveil the detail of inflation and succeeding Big Bang Universe.



Our research subjects and observational equipments
depicted in the image of the evolution of the Universe

Project 2

Gravitational-wave astrophysics and experimental gravity

Like electric and magnetic fields, the gravitational field exhibits wave phenomena: moving masses can create waves of gravitational force that propagate away from the source, moving through space. Because gravitational waves are created by the movement of mass and momentum, they carry with them different information about their sources than light, which is created instead by the movement of electric charges and currents.

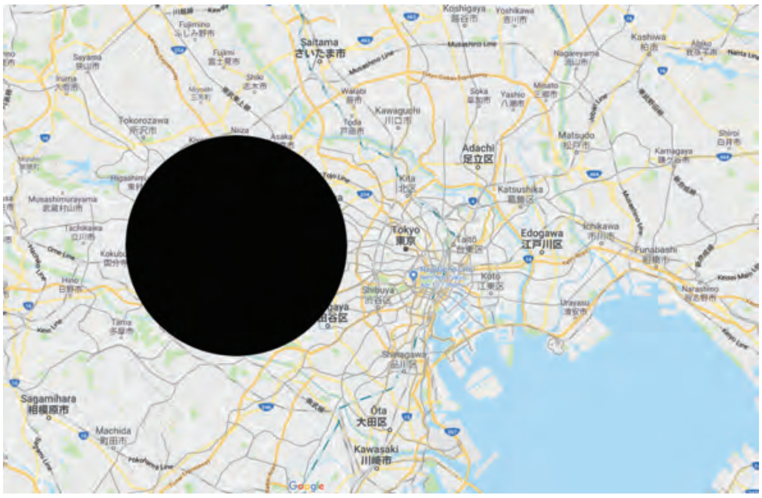
Gravitational waves were discovered in 2015 with the observation of a signal from the collision of a pair of black holes. The signal has been named GW150914 after the date of its discovery. Since then we have found dozens more gravitational-wave signals, also all from the collisions of compact objects. The observational gravitational-wave astrophysics group of RESCEU is active in several areas in this exciting new field. Members of RESCEU participate in both the KAGRA Collaboration and LIGO Scientific Collaboration, and we work with data collected from all interferometer detectors: KAGRA, Geo600, both LIGO detectors, and Virgo.

Computer simulation of the warping of spacetime during GW150914 (from SXS collboration)

We work on KAGRA interferometer design and commissioning. This work is leading to KAGRA joining the global network of gravitational-wave observatories, and will push the detector to higher sensitivities in the future. Looking farther to the future, Our members in Ando Laboratory are developing a setup to investigate Newtonian noise for third generation gravitational-wave detectors. For the B-DECIGO project, a gravitational-wave detector planned for space, members are summarizing preliminary design, and developing a test interferometer setup.

LIGO control room

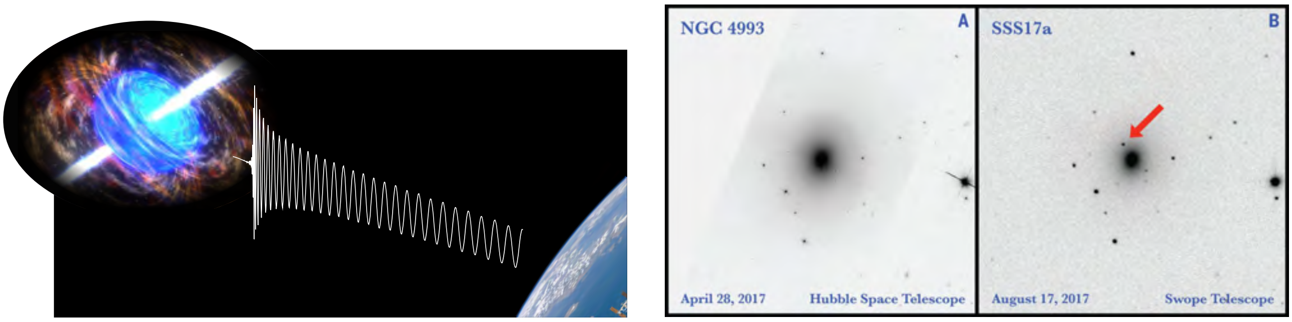
We work closely with researchers studying electromagnetic transients, especially members of the J-GEM Collaboration searching for electromagnetic counterparts of gravitational-wave sources. As described in this brochure, we have developed the Tomo-e Gozen CCD camera for the Kiso Schmidt telescope. This facility will be a very powerful tool for studying the evolution of kilonovae/macronovae following neutron star collisions.



A neutron star superimposed on a map of Tokyo for scale.

A neutron star is the gravitationally-collapsed remnant of a stellar core left over after a supernova. When two neutron stars collide with each other, they are a powerful source of gravitational waves. However, unlike black hole collisions, because of the ultra-dense matter smashing together, neutron star collisions are also intense sources of light.

The first neutron star collision, named GW170817, was discovered by the GstLAL gravitational-wave detection system (https://wiki.ligo.org/Computing/DASWG/GstLAL) developed by members of the RESCEU observational gravitational-wave astrophysics group. This software system has been responsible for the discovery of many gravitational- wave signals, and because it can do so very quickly, with only seconds of latency, it is ideal for sending alerts to electromagnetic telescopes like the Kiso Schmidt telescope and other telescopes in the J-GEM Collaboration. For GW170817, the GstLAL system allowed the optical explosion from the collision to be photographed.



Left panel: artist’s depiction of a gravitational wave signal travelling to Earth from a neutron star collision viewed off-axis. Right panel: image of optical transient at location of GW170817 compared to reference image taken earlier, taken from Science, 358(1556), 2017. We believe this is a photograph of the scenario shown in the left panel.

For the future, the observational gravitational-wave astrophysics group of RESCEU looks forward to making more discoveries and advancing the frontiers of our knowledge of the universe.

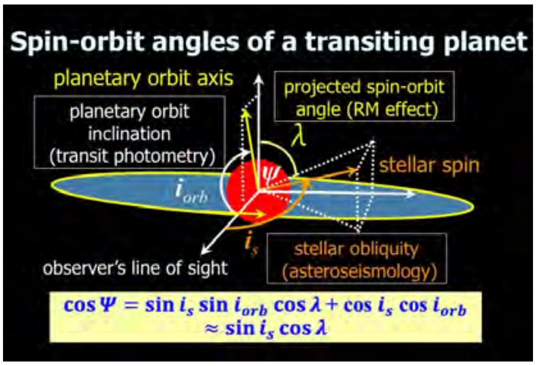
Project 3

Formation and characterization of planetary systems

One of the universal goals of research in astrophysics is to *explore the world beyond the visible horizon*. Clear examples include the origin and fate of the Universe (Project 1), and merging events of binary black-holes and of neutron stars probed from gravitational waves (Project 2). The exploration of the primitive bodies in our Solar system, multi-wavelength observations of the birth and death of stars and planets, and characterization of diversity of exoplanets beyond our Solar system all share the same scientific motivation over completely different scales, which are ultimately connected to one of the most fundamental questions: the origin of life in the Universe.

Project 3 consists of a variety of mutually related research subjects, which explore the nature of planetary systems from different perspectives in a complementary fashion.

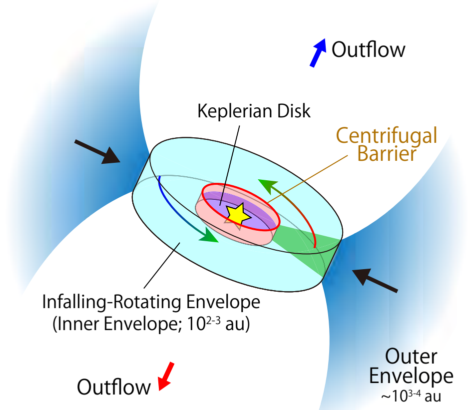
The origin and evolution of spin-orbit (mis)alignment in transiting planetary systems



The orientation of the stellar rotation axis relative to the orbital axis of planets (spin-orbit angle) provides a unique and important clue to the initial conditions and subsequent evolution of the planetary architecture. In particular, for transiting planetary systems, one can estimate the spin-orbit angle by combining the stellar inclination from asteroseismology and the sky-projected spin-orbit angle λ from the Rossiter-McLaughlin effect. We derive those parameters from the Kepler data, and reconstruct the initial conditions using celestial mechanics and hydrodynamic simulations.

Protoplanetary disc formation and associated chemical evolution

By observing radio molecular lines with the ALMA telescope, we study how disc structures are formed around newly formed protostars, and how they are evolved to planetary systems. We thoroughly explore disc structures in the early stage as well as chemical evolution during the disk formation. Combining these observations with the analyses of pre-solar materials found in meteorites and small solar system bodies, we explore the early stage of our own solar system.



The image of the formation of protoplanetary disc

The statistics and detection of long-period transiting planetary systems

Among the transiting exoplanets discovered thus far by the Kepler satellite, those that are like the planets in our solar system are Jupiter-like, long-period, gas giant planets. Using observations by the Subaru telescope and GAIA satellite, we are developing improved techniques for the detection of such planets, expanding their catalog, and comparing their properties to the predictions of planet formation theory. We also explore the design of optical systems with wide fields of view, and satellite missions to investigate the possibility of continuing such explorations with nano satellites.

Accretion of solid and gas on protoplanets

Planet formation is a process in which solids and gas accumulate. The solid accumulation is a process of collision and merger of so-called planetesimals, which are kilometre-size rocky or icy astrophysical objects, whereas the gas accumulation is a process where protoplanets collect gaseous components of circumstellar disks gravitationally. We simulate numerically the gravitational interactions of many planetesimals directly for their dynamics and merging process and study the process of gas accumulation via hydrodynamic calculations.

Formation of habitable aqua planet and climate stability

Water is an indispensable ingredient for the life on the Earth, and it also plays an important role in maintaining a warm, stable climate. We study the process of water acquisition and distribution to the interior and atmosphere of the planet theoretically, aiming at determining the amount of water that the planet acquires and its distribution. We also work to understand the relationship between the amounts of water and of atmosphere from mathematical models of surface environment that include carbon circulation, with the goal of understanding universality or uniqueness of habitable planets like the Earth in the Universe.

Exploration of the origin and evolution of the Solar System via asteroid probes

Planetary orbits have been long thought to be very stable since the formation of the solar system, but now we know they can fluctuate widely. A key for understanding how planetary orbits in the Solar System have evolved lies in the asteroid belt. We study asteroids that might have moved into the inner asteroid belt after forming at a low temperature. More specifically, we analyze data obtained from Hayabusa2 and OSIRIS-REx missions and study the next-generation asteroid mission projects with JAXA and foreign research institutes.

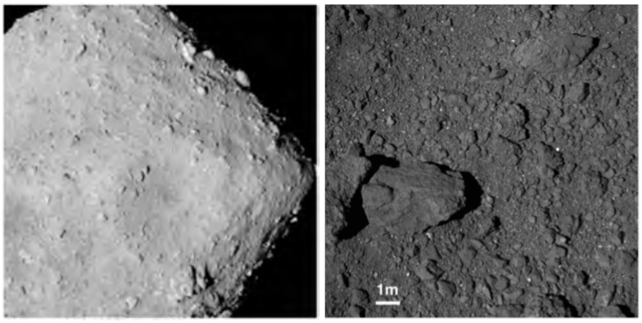


Image of the asteroid Ryugu taken by Hayabusa 2
(Image from JAXA, U Tokyo, Kochi U, Rikkyo U, Nagoya U
Chiba Institute of Technology, Meiji U, Aizu U, AIST)

Direct observations of exoplanets

Almost all exoplanets discovered so far have been discovered with indirect methods. On the other hand, for future study of exoplanets, direct imaging of the light from the planets by hiding the light from the central star is an essential method. Indeed, the Subaru telescope has succeeded to do this a few times. We also installed the instrument called IRD that can perform precise spectroscopy at IR, which has been limited in the optical wave-length on the Subaru telescope. By combining it with the photometric observations in the IR multi-color camera, we proceed the systematic study of the habitable planets around the red dwarfs.

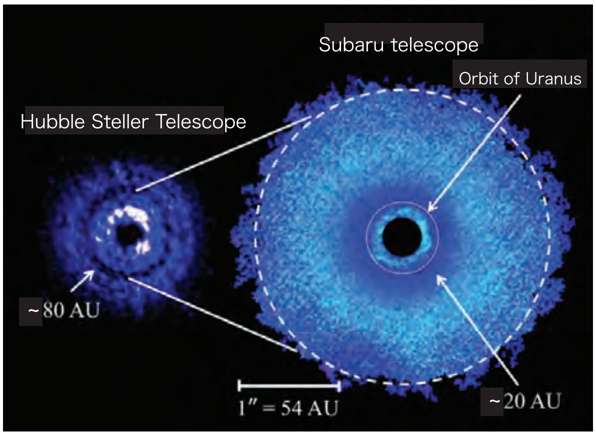
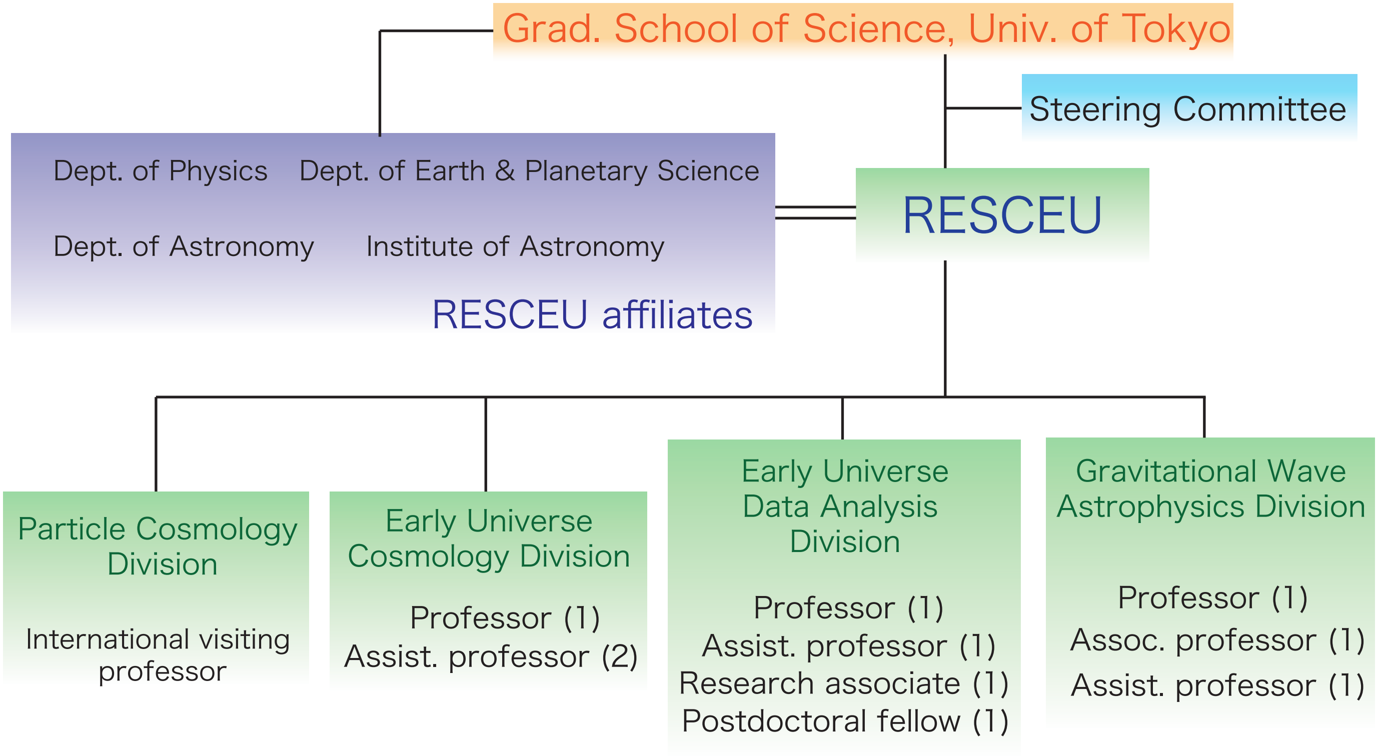


Image of the detail of the birth place of planets
drawn by the Subaru telescope
(Comparison to the Hubble Space Telescope)

Organization



Grad. School of Science, Univ. of Tokyo

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Dept. of Earth & Planetary Science
Dept. of Astronomy
Institute of Astronomy

RESCEU affiliates

Particle Cosmology Division

International visiting professor

Early Universe Cosmology Division

Professor (1)
Assist. professor (2)

Early Universe Data Analysis Division

Professor (1)
Assist. professor (1)
Research associate (1)
Postdoctoral fellow (1)

Gravitational Wave Astrophysics Division

Professor (1)
Assoc. professor (1)
Assist. professor (1)

at Hongo campus, April 2019

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2001, April — 2003, March : Kazuo Makishima
2003, April — 2007, March : Katsuhiko Sato
2007, April — 2015, March : Kazuo Makishima
2015, April — Present : Yasushi Suto

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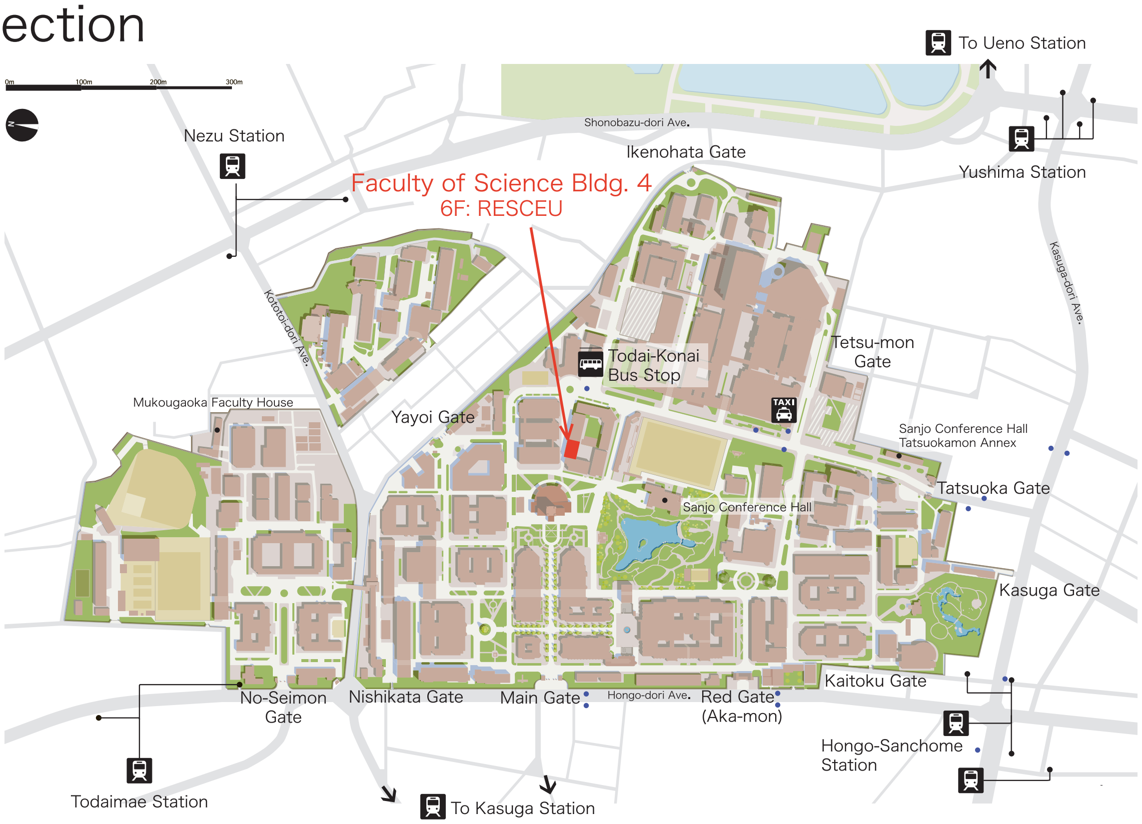

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Transportation

By Train or Subway

Hongo-Sanchome Station (Marunouchi Line & Oedo Line) : 11-min. walk

Nezu Station (Chiyoda Line) : 8-min. walk

Todaimae Station (Namboku Line) : 10-min. walk

Ochanomizu Station (JR Line & Marunouchi Line) : 7 min. by bus (To Todai-Konai Stop (学07))

By Plane

Narita Airport : Keisei Narita (Keisei Main Line (75 min.) / Keisei Sky Liner (40 min.))
~ Keisei Ueno (20-min. walk or 5 min. by taxi)
or Narita Airport Terminal 2･3 station (Narita Express (1 hour))
~ Tokyo (JR Chuo Line) ~ Ochanomizu (Bus (7 min.)) ~ Todai-Konai

Haneda Airport : Haneda Airport Intl. Terminal (Keikyu Airport Line (12 min.))
~ Shinagawa (JR Line (20 min.))
~ Tokyo (Marunouchi Line (10 min.)) ~ Hongo-Sanchome (11min.-walk)

From Main Stations

Ueno Station : 20-min. walk or 10 min. by bus (To Todai-Konai Stop (学01)) or 5 min. by taxi

Tokyo Station : Tokyo (Marunouchi Line (10 min.)) ~ Hongo-Sanchome (11min.-walk)