Department of Earth and Space Science

# Department of Earth and Space Science

**Home Page** http://www.ess.sci.osaka-u.ac.jp/en

## Overview

The Department of Earth and Space Science, Graduate School of Science of Osaka University, is a unique department established in 1995, aimed at developing a new horizon in the research and education of earth and space science from a physics-based perspective. The principal goals of our department's research activities are to understand the extreme state of matter in space, including even life, and to decipher the many diverse phenomena which occur in space, the planets and the Earth.

Our research and educational activities are conducted in eight groups based on Theoretical astrophysics, X-ray astronomy, Infrared astronomy, Isotope cosmochemistry, Earth and planetary physics, Solar system science, Soft matter physics, and Theoretical condensed-matter physics.

Our department focuses on fundamental physics as the basis of Earth and Space science. This is why we aim to conduct research and education in close collaboration with the Department of Physics at the Graduate School of Science. Our department is always open to talented researchers and students from a wide variety of fields, from physics to astronomy, earth science, geology, mineralogy, chemistry, biology, and engineering.

The current student capacity is 28 for the Master's course and 13 for the Doctoral course. After completing the course, students are active in a wide range of fields, including not only universities and research institutes, but also general companies, government offices, and junior high and high schools.

## Scope of Science

The Department of Space and Earth Science focuses on the study of all things in the universe, which take place in the vast space-time of 13.8 billion years and 13.8 billion light-years. In particular, our research and educational activities are based on the four key concepts of “space”, “earth and planets”, “matter”, and “life”.

Of course, these four keywords are deeply related to each other, as in “Earth in the Universe”, “Life on Earth-like Planets”, “Material Evolution in the Universe”, and “Materials in Extreme Planetary Environments”, and the research content of each research group will also span multiple fields. For details, please see the following pages.

## Scientific perspective and social demands

The Department of Space and Earth Science is a new major that promotes in an interdisciplinary way the basic sciences of Astronomy, Earth and Planetary science, Mineralogy, Geology, Chemistry, and Biology. Today, as symbolized by natural disasters and global environmental problems, it is highly required to harmonize human activities with “nature”, and there is a strong demand for people who can grasp the entire picture of the universe and the earth and consider logically while having a background in basic science.

Photograph of the entrance lobby. The wall design symbolizes the evolution of life and the birth of new Earth and Space Science from physics in the microscopic world. The floor is covered with Precambrian granite (2.2 billion years old). The wall design employs “stromatolite” formed by cyanobacteria (1.8 billion years old) and “wave-rippled sandstone” (1.2 billion years old). Let us listen to the sound of Precambrian waves.

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# Theoretical Astrophysics Group

**Members** Kentaro NAGAMINE (Professor), Yoshiyuki INOUE (Associate Professor), Shinsuke TAKASAO (Assistant Professor), Isaac SHLOSMAN (Visiting Guest Prof.), Luca BAIOTTI (Adjunct Associate Prof.)

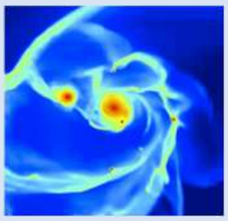
**Home Page** http://astro-osaka.jp/

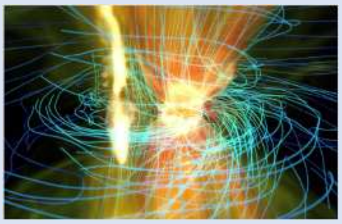
**[Research Area]**

1) Structure formation and cosmology (large scale structure, intergalactic medium, galaxy formation, dark matter)
2) Formation of astrophysical bodies (planets, stars, galaxies, supermassive black holes)
3) High energy astrophysics (jets, black holes, cosmic-rays)
4) Astrophysical plasma, magneto-hydrodynamics, solar physics
5) Gravitational wave astronomy

Our universe was born 13.8 billion years ago in a massive explosion known as the Big Bang. As the universe expanded, large-scale structure and galaxies were formed, and stars and planets were born and evolved within these structures. Various astrophysical phenomena in extreme conditions took place; e.g., supernova explosions, black hole formation, gravitational wave emission, gamma-ray bursts, and acceleration of high-energy cosmic rays.

Our group covers a wide range of research topics as described above, and our research methods range from purely theoretical to model building, numerical simulation, and observational data analysis.





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# X-ray Astronomy Group

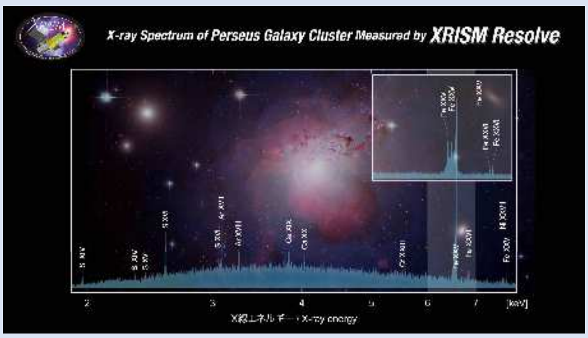
**Members** Hironori MATSUMOTO (Professor), Hirokazu ODAKA (Associate Professor)

**Home Page** https://uosaka-xray-astronomy.github.io/index.html

**[Research Area]**

1) Observational study of high-energy phenomena in the universe
2) Developments of instruments for high-energy astrophysics

**Perseus cluster observed with the XRISM satellite**




Credit : JAXA/NASA/CXC/IoA/A.Fabian et al./NRAO/VLA/ G. Taylor/ESA/ Hubble Heritage (STScI/AURA)/Univ. of Cambridge

High-energy phenomena can be seen everywhere in the universe. For example, a star explodes as a supernova at the end of its life, and leaves hot gas of a temperature of a few tens of millions of Kelvins. The hot gas is called a supernova remnant, and it is luminous in X-rays. Black holes and neutron stars are thought to be born in supernovae. The gravity of these compact objects is extremely strong, and they can emit X-rays when they accrete gas. Almost all galaxies harbor a gigantic black hole at their centers. Some of them accrete interstellar gas and emit X-rays as active galactic nuclei. Clusters of galaxies, the largest gravitationally bounded system in the universe, are filled with hot gas, and they can be observed through X-rays.

We are performing X-ray observations of the hot universe using X-ray astronomical satellites in the world such as XRISM, Suzaku, Hitomi, MAXI, Chandra, XMM-Newton, and so on. We are also developing new instruments for future applications such as X-ray mirrors, MeV gamma-ray detectors, and X-ray CCDs.

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# Planetary Science Group

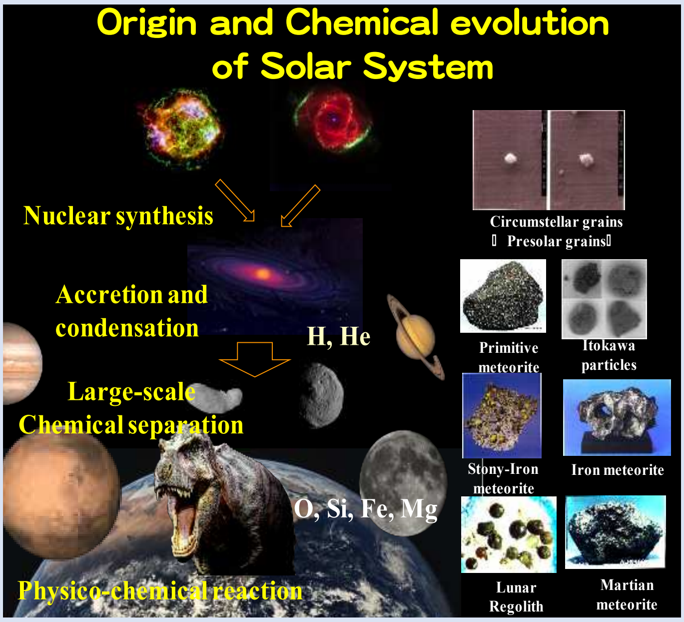
**Members** Kentaro TERADA(Professor), Chihiro YAMANAKA (Associate Professor), Shoichiro YOKOTA(Associate Professor), Kohei FUKUDA(Adjunct Assistant Professor)

**Home Pages** http://planet.ess.sci.osaka-u.ac.jp

## [Research Area]

1) Origin and evolution of the Solar System.
2) Observation of the planetary environment by the laser spectrometry
3) Plasma measurements around planets and moons.
4) Development of the technique/instrument for a new frontier of planetary science.

To decipher the history of the Solar System, we focus on the origin, evolution and current environment of our solar system based on various experimental approaches. Mainly, we carry out precise isotopic analyses from hydrogen to uranium in Apollo samples, other various meteorites and circum-stellar dusts. We also conduct in-situ plasma observation including mass analyses by spacecraft to study the environments around planets and moons. The three-dimensional non-destructive analysis using “muon” is also developed for the planetary science.

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# Planetary Materials Science Group

**Members** Osamu OHTAKA (Associate Professor), Jun KIMURA (Assistant Professor), Tadashi KONDO (Professor)

**Home Page** http://www.astroboy-jp.com/

## [Research Area]

Exploring the evolution of solar system bodies such as planets, moons, icy bodies, and asteroids through theory, experiments, observational methods, and spacecraft data analysis.

1. Formation and evolution of the Solar System bodies (terrestrial planets, moons, asteroids, icy bodies, etc.)
Understanding the evolutionary process by which planetesimals accumulate to protoplanets and moons, and then differentiate their interior into core, mantle, and crust (and formation of the subsurface ocean in icy bodies) to form their present forms. And constructing theoretical models that describe the thermal evolution and compositional differentiation, and performing numerical simulations to understand the various phenomena that take place in planetary bodies. Finally trying to describe a picture of the 4.6 Gyrs' evolution of planetary bodies and providing theoretical explanations for the characteristics and different evolutionary paths among Solar System bodies.

2. Phase transitions and changes in physical properties of deep Earth materials
In order to understand the evolutionary processes and dynamics of the Earth's interior, we investigate changes in the structure and physical properties of germanates (analogue materials of silicates that constitute the Earth's mantle) solids and liquids under high temperature and high pressure using in situ quantum beam (synchrotron radiation and neutrons) experiments. We also measure the density and viscosity of the material using X-ray radiography and other techniques to understand the changes in the physical properties of liquids at high temperatures and high pressures, and to investigate the correlation with structural changes.

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# Infrared Astronomy Group

Members: Takahiro SUMI (Professor), Kento MASUDA (Associate Professor)
Daisuke SUZUKI (Assistant Professor)

Home Page: http://www-ir.ess.sci.osaka-u.ac.jp/index_e.html


**[Research Area]**

1) Observational study of Exoplanets
2) Astrobiology
3) Observation of gravitational wave events
4) Galactic structure and dark matter

We study various astrophysical phenomena by using ground and space telescopes in infrared and develop related instruments. Especially, we focus on the formation of exoplanets and aim to find a bio-signature in exoplanets in future. We also conduct optical follow-up observations of gravitational wave events, studies of the Galactic structure, and dark matter.

We search for exoplanets by using the 1.8m MOA-II telescope with the gravitational microlensing technique. We also constructed the 1.8m PRIME telescope in South Africa to conduct a microlensing exoplanet search in infrared to find Earth-mass exoplanets. We are joining to NASA’s Roman mission to carry out a microlensing exoplanet survey from space.

We are also studying the observational plan to detect the biosignature in exoplanets for future space missions.

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# Theoretical Condensed-Matter Physics Group

Members: Takahiro HATANO (Professor),
Satoshi YUKAWA(Associate Professor), Kazushi AOYAMA(Assistant Professor),
Tomohiro TANOGAMI (Assistant Professor)

Home Page: http://noneq.ess.sci.osaka-u.ac.jp/

**[Research Area]**

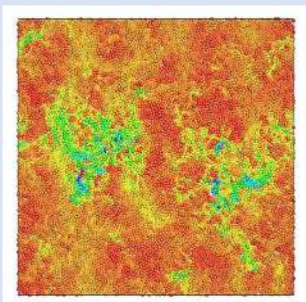
1) Physics of friction, fracture, and earthquakes: Dynamics and statistics of fracture process and their potential application for earthquake forecast. Mechanical instability across the scales. Developing new theoretical tools for time series analyses of earthquakes.

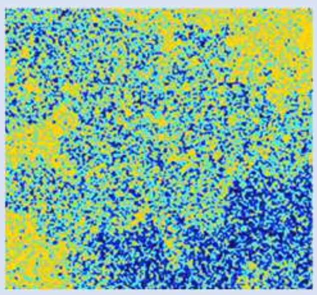
2) Dynamics of nonequilibrium phenomena in earth and planetary sciences: Heat conduction, spin flux, granular flow, etc. Phenomena where fluxes, diffusion, and phase transitions are interrelated. Such phenomena are investigated from the viewpoint of nonequilibrium statistical mechanics.

3) Statistical physics of frustrated spin systems: Ordering and defects in pyrochlore and triangular lattices.

4) Information thermodynamics and its application to fluid mechanics and turbulence

We study dynamics, statistics, and their universality in various natural phenomena on the Earth and planets as well as in condensed matter, brazing a new trail in “cooperative phenomena in many-body systems”. Our approaches are based on statistical mechanics (either equilibrium or nonequilibrium), nonlinear dynamics, stochastic processes, and computational physics.





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# High-pressure Material Physics Group

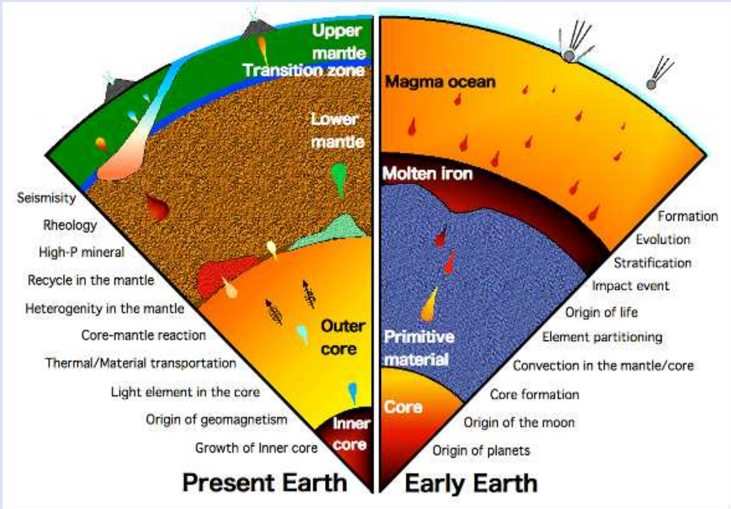
**Members** Tadashi KONDO (Professor), Masayuki NISHI (Associate Professor), Tatsuhiro SAKAIYA(Assistant Professor)

**Home Page** http://anvil.ess.sci.osaka-u.ac.jp/intro/English/index.html

**[Research Area]**

1) Phase transition and mineral physics in the mantle.
2) Formation, light elements, physical properties of the core.
3) Early Earth & planets, satellite and their evolution.
4) In-situ observation under High P-T condition.
5) Development of High P-T generation & measuring.

Our research interests are in the change of materials under ultra-high pressure and high/low temperature corresponding to the planetary interiors. Most materials change their physical and chemical properties drastically in such extreme conditions. For example, crystal structure, density, elastic properties, electrical and magnetic properties, bonding nature and chemical reaction with coexisting phase are important clues for the geophysical modeling and understanding the evolution of the planets. We generate various P-T fields in the laboratory by using various techniques of high-pressure generation (both static and dynamic), with various in-situ observations and recovery analysis. Through these laboratory-based experiments, we aim to understand comprehensively planetary system and components from the point of view of material science.




Interesting issues in the present Earth and early Earth

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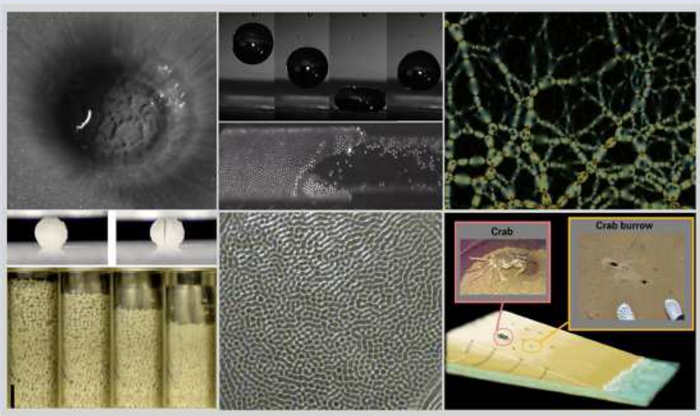
# Soft Matter Earth & Planetary Science Group

**Members** Hiroaki KATSURAGI (Professor), Makoto KATSURA (Assistant Professor), Ken YAMAMOTO (Assistant Professor)

**Home Page** http://life.ess.sci.osaka-u.ac.jp/

**[Research Area]**

1) Physics of granular matter and its application to geophysical and other natural phenomena (impact, vibration, fracturing, pattern formation, ecological environment etc.)
2) Measurement methods for soft matter characterization and environmental study
3) Physics of fluids and multiphase systems and its application to nature




Various complex phenomena occurring on the surface of the Earth and planetary bodies result from the complicated combinations of material behaviors such as fluidization, solidification, and self organization. We are striving to reveal the fundamental processes governing these natural complex phenomena. Examples include, planetary surface terrain, origin of life, and fluid-related phenomena Development of the measurement techniques and experimental apparatus for various soft materials is also investigated in this group.

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# Laser Astrophysics Group (Institute of Laser Engineering)

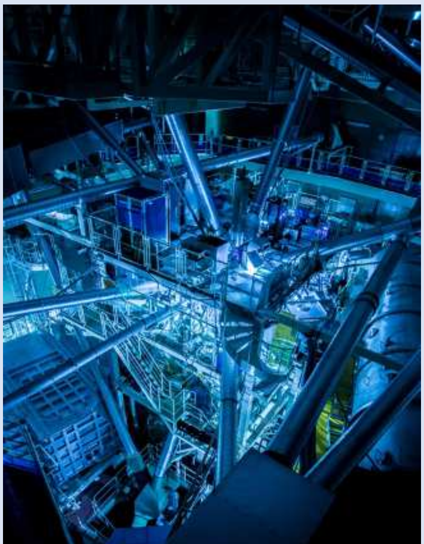
Members Youichi SAKAWA (Associate Professor), Takayoshi SANO (Associate Professor), Hironori MATSUMOTO (Concurrent Professor)

Home Page https://www.ile.osaka-u.ac.jp/research/lap/home_e.html

**[Research Area]**

1) Collisionless shock and cosmic ray acceleration
2) Magnetic reconnection and astrophysical transient phenomena
3) Plasma instability and turbulence driving mechanism

Using high-energy and high-intensity lasers in Japan and abroad, we will realize high-energy-density states and ultrafast plasma flows in the laboratory that would exist only in the universe, and we understand the nature of astrophysical plasmas. By using high-intensity picosecond and femtosecond lasers, in addition to high-energy nanosecond lasers, we will study such as relativistic wave-particle interactions and relativistic plasma generation. In addition to laser experiments, magneto-hydrodynamic and plasma-particle simulations will be performed to understand the physical mechanisms from theoretical and experimental perspectives.



High-power laser systems at ILE, Osaka University (GXII & LFEX)