Search for the origin of Earth and life

EARTH-LIFE SCIENCE INSTITUTE
TOKYO INSTITUTE OF TECHNOLOGY

Search for the origin of Earth and life

EARTH-LIFE SCIENCE INSTITUTE (ELSI) at Tokyo Institute of Technology is a unique research institution gathering top-level researchers from the fields of geoscience, life science, and planetary science to seek "the origin of Earth and life"

ELSI is a springboard for Tokyo Tech to become a world class science and technology university in the global arena

Tokyo Institute of Technology **Yoshinao Mishima**
President

What is the significance of ELSI for Tokyo Institute of Technology?

As the top science and technology university in Japan, Tokyo Tech has a strong history in the field of engineering. ELSI, which seeks to address the fundamental and very challenging problem of the origin of Earth and life, represents a springboard for Tokyo Tech to become a global leader in pure science in addition to applied science.

University Support for ELSI

We fully support ELSI's activities and management. We have committed to the success of ELSI's mission through the support of its activities and management. We provide professor positions using the dean's discretionary funds and salaries for PIs (Principal Investigators) and administrators. We have created a dedicated research facility for ELSI on the Ookayama campus, and a new research building was constracted in 2015. We are planning to improve accommodation and living support in order to attract excellent researchers from overseas.

Future expectations for ELSI?

We will accomplish our goal by bringing together the best researchers from around the world. Our new multi-disciplinary research approach is a breakthrough in Japanese academia, which is traditionally segregated into specialties. I expect the expansion of ELSI's research principles to be a great source of stimulation for the Tokyo Institute of Technology.

Open and stimulating international research environment

Tokyo Institute of Technology
Earth-Life Science Institute **Kei Hirose**
Director, Professor

What is the goal of ELSI?

Though scientists are beginning to understand the joint nature of the problems of origin of Earth and origin of life, no other institution exists to support this integrated conception of Earth and life as inseparable. Our current goal is to understand the formation and evolution of the early Earth and the series of events leading to the rise of life on Earth. This perspective is then being expanded to the question of life elsewhere in the universe.

Research atmosphere?

We have been very busy building ELSI's research facilities and hiring staff since our launch in 2012. The majority of our efforts have involved international recruitment and creation of a stimulating and open research atmosphere. Most of our young researchers are from abroad, and they interact with other researchers in a truly international environment. This approach leads to a "phase transition" within the organization, generating a friendly and active research environment that will help us to achieve our shared scientific goals.

Relationship with Bioplanetology?

At the moment, we are focusing on Earth's formation 4.6 billion years ago and the emergence of Earth-life around 4 billion years ago. By understanding the relationship between this planet and its life, we will be in a better position to address the question of life in other environments in the universe.

The four pillars of the World Premier International (WPI) Research Center Initiative

Science
Advancing leading edge research

ELSI was selected as a World Premier International (WPI) focus center commissioned by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) in 2012. The aim of WPI is to build within Japan globally visible research centers that boast a very high research standard and outstanding research environment, which will attract frontline researchers from around the world. These centers are given a high degree of autonomy, allowing them to revolutionize conventional modes of research operation and administration in Japan. The program is underscored by four main concepts: advancing leading edge research, establishing international research environments, reforming research organizations, and creating interdisciplinary domains.

Fusion
Creating interdisciplinary domains

Globalization
Establishing international research environments

WPI Summary (Based on the programs selected in 2012)

Requirements of a WPI Research Center

WPI center staffing
- 10-20 world-class principal investigators (PI)
- At least 30% of the researchers from abroad

International-standard working and living environments
- Strong leadership by center director
- Strong support for researchers
- English as the primary working language

Securing additional resources that match or exceed the amount of the project grant

Support Summary

Funding period	10 - 15 years
Project Funding	Around ¥700 million per year per focus center

Reform
Reforming research organizations

Science

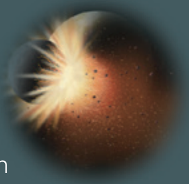
First pillar of WPI: Advancing leading edge research.
ELSI achieves unique results by setting up a clear research theme and roadmap.

Exploring the origins of the Earth-life system...and life in the universe

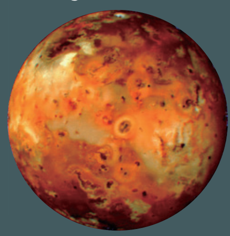
A Origin of the Earth

The birth of the solar system

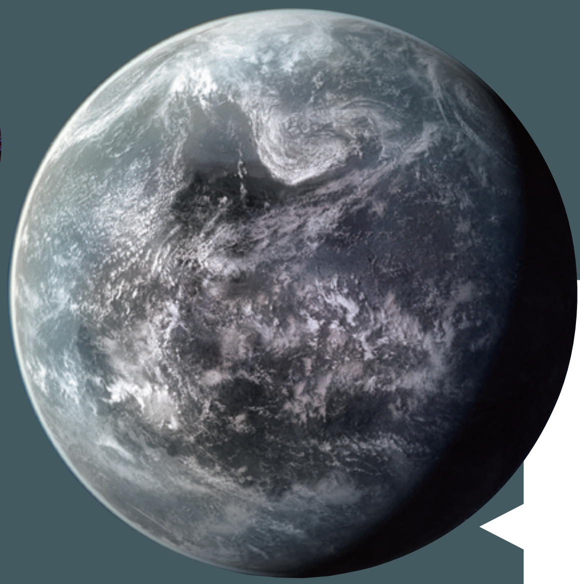
Giant Impact



Magma Ocean



Formation of primordial oceans and crust



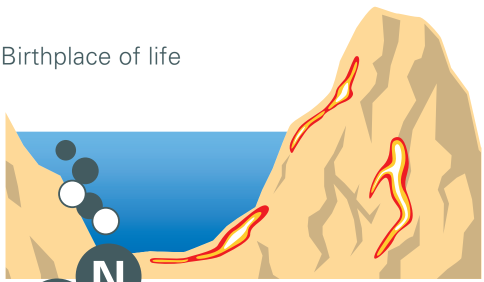
The solar system was formed following gravitational collapse of a disk of gas and dust 4.5 billion years ago. It is believed that the Moon was formed in the aftermath of a giant impact between the Earth and another proto-planet. The Earth was extensively molten (magma ocean) but rapidly cooled to form the early atmosphere, ocean, and surface environment.

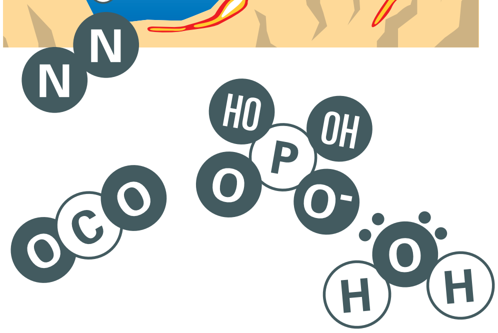
Approx. 4.6 – 4.5 billion years ago

Approx. 4 billion years ago

B Origin of the Earth-Life System

Birthplace of life





Chemical Evolution
(Organic molecule formation)

ELSI Research Approach

ELSI is seeking answers in the following key areas.

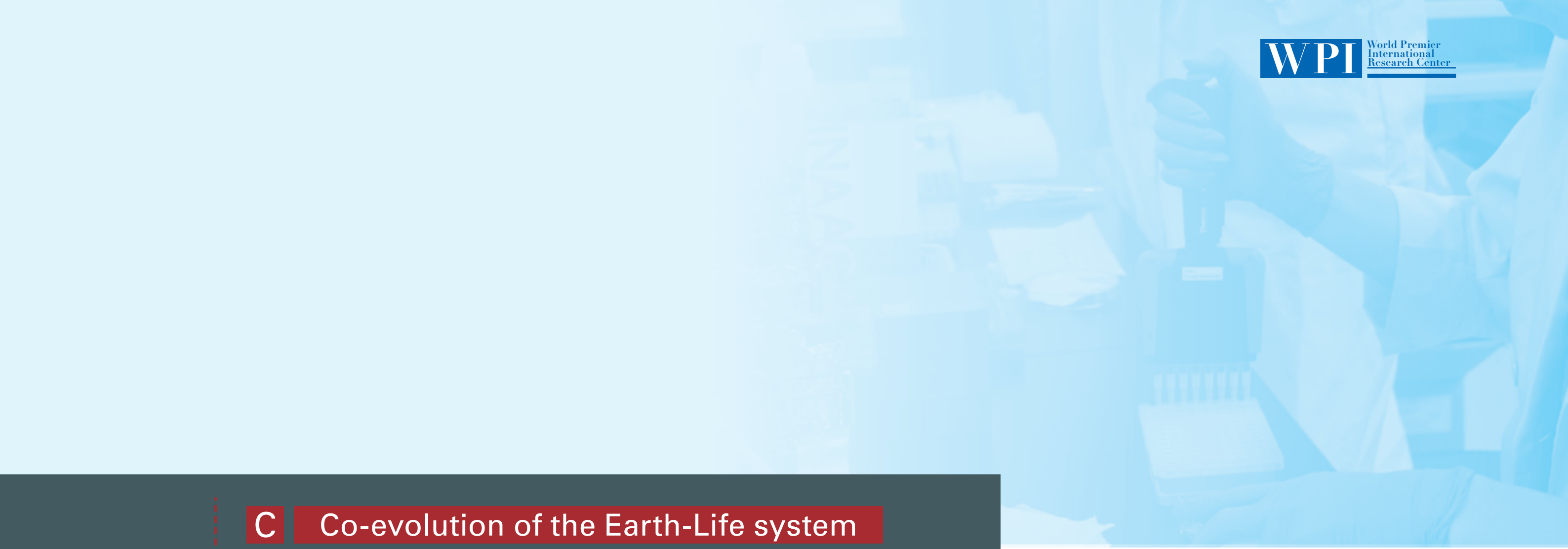
1: Identify the key stages in the formation of Earth, by answering questions such as how the Earth emerged in the early solar system, the composition and internal state of the early planet, and how water was delivered to the Earth.

2: Seek the origin of life as the emergence of a new geological system, accounting for the interactions between oceans, atmosphere, and solid Earth that are key ingredients for early chemical evolution.

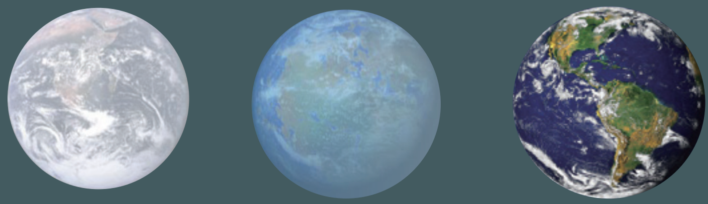
3: Investigate the co-evolution of the Earth-life system. For example, how did life modify its environment, such as the production of an oxygen atmosphere? What are the influences and feedbacks between the solid Earth and surface environment? What is the importance of extra-terrestrial events in the Earth-life system?

4: Use the foundation of Earth-life science as a springboard to identify habitable environments in the universe, and thereby establish a new dialogue for studies of the origin of universal life.

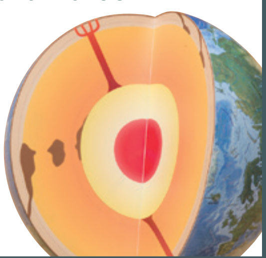
ELSI brings together researchers from a broad spectrum of fields to address these questions as a multi-disciplinary effort.



C Co-evolution of the Earth-Life system

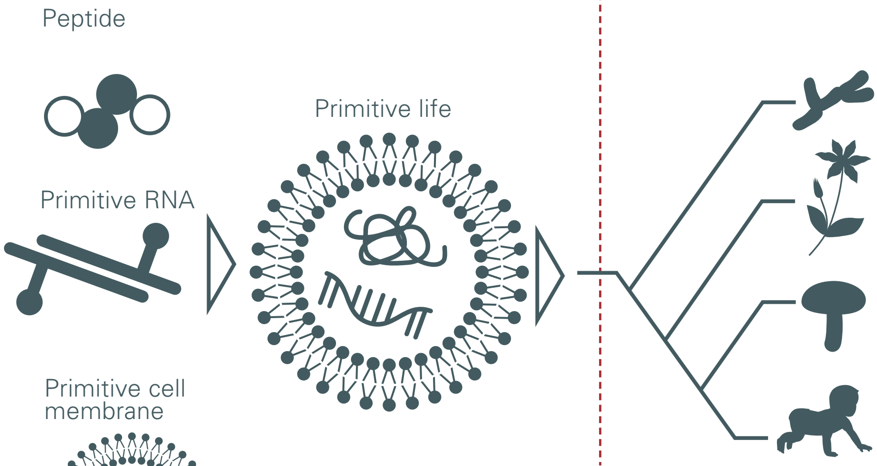


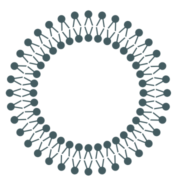
Formation of the core and mantle



The evolution of Earth and life are intimately linked. Examples of co-evolution of the Earth-life system include: The emergence of a magnetic field from the core along with magnetic minerals in biological organisms, the rise of oxygen in the atmosphere due to the advent of photosynthesis, the formation and migration of continents driven by mantle convection creating bridges between life from different environments, and periods of climactic instability such as snowball Earth that exerted a strong evolutionary pressure on life.

Approx. 0.8 – 0.6 billion years ago | Approx. 0.2 billion years ago | Present

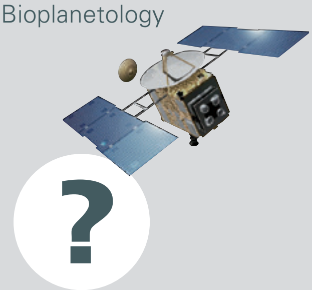




Life on Earth emerged early in our planet's history. Though the precise processes that led to the rise of life remain unknown, we believe that prebiotic organic materials interacted with minerals, eventually forming more complex molecules such as peptide, primitive RNA, and eventually cell membranes allowing the encapsulation of processes critical to sustaining life.

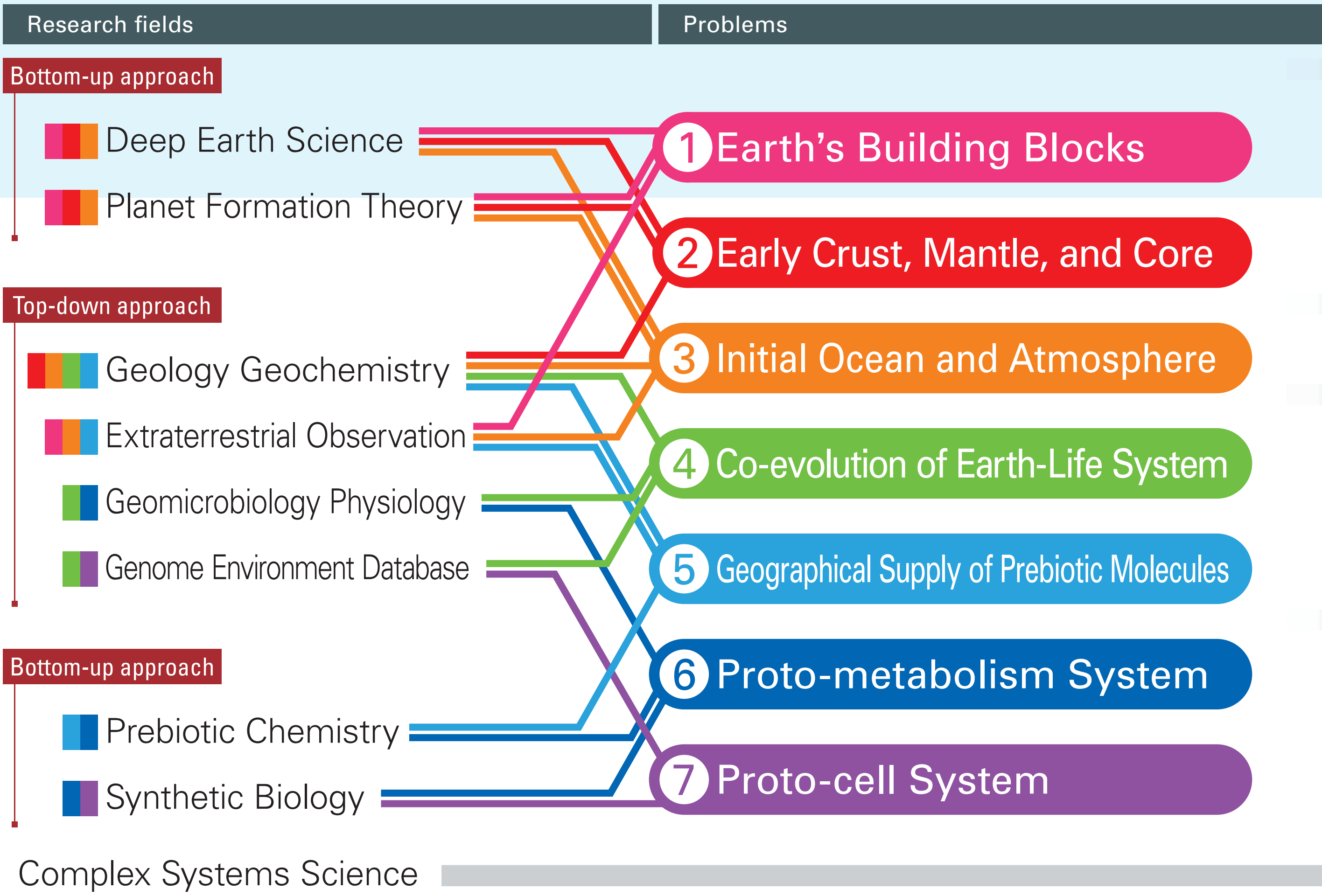
D Habitable planets in the universe

Bioplanetology



Recent astronomical observations have revealed a large variety of planets in the universe, some of which may exhibit conditions similar to the Earth. Understanding how life emerged on the Earth will guide our approach to identifying potential habitable environments on these planets and elsewhere in the universe.

Roadmaps from the present to the future



Road Map Establishing a roadmap for ELSI's success as a WPI institute

Moving from disciplines to common questions

Building a new multi-disciplinary institute with ambitious scientific goals presents exciting challenges and necessitates careful planning and consideration of a "road map" for the future.

The current version of ELSI's road map shows an initial migration from established scientific disciplines toward the first goal of addressing common scientific questions together as a collaboration. Although much progress has already been made in understanding Earth and life from a specialized approach, the questions that ELSI seeks to address are too big and complex to be encapsulated by any particular field. Thus an important first step forward as an institute is to re-focus on key problems where a variety of disciplinary perspectives may combine to produce new ideas and approaches that will help illuminate ELSI's future road map. This makes ELSI unique and very different from a traditional Japanese academic unit consisting of independent and unrelated research teams. ELSI members perceive their roles at the institute in the context of the common scientific questions they are addressing with their colleagues, rather than simply as practitioners of a particular tool or methodology, or as members of a single research group or lab controlled by a single Professor. Funding from WPI and support from Tokyo Tech give ELSI's management the flexibility it needs to hire research staff in a way that helps to achieve our goal of scientific fusion.

Mid-goal

Long-term target

Earth formation theory

ELSI is exploiting the productive fusion between the fields of planetary formation theory and Earth structure, composition, and evolution. Many new ideas, models, and questions are being produced by this effort.

Modeling the early Earth environment

Following Earth's formation, differentiation into a core, mantle, and atmosphere, the oceans were condensed and a surface environment was established that was capable of both producing and sustaining life. ELSI is combining approaches from geology, geochemistry, and planetary science to characterize the essential components of living systems.

Origin of life scenarios

One of our goals is to map scenarios for the origin of life on the Earth, and to begin modeling and testing their relationship. This combines perspectives from fields ranging from chemical evolution, biochemical synthesis, and complex systems science.

Characterization of habitable environments in the universe

By understanding the key events in the Earth's formation, early evolution, and origin of Earth-life, we will be in a better position to understand the possibility of similar kinds of life elsewhere in the universe. Establishment of a unified systems science theory encompassing all of the key processes through deep space and time is ELSI's most ambitious goal.

Road Map — An integrated approach using top-down (from the present to the past) and bottom-up (from the past to the present) methods

There are many established disciplinary research approaches that are presently contributing to ELSI's science, some of which are listed below. These fields use many approaches, such as "bottom-up" which uses theoretical models to predict the course of events in the early solar system, or "top-down" which seeks to determine early conditions by looking at fossils and other relics that can be observed today.

Deep Earth Science
Determination of the chemical composition and evolution of Earth's interior using theory, observations, and experiments.

Planet Formation Theory
Theoretical and observational work on the formation of planets from a primitive disk of gas and dust.

Geology Geochemistry
Examination of the historical rock and chemical isotopic records to illuminate the early Earth environment.

Extraterrestrial Observation
Astronomical observation and characterization of exoplanetary systems.

Geomicrobiology Physiology
Understanding life on early Earth by studying present life in extreme environments.

Genome Environment Database
Collect and analyze genome and environment data to understand early life.

Prebiotic Chemistry
Formation of complex biomolecules from abiotic chemical processes.

Synthetic Biology
Experiments and models of life-like molecular systems.

Complex Systems Science
Modeling of complex phenomena such as life from a general theoretical systems approach.

Key questions as rallying points to understand the origin of Earth and life.

Our mission, to understand the origin of Earth and life, is very challenging and exciting. In order to succeed, we believe it is necessary to bring together perspectives from a variety of different research fields and approaches. At the present, ELSI researchers are uniting around common key questions regarding the origin of Earth and life.

Seven Problems

1. Earth's Building Blocks
What is the composition of the initial Earth, and how has it been distributed over time?

2. Early Crust, Mantle, and Core
What was the state of the early core, mantle, and crust?

3. Initial Ocean and Atmosphere
What was the state of the early ocean and atmosphere, and how did it evolve with time?

4. Co-evolution of Earth-life System
How did Earth and life influence one another over time?

5. Geological Supply of Prebiotic Molecules
What were the key geological environments for minerals and abiotic organic matter to combine into complex biological molecules?

6. Proto-metabolism System
What are the essential components of the earliest metabolic processes on Earth?

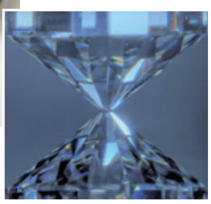
7. Proto-cell System
How did early cellular life come to exist, and what are its essential components?

1 Earth's Building Blocks

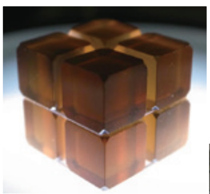
Goals

1) Measurement and calculation of density and sound velocity of lower mantle/subducted crustal materials at relevant P-T in order to test whether the lower mantle is chemically identical to the upper mantle.
2) Constraint of core composition from properties of liquid Fe alloys
   - Measurement and calculation of density and sound velocity of liquid Fe alloy at core P-T
   - Creation of phase diagrams relevant to inner core crystallization
   - Test feasibility of alloy compositions
3) Estimation of core composition from formation scenarios
4) Model Earth composition from planet formation theory

Understanding the composition, constitution, and dynamics of the present Earth's interior is vital to address its origin and evolution. ELSI researchers study these subjects using state-of-the-art technologies of high-pressure experiments, synchrotron radiation, ab initio computations, and geophysical modeling. ELSI researchers are currently addressing the composition of the bulk Earth, by focusing particular attention on the uncertain composition of the lower mantle and core.

The enlarged view of diamond anvil cell (DAC)
The DAC can simulate extremely high pressures and temperatures up to the center of the Earth.




The world's largest multi-anvil apparatus and polycrystalline diamond installed at the Ehime University satellite.

2 Early Crust, Mantle, and Core

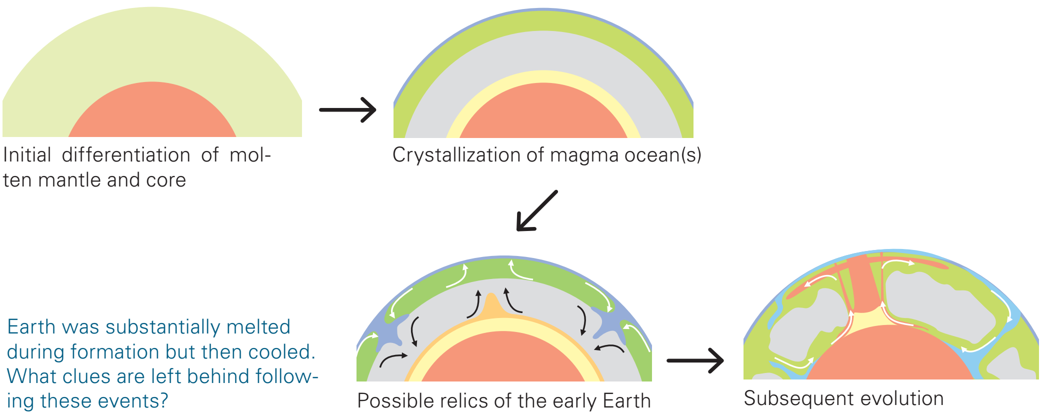
Goals

1) Initial conditions: Crystallization and outgassing of molten Earth following a giant impact, production of early crust and atmosphere.
2) Hadean tectonics: Model connections between Earth's interior and surface environment, and dependence upon tectonic styles and rates.
3) Hadean deep Earth: Age of geomagnetic field, thermal evolution, formation and preservation of geochemical reservoirs, and connection to present Earth structure

In order to understand the early Earth as the birthplace of living systems, it is essential to consider the geological processes that influenced the surface environment.

Researchers from "Deep Earth Science", "Planet Formation Theory", and "Geology and Geochemistry" are developing the next generation of models of the formation and subsequent evolution of early Earth that are consistent with the present internal structure and chemical composition.

They are using high P-T experiments, seismological imaging, and a combination of mathematical and numerical models that integrate geological and geochemical observations.



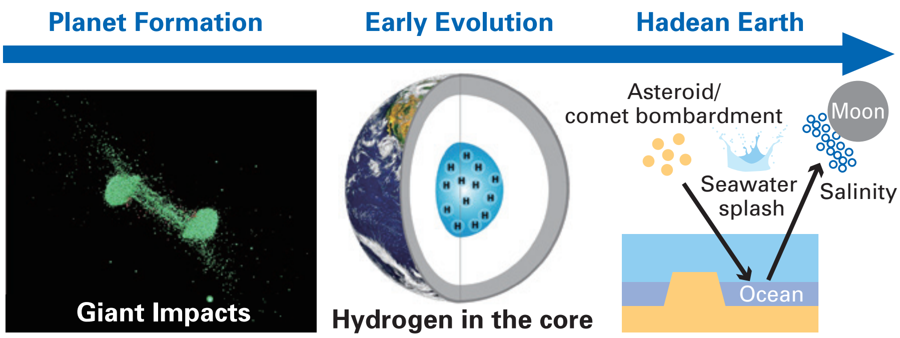
Earth was substantially melted during formation but then cooled. What clues are left behind following these events?

3 Initial Ocean and Atmosphere

Goals

1) Total amount of Earth's water and its distribution mechanism
   - Water in the present lower mantle and core
   - Partitioning between interior and surface
2) Origin of water on Earth and in the solar system
   - Supply mechanism of water on Earth
   - Understanding of water in the solar system
3) Chemical compositions of initial atmosphere and ocean
   - Redox condition of atmosphere (H_2/CH_4/CO/CO_2)
   - pH, alkalinity, and heavy metals of early ocean

We are trying to understand the origin and total amount of Earth's water and chemical compositions in the very early atmosphere and ocean, which can give us information about the environment where life emerged on Earth. Collaboration among ELSI members from different fields, such as planetary science, geochemistry, and geophysics is the key to addressing these problems. We are constructing general models of planet formation and early Earth evolution with particular attention directed towards the behavior of volatile elements.



It is believed that the chemical composition of the initial Earth ocean and atmosphere fluctuated dynamically as a result of exterior influences.

4 Co-evolution of the Earth-Life System

Goals

1) Determine initial/minimal conditions for the emergence of oxygenic photosynthesis
2) Decoding the chemistry of the early atmosphere and ocean
   - Speciation / metal concentration / redox state / pH
   - Redox evolution through S cycling and H cycling (H-escape)
3) Reconstructing the history of metabolic evolution between LUCA and oxygenic photosynthesis: Systematic microbiology
4) Developing new isotopic proxies for testing (2) and (3) (e.g., intramolecular signatures)
5) Coupling to thermo-chemical evolution of solid Earth (crust, mantle, and core) and the role of volcanic outgassing, hydrothermal circulation, magnetic field, etc.

Redox evolution is a key to understand early evolution of the biosphere as well as the origin of life.

We are trying to understand how the chemistry of the ocean and atmosphere changed through the combination of biological and geological co-evolutionary processes through interdisciplinary research based on geomicrobiology, evolutionary biology, genome analysis, geology and geochemistry.

ELSI researchers are now developing new biogeochemical tracers for the chemistry of the early atmosphere and ocean, as well as trying to create proto-cyanobacteria artificially in the laboratory.

Isotope Ratio Mass Spectrometer

5 Geological Supply of Prebiotic Molecules

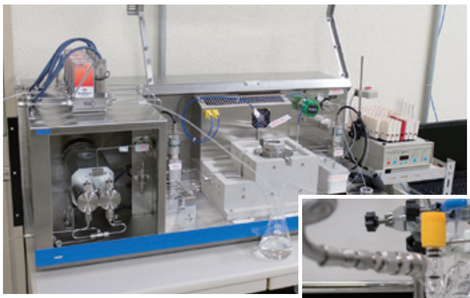
Goals

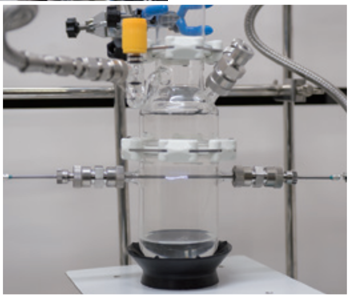
1) Reductive environment
   - Ammonia: Haber-Bosch reaction in low-temp. condition w/ cement catalyst
   - Amino acids and nucleobases: Miller-Urey experiments w/ minerals and light
2) Oxidative environment
   - Ribose: Formose reaction w/ borate
   - Acetate: CO_2→Methanethiol→Acetate
3) Phosphates: Phosphate mineral reaction with H_2O
4) Proto-metabolic roles played by minerals and light:
   - AFM/STM/TDS/NSOM measurements of Organics-Surface-Light interactions

Challenging goals

5) Abiotic synthesis of ATP (adenosine triphosphate)
   - Reactions driven jointly by the influence of minerals and light
6) Oligonucleotides and oligopeptides
   - Nucleotides and amino acids oligomerized on mineral surface with light
7) Computer simulation for exploring potential pathways
   - Development of computational algorithms and models

Provided with up-to-date knowledge of plausible conditions on the early Earth, we focus on a question: How could the geological environments supply simpler inorganic and organic compounds, leading to the building blocks of life? We try to reproduce continuous chemical evolution in a consistent set of environmental conditions, where minerals may be of particular importance in catalyzing various reactions. We have designed an integrated experimental system to realize multistep chemical evolution, starting from the simple chemicals and minerals available on the early Earth.





Top: Flow type hydrothermal reactor
Right: Miller-Urey discharge experiment

6 Proto-metabolism System

Goals

1) Reproduce previous experiments and beyond
  - CO_2 → CH_3SH
  - CH_3SH → CH_3COOH
  - CH_3COOH → Pyruvate
  - Catalytic efficiencies of His and Cys in the TCA cycle

2) Demonstration of non-enzymatic metabolism core from C_2 to C_5
  - Acetate → Pyruvate
  - Pyruvate → Oxaloacetate
  - Oxaloacetate → Malate
  - Malate → Fumarate
  - Fumarate → Succinate
  - Succinate → α-ketoglutarate

3) Production of biological building blocks
  - Pyruvate → Ala and ribose
  - Oxaloacetate → Asp → Amino acids and pyrimidines
  - Succinate → pyrroles
  - α-ketoglutarate (C_5) → Glu → Amino acids

We attempt to understand how the Earth has systematically produced building blocks of life through geochemical processes. To understand the geochemical system in the Hadean Earth, we have performed laboratory experiments of prebiotic synthesis and analyzed the results from the viewpoint of systems chemistry. Particularly, we closely collaborate with geologists and geochemists and focus on specific environmental conditions on the Hadean Earth.

Proto metabolism experiment using ultra-violet rays

7 Proto-cell System

Goals

Experimental investigation of the possibility for proto-cell emergence

1) Reaction of proto-cell
  - Gene replication by proto-cell
  - Growth of lipid bilayer vesicle

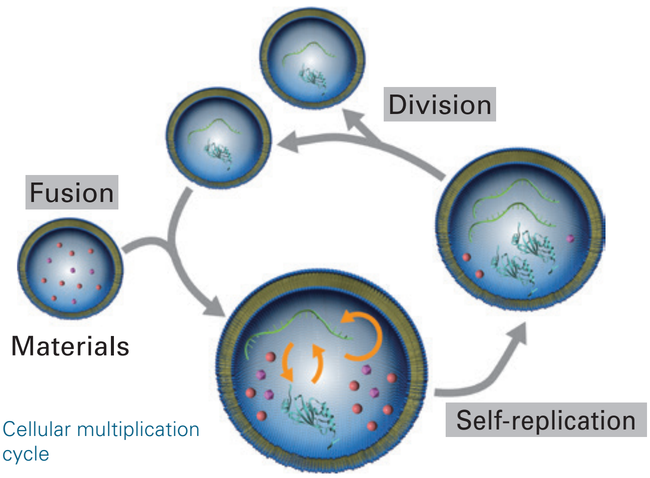
2) Gene replication before enzyme generation
  - Primitive replication of RNA

3) Genetic code protecting proto-cell

To make the studies on the origin of life more solid and concrete, it is essential to experimentally establish proto-cell models that allow researchers to test scenarios on how primordial cellular life originated.

In the studies of the proto-cell through a constructive approach using biomolecules and computational analysis of genome information, ELSI researchers use a combination of synthetic and evolutionary biology to construct the proto-cell.

ELSI researchers are in the midst of experimentally developing simple cell models with metabolic reactions, gene replication, gene expression, and evolution.



Cellular multiplication cycle

Recent research results and highlights

Research Topic Prebiotic hydrocarbon synthesis in the early Earth

The origin of methane contained in unique hot springs

The ELSI research group of Prof. Naohiro Yoshida, Prof. Shigenori Maruyama, Prof. Ken Kurokawa, and A. Prof. Yuichiro Ueno, in January 2014, discovered that the hot-spring water in the Hakuba area of Nagano prefecture contained inorganically produced methane gas after continuous research from 2010, which was a significant achievement in addressing the mechanism of life's emergence in the early Earth.

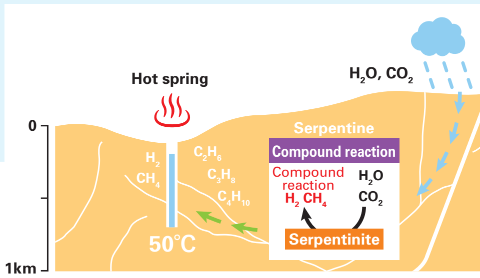
This hot-spring water reveals a high density of alkaline and H_2 caused by reaction with a unique rock called serpentinite, which was very abundant during the early Earth before life's emergence.

The discovery of hydrocarbons, which are necessary to create life, generated by the inorganic chemical reaction suggest a source of organic compounds leading to the emergence of life.

This project is managed by Prof. Ken Kurokawa of ELSI and was selected to receive a "Grant-in-Aid for Scientific Research in Innovative Areas" in 2014. This new research field program focuses on the "Hadean", the first 600 million years of Earth's history. Its purpose is to analyze when, where, and how life emerged through combining Earth and planetary sciences, biological science, and organic chemistry.

Earth and Planetary Science Letters, 2014, Vol. 386 pp. 112-125.
DOI: 10.1016/j.epsl.2013.11.001

Hakuba Village in Nagano



Hydrocarbon's composition schema on surface of serpentinite

Hydro carbon reaction occurs with the low temperature of 50 deg. in serpentinite hot springs, although previously the reaction between hydrogen and carbon dioxide was considered impossible at temperature of over 100 deg. in a hot spring with a high density of hydrogen.

Research Topic Earth's deep interior may contain up to 80 oceans of water

Relation to the melting temperature of the deep mantle and core

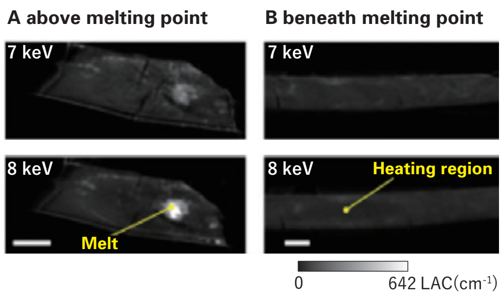
In January 2014, Dr. Ryuichi Nomura; ELSI research scientist, (a former Ph.D student from the Science Engineering Department at Tokyo Institute of Technology) and Prof. Kei Hirose carried out a research in collaboration with Japan Synchrotron Radiation Research Institute (JASRI), Kyoto University, and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and found that there was a large amount of hydrogen in the Earth's core.

At 2900 km depth inside the Earth, the solid rocky mantle meets the liquid iron core. The melting temperature of the mantle provides a limit on the temperature of the core.

The inner core is solid, and its own melting temperature depends on the concentration of alloys present in the liquid outer core. Therefore the melting temperature of the mantle can provide constraints upon the composition of the core.

Nomura and his team placed samples in a diamond anvil cell to simulate pressures at the core-mantle boundary, and used a large synchrotron radiation facility (SPring-8) to detect the presence of melting. Their samples were melting at around 3600K, at least 400K cooler than previous estimates. Such cool mantle temperatures imply that the inner core solidifies at much lower temperatures than previously thought, and is only possible if the core contains a significant amount of hydrogen. This amount of hydrogen could have been taken into the core during Earth's formation, and implies that the material that formed the Earth also contained a lot of water.

Science 31 January 2014: Vol. 343 no. 6170 pp. 522-525
DOI: 10.1126/science.1248186



X-ray CT Image from the sample obtained after the high P-T experiment.

The unique structure was observed successfully by the combination of high P-T generation technology and high-resolution Microtomography (CT) technology utilizing high-luminance X-ray from the large synchrotron radiation facility "SPring-8".

Fusion

Second requirement of WPI: Creating interdisciplinary domains.
ELSI employs various approaches toward promotion of interdisciplinary research.

Multi-layered communication between researchers

193 people visited ELSI in 2016

In order to address "the origin of the Earth and life", interdisciplinary communication is necessary. Therefore, we are introducing a multi-layered research and communication structure.

For example, we held an international symposium, 42 workshops and seminars in 2016 and invited a total of 193 researchers from abroad to our facilities in Tokyo.

We encouraged these guest researchers to present at the ELSI seminar and during lunch, discuss about research status and future collaboration, and participate fully in our open discussion environment.

We hold proactive discussions

Regular events to catalyze interactions

ELSI PI Piet Hut has had great success in establishing an interdisciplinary research program at the Institute for Advanced Study in Princeton, New Jersey. Following Professor Hut's advice, ELSI established regular events that increase interactions and encourage researchers from a broad range of fields to engage in dialogues on common questions. These events also seek to remove language barriers and increase cross-cultural understanding.

- **ELSI Assembly**: Cross-disciplinary discussion and training sessions led by ELSI researchers
- **ELSI Seminar**: Occasional seminar series in which our guests present talks on their studies
- **Lunch Talk**: Research topics presentation and introduction of different research fields twice a week
- **Coffee Break**: Coffee break in communication room at 3pm every day
- **IZAKAYA ELSI**: Happy hour on Friday nights. We enjoy International hors d'oeuvres

IZAKAYA ELSI

Director's fund for interdisciplinary research

Seed funding to spur synthesis

The Director's fund provides an opportunity for young researchers to nurture an idea, and is only available for genuinely multi-disciplinary research. Seed funding for projects ranges from 0.1 to 4 million yen.

Proposer	Co-investigators	Project Title
Fujishima	Mamajanov	Liquid CO_2 - seawater reactor: abiotic polymer formation in Hadean ocean
Lasbleis	Brasser	Expected magnetic field strength of rocky exoplanets
McGlynn	Bio-Unit and EON researchers	Infrastructure for Anaerobic Microbiology
Mochizuki	Gilbert, Hongo	Investigating DNA analogues in modern thermophilic organisms: challenge for the RNA-DNA world transition
Virgo	Aono, Chandru, Cleaves, Mamajanov, Ruiqin	High-Throughput Robotics for the Exploration of Prebiotic Chemistry

(FY 2016)

EON: The ELSI Origins Network

Making ELSI a global hub for research on the Origin of Life

ELSI's unique approach to the origin of life as part of Earth's planetary maturation requires a fusion of the leading concepts from biological and physical sciences. To tap the best ideas in the world community and bring them to work together, we have formed the ELSI Origins Network (EON). EON will create a web of affiliated centers worldwide, with ELSI as the hub. It will support visiting researchers, jointly-hosted postdoctoral fellows, and workshops, and will provide seed grants for path-breaking research on fundamental problems in the origin of life.

Globalization

Third requirement of WPI: Establishing international research environments.
At ELSI we have established a truly international research environment.

Over 40% of researchers are non-Japanese

Cultural and gender diversity

As of April 2017, the total number of ELSI researchers is 82: [15 PIs (Principal Investigators), 4 APIs (Associate Principal Investigators), 8 Affiliated Faculties, and 45 Research Scientists]. 31 are non-Japanese researchers (43%) and 14 are female researchers (19%).

We perform international searches in order to attract the very best researchers from around the world.

Researchers	Total	non-Japanese	Female
PIs	15	8(53%)	1 (7%)
APIs	4	1(25%)	1(25%)
Affiliated Faculties	8	0(-)	0 (-)
Research Scientists	45	21(45%)	12(27%)
Total	72	31 (43%)	14 (19%)

As of April, 2017

Proactive recruiting of foreign researchers

Over 90% of applicants are from outside Japan

ELSI Director Kei Hirose assigned Vice Director John Hernlund as the head of international recruitment, with a specific target to implement international recruiting methods and find the brightest young researchers from around the globe. Using an unprecedented advertising campaign targeting international science journals (e.g., Science, Nature), job listing services overseas, ELSI booths at international conferences, and the professional networks of existing ELSI members, Hernlund has transformed the way hiring has traditionally been conducted at Tokyo Tech. Currently, more than 90% of applicants to the ELSI Research Scientist positions is from outside Japan.

Invitation of Nobel laureate

Nobel laureate Jack W. Szostak, director of the Origins of Life Initiative at Harvard University, is one of ELSI's foreign PIs. Professor Szostak is widely respected in the field of synthetic biology, and members of the Szostak team regularly travel between ELSI and Harvard to perform collaborative research. Szostak has contributed to ELSI workshops and gave public lectures at Tokyo Tech in support of ELSI's outreach efforts.

Jack Szostak, PI

International Summer School

In August 2014, ELSI held its very first summer school. Its purpose was to provide practical education about mathematical models of planet formation and early Earth evolution using numerical simulations on ELSI's super-computers. A total of 24 young researchers attended the school, and ELSI staff managed the transportation, accommodation, and other local needs of attendees.

In 2018 January a similar program is planned as the first ELSI/EON Winter School.

● August 2nd - Saturday

9:30	Breakfast in ELSI communication room
10:00 - 11:00	Oral session: two 20 minute talks with 10 minute discussion
11:00 - 11:15	Coffee break
11:15 - 12:15	Oral session: two 20 minute talks with 10 minute discussion
12:15 - 13:15	Lunch Break
13:15 - 14:00	Oral session: one 20 minute talk with 10 minute discussion
14:00 - 14:15	Coffee break
14:15 - 17:15	First tutorial session
17:15 - 18:00	Gather and debrief
18:00	Dinner Break

● August 3rd - Sunday

9:30	Light breakfast in ELSI communication room
10:00 - 13:00	Second tutorial session
13:00 - 13:30	Gather and final discussions
13:30	End
14:00	Bus leaves for Shonan Village

Reform

Fourth Requirement of WPI: Reforming research organizations.
ELSI takes a unique approach toward innovation of research administration.

Top-down and independent organization

The director's strong leadership

ELSI is a highly independent research facility unlike other conventional university organization structures. Under the leadership of Hirose, the ways ELSI determines research themes, recruits researchers, and organizes management rules are unique and exceptional.

The annual evaluation process takes place in January, in which all the ELSI researchers submit the Research Activity Sheet describing their research and other activities. A mentor had been assigned to each API or Research Scientist and prepares the evaluation report. PIs are evaluated by the Director's Office. The evaluation results are informed to the researchers to assist their next steps in research. The Research Scientists may get ELSI Incentive Awards, which include contract extension to 3+2 years, salary increase, and additional research budget.

"ELSI Incentive Awards 2016" Testimonial

Communication room on the 1st floor of the ELSI building

Thorough information sharing during ALL ELSI Meeting

The director holds the monthly ALL ELSI meeting requiring all (from researchers to administrative divisions) to attend. This meeting is a monthly opportunity for the director to provide all up-to-date information. ELSI welcomes all PIs from overseas to attend this monthly meeting remotely.

The director also holds a monthly meeting with the purpose of intimate discussion with the president and vice presidents of Tokyo Institute of Technology about various issues, such as the budget, human resources, and so on.

One-stop service for research - focused environment

Providing services unavailable from usual administrative divisions

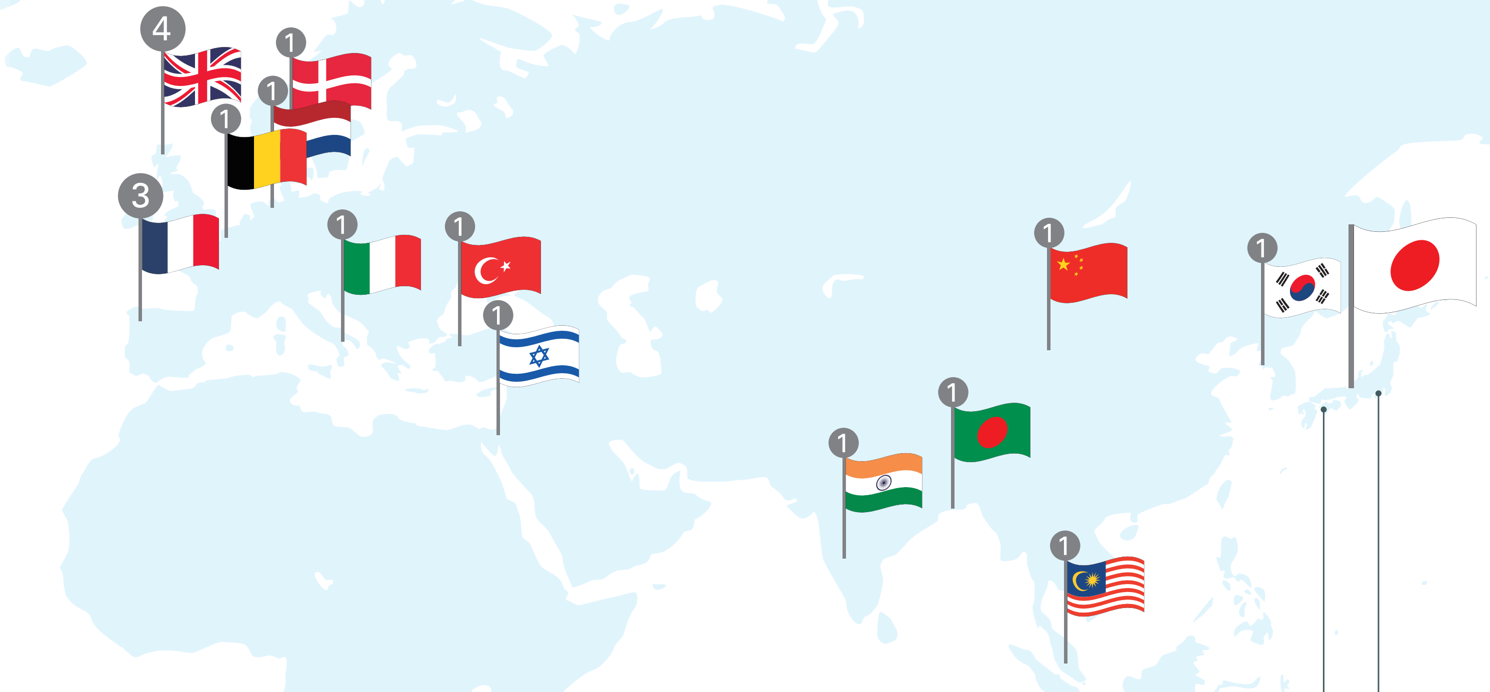
ELSI provides a friendly one-stop support, much improved compared to those provided from usual university administrative divisions, in order to maintain an environment where our mainly non-Japanese researchers can focus on their research.

For example, our two research administrators support the grant application process. Our life-support staff assists the visa acquisition process, family and child care, and overall daily life. In 2017 April a child care facility "Tech Tech Nursery" was opened within the campus. These considerate supports greatly contribute to the recruiting of foreign researchers.

Japanese language class a part of living support

Close cooperation with four satellites

ELSI gathers researchers from all over the world,
has close relationships with the four satellites inside and outside Japan,
and spreads its research network globally.



Geodynamics Research Center (GRC), Ehime University

We study the dynamics of the interior of the Earth based on computer simulations and experiments.

The Geodynamics Research Center (GRC) was founded in April 2001 as an advanced research center of Ehime University for studies of the structure, constitution, and dynamics of the Earth's deep interior, connecting Science and Engineering fields.

The relationship with ELSI

GRC research on the interior of the Earth is at the forefront of its field. Ten researchers, including Professor Tetsuo Irifune, GRC director and ELSI PI, maintain the satellite.

ELSI and GRC work together to recruit young researchers utilizing the researchers' network TANDEM (The Asian Network in Deep Earth Mineralogy) initiated and maintained by Professor Irifune and his team in west Japan.

Department of Earth and Planetary Science, the University of Tokyo

The Department of Earth and Planetary Science (EPS) of the University of Tokyo covers wide research fields; Earth's interior, ocean, atmosphere, and biosphere, Earth as a planet and researches on Solar-System bodies, and space science. The EPS department consists of about 50 research staff and is one of the most prominent research groups in Japan's geophysics.

The relationship with ELSI

ELSI and EPS of the University of Tokyo will conduct joint researches on the formation and evolution of Solar-System planets and satellites, habitability on the planets, and geology, geochemistry, and life on early Earth. The ELSI director Hirose is cross-appointed to the University of Tokyo from FY2017 and will spend 20% of his time as University of Tokyo professor and take leadership of the ELSI satellite at the EPS department of the University of Tokyo.

Many cooperating facilities and affiliates

ELSI has built relationships with cooperating and affiliated facilities by inviting PIs and sharing opinions with researchers from inside and outside Japan. This has led to major projects of importance to ELSI. Proactive co-research, relationships, and communication are extremely important for ELSI to function as a research hub.

1 The number of foreign researchers

Researcher's Origin

* As of April, 2017

Interdisciplinary Studies Program, Institute for Advanced Study, Princeton

A private and independent academic institution hosting 33 brilliant scholars and Nobel laureates, including Albert Einstein and John von Neumann, has flourished since its launch in 1930.

The institute specializes in four studies: Historical Studies, Mathematics, Natural Sciences, and Social Science.

Each year, approximately thirty eminent academics work with two hundred members from research institutions throughout the world. One program that we are particularly proud of is the Interdisciplinary Studies Program led by ELSI PI Piet Hut.

The relationship with ELSI

With Professor Piet Hut, the director of the Interdisciplinary Program and an authority in the field of astrophysics, ELSI and the satellite directors aim to improve interdisciplinary research.

Piet Hut is also the Principal Investigator of the ELSI Origins Network (EON), which was launched in July 2015.

Origins of Life Initiative, Harvard University

The Origins of Life Initiative is an interdisciplinary program that was initiated in 2007. The joint effort is made up of scientists representing five distinct areas: Earth and Planetary Sciences, Organismic and Evolutionary Biology, Molecular Biology, Chemistry, and Astronomy.

The initiative has grown to over 50 members who are dispersed across the university's main campus in Cambridge and Boston.

The relationship with ELSI

Professor Jack Szostak, recognized worldwide as an authority on Synthetic Biology, has joined ELSI. This satellite studies the origin of life based on the environmental findings of early Earth provided by ELSI.

This satellite also promotes mutual communication between young researchers. The workshop "Origins of Life Chemistry Workshop" was held in March 2014, and following its successful outcome it was held again in February 2015.

World top-level research environments

In addition to the ELSI-2 building that was a renovated existing building, a new building, ELSI-1, was completed in 2015.
With these two neighboring buildings and advanced research facilities, ELSI's research activity will be accelerated further.

Newly-designed research building ELSI-1

Utilizing a supplementary budget from MEXT, the long-awaited research building ELSI-1 was built in 2015 in the Ookayama campus. The building was designed under the concept of "harmony between Japanese and western styles", paying attention to a good balance in research and communication spaces.

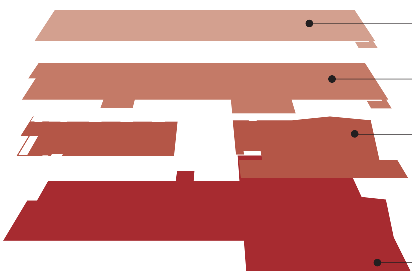
The basement houses an electron microscope room, focusing ion beam room, high-pressure experiment lab, geochemistry experiment lab, and chemical evolution lab.

The entrance on the 1st floor features an open information-sharing space called "the Gallery", and a lecture hall that can hold over one hundred people.

The 2nd and 3rd floors will include compact and functional research rooms for ELSI researchers and extended-stay guest researchers.

The open-ceiling communication room on the 2nd floor, called the Agora, can be used by many researchers to participate in interdisciplinary communication.

Interior of ELSI-1
Big and open common area (the Agora), the Lecture Hall, and compact and functional labs.



ELSI's Interdisciplinary research facility

ELSI's research facilities are designed to accommodate a wide variety of research methods and tools.

Cray XC30™ Super Computer

ELSI's super-computing facilities include a Cray XC30 using Intel Xeon processors with a total of 960 cores. We have computing power sufficient to simulate many phenomena.

Diamond anvil cell

This device uses laser-heating and the immense pressures generated by forcing the tips of two diamond crystals together to simulate conditions deep inside the Earth, and is a key tool for understanding Earth's structure composition.

Exterior of ELSI-1

ELSI has two buildings to accommodate our growing institute

ELSI researchers have been utilizing ELSI-2, an existing building of 2,670 m^2 renovated for ELSI in 2012.

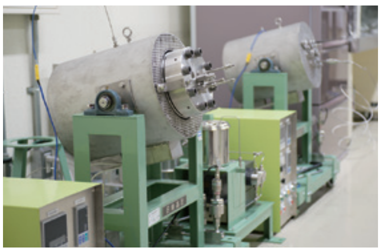
The 1st floor includes a large communication room (called the Lounge) with continent-shaped tables, a giant blackboard, and a refreshment area. Researchers utilize this space for meetings and communication.

ELSI-2 still hosts part of the labs and admin office after the new ELSI-1 building was opened, allowing ELSI to expand and organize its space more efficiently.

Left: ELSI-2 communication room (the Lounge)
Top: Meeting room with Kotatsu table by the communication room

Next generation sequencer (NGS)

This device analyzes genomes using a massive parallel sequencer, enabling ELSI researchers to perform biological experiments with unprecedented speed and flexibility.



Batch-type high P-T Reactor

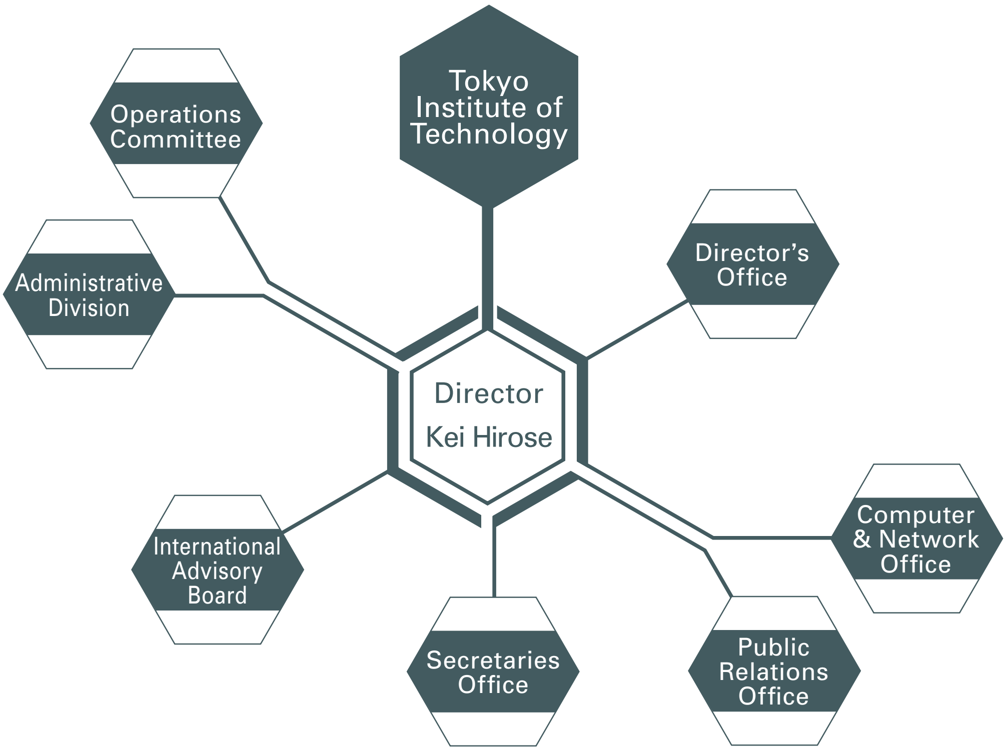
This device reproduces a high P-T environment of up to 600 ATM/600 degC /, which can be utilized to investigate how organic compounds, the elements of life, are synthesized and to simulate conditions in primitive oceans.

Research rock library

The Museum of Evolving Earth at Tokyo Tech stores 170,000 sample rocks and information collected from locations all over the world. Samples in this collection provide a record from 2.8 to 4.0 billion years ago.

Strong leadership and thorough information sharing

ELSI has independently established an original organizational structure tailored to its unique needs, which operates efficiently and transparently in order to nurture the best possible research environment.



* As of April, 2017

Research Members

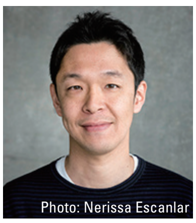
Principal Investigator (Director)
Kei Hirose
High-pressure geoscience

Principal Investigator (Vice Director)
Shigeru Ida
Planet formation

Principal Investigator (Vice Director)
John Hernlund
Geophysical modeling

Principal Investigator (Councilor)
Piet Hut
Astrophysics

Principal Investigator
George Helffrich
Solid Earth geophysics



Principal Investigator
Ryuhei Nakamura
Electrochemistry

Principal Investigator
Eric Smith
Complex systems

Principal Investigator
Jack Szostak
Biochemistry

Principal Investigator
Yuichiro Ueno
Biogeochemistry

Principal Investigator
Naohiro Yoshida
Environmental geochemistry

Director's Office

The director, vice directors, administrative director, and assistants to the director are responsible for making decisions at ELSI. The director holds the ultimate responsibility related to ELSI's structure and management as a leading global research facility.

International Advisory Board

The International Advisory Board provides valuable strategic advice to ELSI on a regular basis. The current members are Masuo Aizawa (Chair), Robert Hazen, Douglas Lin, Carl Pilcher, and Frances Westall.

Operations Committee

The director, vice directors, administrative director, and other members hold monthly Operations Committee and give advice to the director regarding campus-wide arrangements, setting up and revising various regulations, improvement in research environment, and human resources issues. In order to implement a smooth operation of the institute, the Operations Committee is attended by the chiefs of administration, secretary, and PR offices as observers.

Administrative Division

Administrative Director
Takashi Sakurai

The administrative director and vice director oversee matters between the university and ELSI, such as employment contracts, financial affairs, and safety management. The administrative team also provides support for foreign researchers living in Japan.

Secretaries Office

We have a dedicated secretary's office whose staff support the research activities of ELSI members, such as travel, purchases, and other administrative tasks.

Public Relations Office

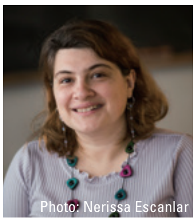
The PR office helps promote ELSI to the public and assists in outreach activities. They also host events such as public lectures and maintain booths at international conferences.

Computer & Network Office

ELSI's technical staff maintains a top-level information technology infrastructure in support of a research-focused environment.

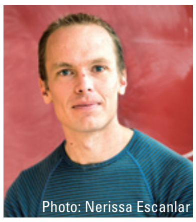
Principal Investigator
Tetsuo Irifune
Solid Earth material science

Principal Investigator
Joseph Kirschvink
Geobiology

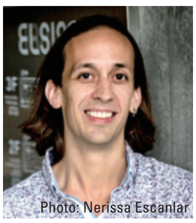


Principal Investigator
Irena Mamajanov
Astrobiology

Principal Investigator
Shigenori Maruyama
History of the Earth



Principal Investigator
Shawn McGlynn
Evolutionary biology, Microbiology



A.Principal Investigator
Albert Fahrenbach
Organic chemistry, Origins of life

A.Principal Investigator
Yuka Fujii
Planetary Science
(appointed 2017 June)

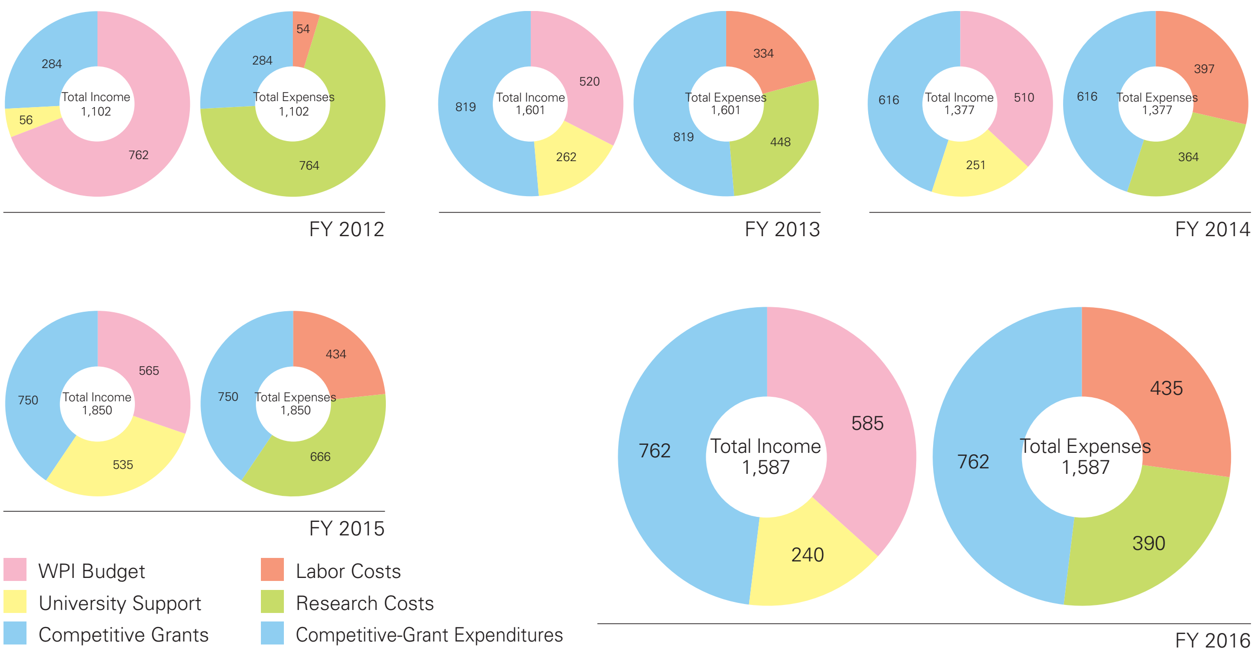
A.Principal Investigator
Hidenori Genda
Planet formation

A.Principal Investigator
Betur Kacar
Evolutionary Biology, Astrobiology

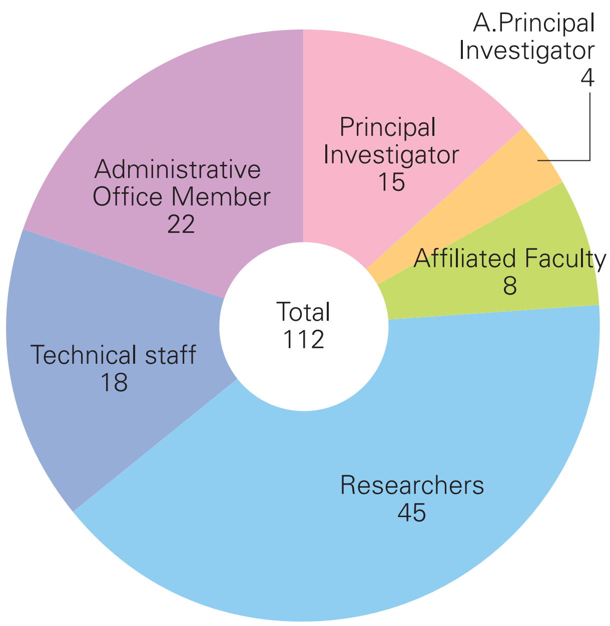
A.Principal Investigator
Tomohiro Usui
Geo- and Cosmo-Chemistry

Data: ELSI progress and current status

Program Budget (Million JPY)

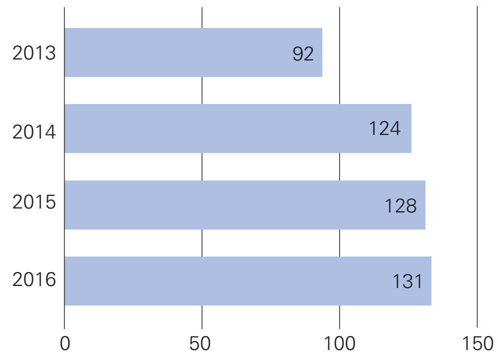


The number of persons

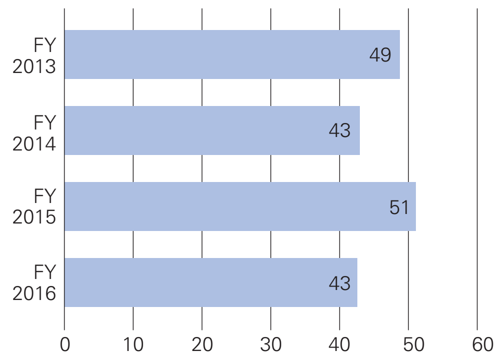


As of April, 2017

Total number of refereed publications



Number of seminars



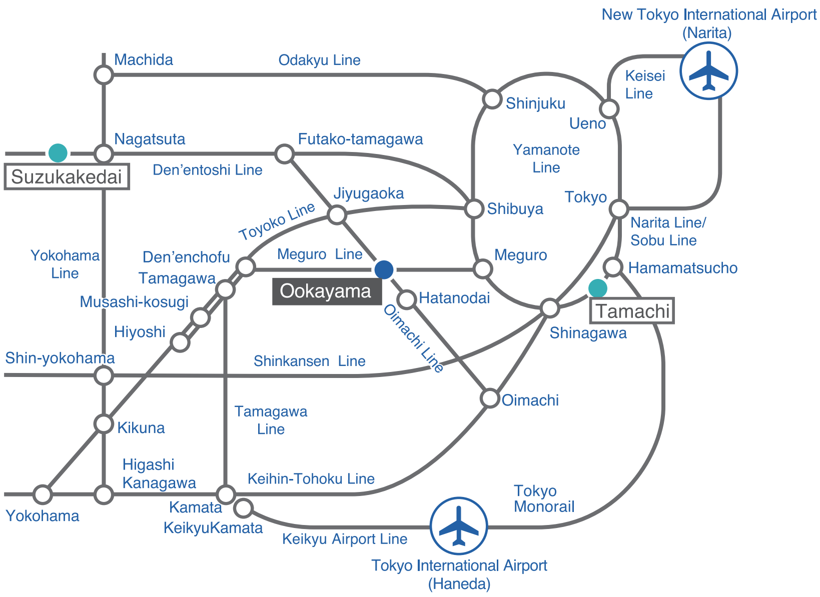
Recent Awards

Month/Year	Name	Type
February 2015	Ryuichi Nomura	Inoue Research Award for Young Scientists
April 2015	Hiroki Ichikawa	MEXT Prize for Science and Technology
April 2015	Joseph Kirschvink	Geological Society of America Fellow
April 2015	Tetsuo Irifune	Medal with Purple Ribbon
November 2015	Tetsuo Irifune	R.W. Bunsen Medal (European Geosciences Union)
February 2016	Yuka Fujii	Inoue Research Award for Young Scientist
March 2016	Daisuke Kiga	JSPS Prize
April 2016	Masashi Aono	MEXT Young Scientists' Prize
June 2016	Kei Hirose	57th Fujihara Award
December 2016	Kosuke Fujishima	WIRED Audi INNOVATION AWARD2016

Tokyo and ELSI Map

Tokyo is one of the world's most important and intriguing cities, in addition to being the largest by a significant margin. While famous neighborhoods like Shibuya or Shinjuku often conjure images of an over-crowded megalopolis, much of Tokyo is composed of relatively quiet neighborhoods where families shop in small markets, play in the parks, and find tranquility at numerous shrines and temples. There are more excellent restaurants in Tokyo than meals to be eaten in an entire lifetime. Many fascinating discoveries and surprises await the urban explorer in this city of stunning intricacy and diversity. We are certain that you will fall in love...welcome to Tokyo!

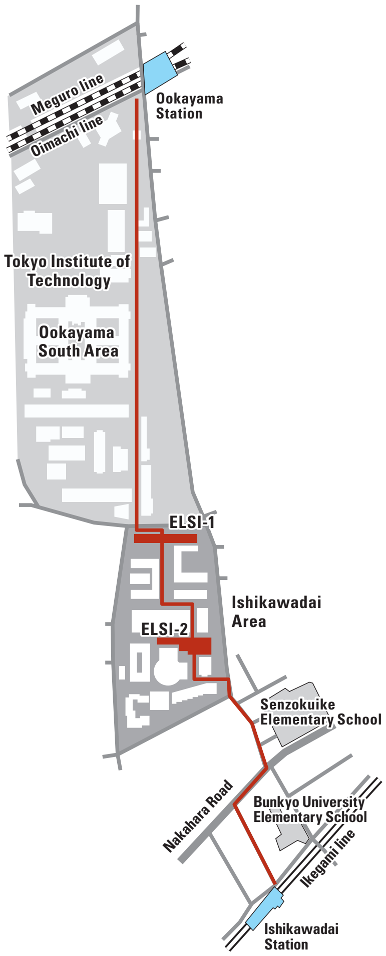
The world's largest metropolitan area is inter-connected by the world's largest train network, truly one of the human-made wonders of the world. The Tokyo train system map beckons the urban traveler, evoking analogies to complex metabolic pathways or electronic circuits. This efficient and user-friendly mass transit network encourages people to leave their cars at home, thereby mitigating air pollution, and catalyzes interactions between all of humanity in the Tokyo region. Shinjuku, the world's busiest train station, efficiently handles over 3 million passengers every day! Besides trains, Tokyo is also very pedestrian and bicycle friendly, and these are the best means to explore its nooks and crannies.



EARTH-LIFE SCIENCE INSTITUTE
TOKYO INSTITUTE OF TECHNOLOGY

Earth-Life Science Institute (ELSI)
Tokyo Institute of Technology
2-12-1-IE-1 Ookayama,
Meguro-ku,Tokyo,
152-8550,Japan
Tel:+81-3-5734-3414
Fax:+81-3-5734-3416
E-mail:information@elsi.jp

http://www.elsi.jp



Tokyo Tech

wpi

Published December 2017
Created by Earth-Life Science Institute,
Tokyo Institute of Technology

Search for the origin of Earth and life

Tokyo Institute of Technology
President
Yoshinao Mishima
Tokyo Institute of Technology
Earth-Life Science Institute
Director, Professor
Kei Hirose

WPI

The four pillars of the World Premier International (WPI) Research Center Initiative

Science/Fusion/Globalization/Reform

Network

Close cooperation with three satellites

Facilities

The new research building in 2015

Organization

Strong leadership and thorough information sharing

Data

Data : ELSI progress and current status