

# World Premier International Research Center Initiative (WPI) Activities Report of the WPI Academy Center (FY 2021 – FY 2024)

Host Institution	Institute of Science Tokyo	Host Institution Head	Naoto Ohtake
Research Center	Earth-Life Science Institute (ELSI)		
Center Director	Yasuhito Sekine	Administrative Director	Kei Kurita

**Common Instructions:**

- \* Unless otherwise specified, prepare this report based on the current (31 March 2025) situation of your Center.
- \* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.
- \* Prepare this report within 10 pages (excluding the appendices, and including "Summary of State of WPI Academy Center Progress" (within 2 pages)).

### Summary of WPI Academy Center's Activities (write within 2 pages)

- \* Describe clearly and concisely the progress being made by the Center from the viewpoints below.
- In addressing the below-listed 1-8 viewpoints, place emphasis on the following:
  - (1) Whether research standards and operation of the Center is maintaining a "world premier" status.
  - (2) Whether the Center participate and cooperate to the activities to advance the overall development of the WPI Program and to promulgate its achievements.

In the first 10 years from 2012–2022, ELSI provided the view of the sequence of diversifications and filter selections toward the current Earth-Life system (called "ELSI model"). However, at the same time, this raises new fundamental questions. Are there alternative planet-life systems in the universe? Are there any other paths to reach to emergences of lives? If we find lifeless planets, how can we characterize them and what can we learn from them? Earth is the only one planet that we know the existence of life. Revealing of the origin of life on Earth may be more like the study of one specific history. The origin-of-life science can be Universal Biology only after understanding the possibilities of emergence of alternative lives and lifeless planets in the ELSI model.

After the WPI funded period, ELSI has sought to elucidate the formation and evolution of diverse planetary environments and the chemical evolutionary processes therein toward development of Universal Biology (Figure 1). Planetary environments, including surface water contents, nutrient availability, and redox conditions of atmospheres and oceans, are diverse on terrestrial planets and icy bodies in the Solar System and beyond. Planetary formation processes were crucial in determining these planetary environments. We are also investigating how geochemical cycles and organic chemical evolution occur in these diverse planetary environments, and whether classifications and classifications are possible. Finally, we are also trying to study methodologies to predict the molecular systems that can be created in each environment using synthetic biology and complex systems science methods.

Among the vision of research shown in Figure 1, which span from planetary formation to the formation of molecular systems, ELSI is particularly interested in the following two major topics and four sub-topics. In one of the major topics, ELSI tries to predict organic and geochemical networks in planetary environments (1. Organic and geochemical networks on planets). By combining knowledges on geodynamic circulation and hydrogeochemical cycles, ELSI tries to construct general models of chemical cycling of bioessential elements and nutrients on planets. Plus, through collaborations with organic chemistry, systems chemistry, and catalytic chemistry, we will investigate possibilities of networks of proto-metabolism and chemical evolution on planetary bodies with different geological settings. These would be a bottom-up approach to predict a diversity and selectivity of functional polymers and molecules.

In the other, we will develop synthetic and theoretical biology in planetary contexts (2. Synthetic and theoretical biology in space). Through collaborations between synthetic biology, astronomy, and planetary sciences, we will perform artificial evolution experiments under changing planetary environments. Considering early Mars and Hadean Earth, planetary habitable environments in those systems could have evolved more dynamically than the present-day Earth. With combinations of network theory, geophysics, and astronomy, we will predict changes in the size and complexity of biogeochemical networks in response to environmental changes. Detailed individual research concerning these two topics can be found below in Section 2.

The formation of these hypothetical planetary environments and the organic chemical evolution therein should be compared to ongoing or future solar system exploration and exoplanet space telescope observations. Therefore, ELSI should collaborate internationally and domestically with research institutions such as JAXA, NASA, ESA, and NAOJ, which is exactly in line with our vision of becoming a research hub as a WPI.

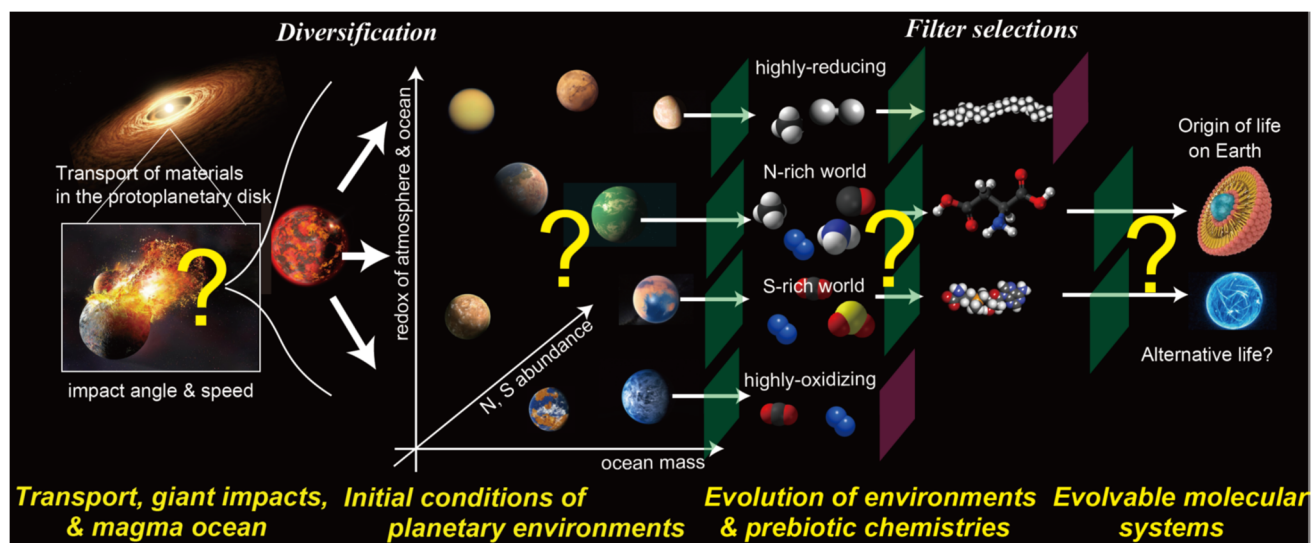


Figure 1. Schematic illustration of formation of diversification of planetary environments, including mass of ocean, nutrient availability, and redox states of the atmosphere-ocean systems. In particular environments, organic chemical evolution would arise. ELSI has been trying to draw a whole of this picture and to compare with observations by spacecrafts and telescopes.

The Director and Science Coordinators have taken initiative to lead the international collaborative research. The Director and Science Coordinator have promoted the international circulation of world's best brains in three ways. First, ELSI promotes long-term (~two years) exchanges of early-career scientists (researchers and Ph.D. graduate students of ELSI course) with key research partners in USA and Europe. Second, ELSI has hired promising, mid-to-early career researchers as fixed-term A-PIs or researchers in ELSI. As the host institute, ELSI has provided world-class facilities and equipment as well as living support to foreign researchers. Through these two, ELSI can continue to be "Agora (gathering place)" for interdisciplinary scientists, connecting space, Earth, and life sciences, and to create real new fields of science, such as astrobiology and universal biology. In addition to these two, we continuously hold international symposia and conferences in order for ELSI to keep as one of the top leading institutes of astrobiology and the origin of life science. ELSI has worked hard to be a globally accessible and appealing center for research that serves as a hub for outstanding science.

## 1. Overall Image of Your Center

- Describe the Center's current identity and overall image.
- List the Principal Investigators in Appendix 2, diagram the Center's management system in Appendix 3-1, enter the number of center personnel in Appendix 3-1a, and enter center funding in Appendix 3-2.

In the first decade of the WPI funded period, ELSI's organization of scientists (i.e., PIs, A-PIs, and researchers) was basically flat (Figure 2). This flat system guaranteed a research diversity within the institute. In this system, there were also low barriers to collaborate with other researchers of different disciplines, enhancing chances of creating interdisciplinary researches. ELSI's current lab units, in which lab managers managed experimental works in the units, helped for young researchers to start up their researches effectively in this system. However, ELSI will have graduate students after the WPI funded period. They are not categorized in the past system and will not be flat to PIs (i.e., supervisors). The number of graduate students reached 60-70, which was almost twice those of scientists. In the past system, roles of PIs, A-PIs, and researchers for increasing students are unclear.

While keeping the research diversity and interdisciplinarity in the next decade, ELSI needs to make one compact and effective research network within the institute. To this end, roles of PIs, A-PIs,

researchers, and students need to be clarified in ELSI's organization (Figure 2). PI's responsibilities are to anchor core research themes with long-term programs, to acquire stable funding to support junior project researchers and students as well as experimental facilities, to manage the education program, and to facilitate collaborations and joint projects across themes. Fixed-term A-PIs (and researchers) are engines of innovation. A-PIs responsibilities are to be key bridges across disciplines. A significant criterion in hiring/mentoring A-PIs is their ability to work in/with projects in more than one theme area, to expand diversity and originality of research topics, to provide flexibility and interdisciplinarity to ELSI research, and to maintain exchange and collaboration within Japan and internationally. Through co-supervision by PIs and A-PIs, graduate students can be actual bridges to connect PIs and A-PIs, making one research network in the institute.

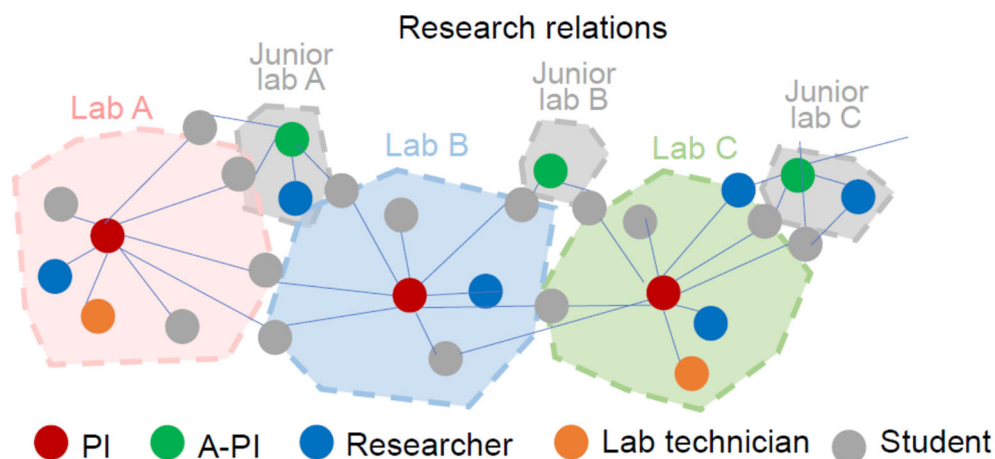


Figure 2. ELSI's organization after the WPI funded period.

Specific job expectations for each category of ELSI members include:

PIs – 1. Administration, 2. Acquisition of large research grants and donations, 3. Management of an education program for graduate students and ones' laboratories (ELSI's own special curriculum and/or contributions in collaboration with the existing departments), 4. Engagement in inter-institute collaborations, 5. Supervision of early career postdocs and students, 6. Promotion of in-house collaborations.

A-PIs – 1. Initiation of interdisciplinary research (in-house and inter-institute collaborations), 2. High levels of research activity, 3. Connecting PIs' research, 4. Co-supervision of graduate students

Researchers and graduate students – 1. Research activity under supervision by PIs (and A-PIs). We will look for opportunities for jointly-mentored researchers for projects spanning disciplines, as a way to increase group overlap and communication.

In addition to these existing categories, a new category of Science Coordinator has been created to achieve effectiveness and efficiency in research and institutional development. Science coordinator makes one research network in a compact ELSI. This science coordinator is the person who keeps on top of all the research taking place at ELSI and uses the information to promote fusions among PIs and A-PIs to acquire large grant and support from industries, and to develop institutional collaborations inside and outside Japan. In addition to the science coordinator, the director and administration director actively participate in such development roles.

Science coordinators – 1. Develop fusion of multiple disciplines through promoting collaborations between PIs' (A-PIs') research, 2. Connecting in-house research projects with international/domestic institutional collaborations, 3. Promoting and coordinating in-house research projects, aiming to acquire funds from JSPS and industries.

## 2. Advancing Research of the Highest Global Level

- Describe what's been accomplished in the Center's research objectives and plans.
- In Appendix 1, list the papers underscoring those research achievement and list the Center's research papers published in 2021-2024 in a manner prescribed in Appendix A.

Toward the establishment of Universal Biology, we have been focusing on tackling following four research themes as for studies on the planet-life systems; that is, diversity of nutrient cycles, organo-

geochemical cycles, expansion of biology to Earth-planetary system, and eco/geosystem transition on planets. These researches have been done by in-house collaborations among astronomy, geoscience, chemistry, and life science, and will maximize science values of space missions and telescope observations planned by mission-design agencies.

The first two themes relate to reveal organo-chemical networks in planetary cycles. In first, we aim to predict and interpret cycles of nutrients. The limiting nutrients for Earth's life activities are phosphate and nitrogen. Concerning the availability of phosphate in oceans beyond Earth, we have discovered anomalous enrichments of phosphates in Enceladus' ocean (Postberg et al. 2023 Nature). The small moon is known to possess a subsurface ocean, and water from that ocean erupts through cracks in Enceladus' icy crust as geysers at its south pole, creating a plume. The plume then feeds Saturn's E ring with icy particles.

During its mission at the Saturnian system from 2004 to 2017, the Cassini spacecraft flew through the plume and E ring numerous times. Cassini found that Enceladus' ice grains contain a variety of minerals and organic compounds associated with life on Earth. Previous analysis of Enceladus' ice grains also revealed concentrations of sodium, potassium, chlorine, and carbonate-containing compounds, and geochemical modeling suggested the subsurface ocean is of moderate alkalinity. However, the availability of nutrients was largely unknown in Enceladus' ocean. In particular, phosphate is one of the most important nutrients for Earth's life as it is a fundamental building blocks of DNA, RNA, phospholipids, and ATP and has controlled bioproductivity in Earth's oceans throughout the history.

Yasuhito Sekine and colleagues have found phosphate in the plume particles with a 1–20 mM of concentration in the ocean using the Cassini data (Postberg et al., 2023 Nature) (Figure 3). This concentration is  $10^4$  times more than Earth's ocean. The ELSI group led by Yasuhito Sekine conducted laboratory experiments to interpret the enrichments. They found that the high phosphate concentrations are a result of interactions between carbonate-rich, alkaline liquid water and rocky minerals (Ca phosphate) on Enceladus' ocean floor. In alkaline carbonate-rich water, Ca phosphate dissolved to form Ca carbonate, releasing phosphate into solution. This suggests that phosphate-rich water chemistry should occur on a number of other ocean worlds beyond the CO<sub>2</sub> snowline (CO<sub>2</sub> condensation line in the protoplanetary disk) in the Solar System and alkaline, CO<sub>2</sub>-rich environments (such as alkaline hydrothermal vents) on early Earth (Figure 3).

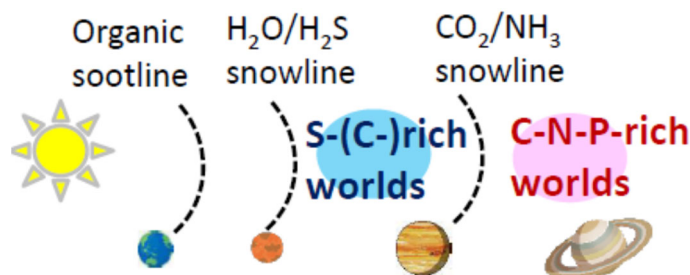


Figure 3. Schematic illustration of nutrient dichotomy in the outer Solar System. Outside the CO<sub>2</sub> snowline, NH<sub>3</sub> and phosphate would be enriched in the oceans, similar to Enceladus' ocean (Postberg et al., 2023 Nature). On the other hand, inside the CO<sub>2</sub> snowline, sulfur may be a central nutrient element in the oceans.

The other important nutrient for Earth's life is nitrogen. However, N<sub>2</sub> is generally inert in a natural environment; accordingly, any natural catalyst capable of activating N-bearing compounds, if any, would have played a key role in the origin of life. The ELSI research team led by Ryuhei Nakamura found that copper sulfide (covellite), a mineral found in anaerobic environments, has the ability to artificially drive anaerobic ammonia oxidation performed by bacteria (He et al., 2024 Nature Chemistry) (Figure 4). Anaerobic ammonia oxidation (anammox), a reaction that produces nitrogen gas from ammonia and nitrite, was discovered in 1995 in bacteria living in wastewater treatment plants. This is an important reaction involved in the removal of nearly 50% of the fixed nitrogen in the Earth's oceans, and despite nearly 30 years of research, no artificial catalyst has ever been developed that can drive the anammox reaction.

Ryuhei Nakamura and colleagues investigated the catalytic activity of 37 different mineral materials and found that copper sulfide specifically catalyzes the anammox reaction (He et al., 2024, Nature Chemistry). Detailed examination of the reaction mechanism revealed that copper sulfide can reproduce the entire biological anammox pathway, which is composed of three metalloenzymes. This achievement provides a new reaction pathway for activating ammonia and will have a significant impact on the study of the origin of life, in which nitrogen compounds such as amino acids and nucleobases play an important role.

CuS is a mineral that forms in reducing aqueous environments and may be present in the interior of ice satellites in the outer solar system as well as in hydrothermal vents on early Earth. In fact, an

analysis of returned samples from the Hayabusa2 spacecraft, in which Hidenori Genda was a co-author, revealed the presence of CuS on the outer solar system-derived asteroid Ryugu (Nakamura et al., 2023, Science). In this study, Hidenori Genda has revealed that the asteroid Ryugu was originally a part of a large icy planetesimal and was formed by ejection of surface/subsurface materials through an impact of another asteroid without any significant thermal alterations (Nakamura et al., 2023 Science).

ELSI's series of studies (including Postberg et al., 2023 Nature, He et al., 2024 Nature Chemistry; Nakamura et al., 2023 Science) strongly suggest the existence of a P- and N-rich oceanic world outside the CO<sub>2</sub> snowline in the Solar System. These bodies include Enceladus, Titan, Mimas, the Uranian moons, Pluto, Ceres, and Kuiper belt objects. On the other hand, these studies suggest that within the CO<sub>2</sub> snowline, the availability of P and N would be low. Instead, sulfur would have played a key role in organic chemical evolution. Shawn McGlynn and his colleagues show that S-bearing esters, thioesters, would be thermodynamically and kinetically stable in water environments with acidic to neutral pH, including acidic hydrothermal vents on early Earth, Mars surface water, and Jupiter's moon – Europa's subsurface ocean (Sanden et al., 2024 iScience). We suggest the occurrence of S-rich oceans inside the CO<sub>2</sub> snowline, such as Mars and Europa, and P-N-rich oceans outside the Solar System.

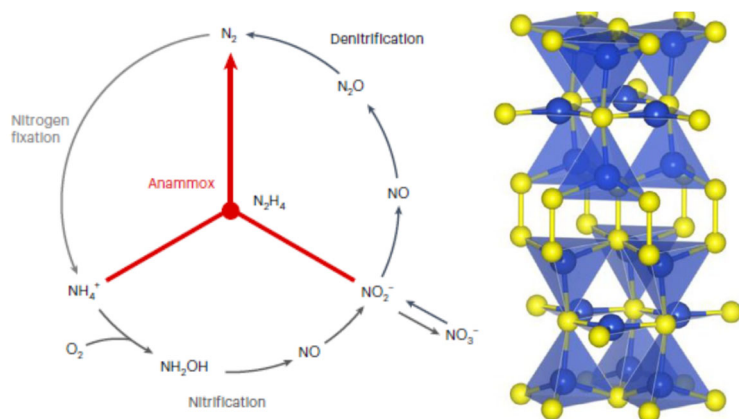


Figure 4. Mineral screening for non-enzymatic anammox (He et al., 2024 Nature Chemistry). Major transformations in the nitrogen cycle (left). The reactions studied in the preset study are shown in red. Structural model of the synthetic CuS mineral (right)

In second, we investigate organo-geochemical cycles in habitable environments. Through more integrated linkages of organic chemistry experiments, geohydrological modeling, and complexity science, we will examine a variety of networks of organo-geochemical cycles depending on different geological settings (geohydrological cycles) of planetary environments.

An interdisciplinary research group led by Yamei Li, collaborating with Hiroyuki Kurokawa, Yasuhito Sekine, and Ryuhei Nakamura, in ELSI has been tackling this research theme. Based on ELSI's previous achievements of geoelectrochemistry on hydrothermal vents on early Earth (Kitadai et al., 2018, Science Advances), Yamei Li and colleagues found that  $\alpha$ -amino acids were electrochemically altered to monoamines and  $\alpha$ -hydroxy acids on FeS and NiS catalysts at low temperatures within icy planetesimals and icy ocean worlds beyond the CO<sub>2</sub> snowline (Li et al., 2022 Nature Communications) (Figure 5). This conversion is consistent with their enrichment compared to amino acid analogs in heavily altered carbonaceous chondrites. Their results thus suggest that H<sub>2</sub> can be an important driver for organic evolution in water-rock differentiated parent bodies of carbonaceous chondrites as well as the Solar System icy bodies that might possess similar pH and redox gradients. They first proposed an organo-geochemical cycle of amino acids and other N-bearing organic compounds within the icy ocean worlds.

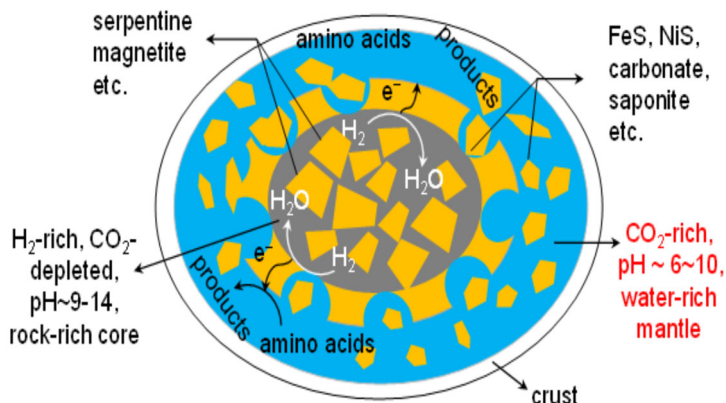


Figure 5. Schematic model of geoelectrochemical amino acid decomposition on the icy parent planetesimals of carbonaceous chondrites and asteroid Ryugu (Li et al., 2022; 2023)

By further developing this idea, Yamei Li also interpreted the finding of amino acids and pattern of enrichments and depletion of particular types of organic compounds in the return samples from the asteroid Ryugu (Li et al., 2023 Science Advances). In particular, they found that two proteinogenic amino acids, glutamic acid and aspartic acid, decompose to two non-proteinogenic amino acids ( $\gamma$ -ABA and  $\beta$ -Ala, respectively) using FeS and NiS as the catalysts. This sufficiently explains the meteoritic observation that heavily aqueously altered Ryugu's return samples contain markedly enriched non-proteinogenic amino acids while the less altered carbonaceous chondrites have more proteinogenic amino acids. Moreover, Li et al. proposed a new evolutionary model for justifying the chemical heterogeneity between different groups of carbonaceous chondrites: CM, CI, and CR groups. Provided the icy parent planetesimals were water/rock differentiated due to the very different water/rock ratios in the core and mantle, steep chemical and redox gradients would have been developed. Amino acids can be well preserved in the core but will be decomposed in the mantle. Along with the inward migration of these bodies, the collision and fragmentation of the body would generate asteroids with very different amino acid distributions. They proposed that such core/mantle differentiation can at least partly explain the observed amino acid heterogeneity among CM, CI, and CR groups and asteroid Ryugu (Li et al., 2023 Nature Communications).

The last two themes are about expansion of theoretical/synthetic biology to Earth and beyond and to reveal ecosystem/geosystem transition on planets through collaborations of biology, Earth and planetary science, and complexity science.

Early Earth and other habitable planetary bodies are rich in simple compounds such as hydrogen sulfide, ammonia, and carbon dioxide – molecules not usually associated with sustaining life. But, billions of years ago, early life on Earth relied on these simple molecules as a raw material source. As life evolved, biochemical processes gradually transformed these precursors into compounds still found today. These processes represent the earliest metabolic pathways.

To understand what types of chemistry life is able to perform, Harrison Smith, Liam Longo, and Shawn McGlynn modeled the history of biochemistry using an inventory of all known biochemical reactions (Goldford et al., 2024 Nature Ecology & Ecosystem) (Figure 6). With reactions in hand, they began to model the stepwise development of metabolism based on theory of complexity science. They find that purine synthesis constitutes a bottleneck for metabolic expansion, which can be alleviated by non-autocatalytic phosphoryl coupling agents. Early phases of the expansion are enriched with enzymes that are metal dependent and structurally symmetric, supporting models of early biochemical evolution. This expansion trajectory suggests distinct hypotheses regarding the tempo, mode and timing of metabolic pathway evolution, including a late appearance of methane metabolisms and oxygenic photosynthesis consistent with the geochemical record. The concordance between biological and geological analyses suggests that this trajectory provides a plausible evolutionary history for the vast majority of core biochemistry. These identification of the transition from geochemical cycles to biochemical cycles on the primitive Earth and the key chemical reactions for this transition are highly significant. Once the database of chemical reactions is available, theory can predict the chemical evolution and possible metabolic cycles in other P-N-rich ocean worlds and S-rich environments.

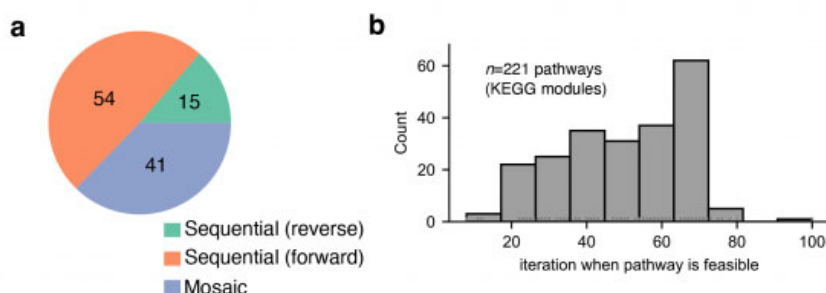
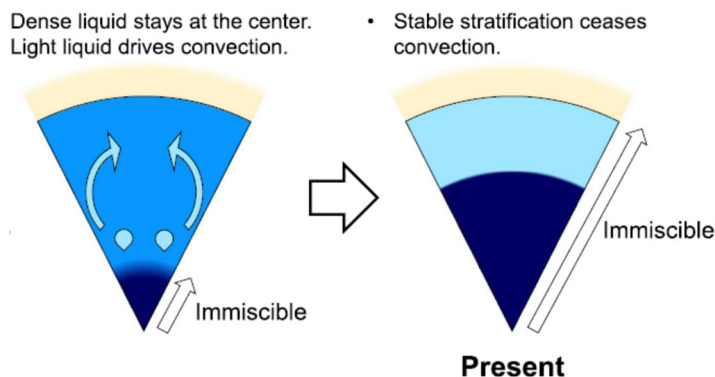


Figure 6. Timing the emergence of metabolic pathways. To construct a model of the evolutionary history of metabolism at the biosphere scale, the research team compiled a database of 12,262 biochemical reactions (Goldford et al., 2024).

Smith, Longo, and McGlynn investigated a transition from geochemical cycles to metabolic cycles in development of ecosystem, but ELSI also found another important transition in planetary systems. Kei Hirose and his colleagues found how the magnetic field was lost in ancient Mars (Yokoo et al., 2022 Nature Communications). Recently, NASA's Mars Lander InSight indicated that the Martian core would contain a large amount of hydrogen in addition to sulfur. This is consistent with the ELSI model, in which a large amount of hydrogen/water must have been stored within the metallic cores of terrestrial planets, including Earth and Mars (Hirose et al., 2021 Nature Reviews Earth Environment).

Using ultrahigh-pressure and high-temperature experiments using the laser-heated diamond anvil cell (LH-DAC), they investigated the behavior of iron-sulfur-hydrogen alloy when it was liquid under ultrahigh pressure and high temperature corresponding to Martian interior. The results show that at sufficiently high temperatures in the Martian core, the liquid iron-sulfur-hydrogen alloy exists as a single homogeneous liquid, whereas at lower temperatures it separates into two phases, a sulfur-rich liquid and a hydrogen-rich liquid. They concluded that the pressures (about 20-40 GPa) and temperatures (about 2000-2500 K) estimated for the present Martian core coincide with the conditions under which this liquid alloy would separate (Yokoo et al., 2022 Nature Communications) (Figure 7).

Figure 7. Stratification in Mars' core caused by liquid immiscibility. Light- and dark-blue represent buoyant and dense liquids, respectively. In the Martian core, liquid immiscibility that started from the center had driven convection and dynamo but eventually formed entire core stratification which ended Mars' planetary magnetic field (Yokoo et al. 2022).



The conditions under which the liquid iron-sulfur-hydrogen alloy separates into two phases coincide with the present-day pressure and temperature conditions of the Martian core. Mars had a magnetic field until about 4 billion years ago, but it is known to have been lost since then, and the cause of this loss has been a great mystery. The loss of the magnetic field is also thought to have led to the dissipation of hydrogen in the Martian atmosphere into space and the evaporation of the oceans. The results of this study indicate that the separation of the Martian core into two phases during cooling drove convection in the core, which is necessary for the generation of planetary magnetic fields in the early stages of Mars, to produce a magnetic field, and that the further separation of the two phases likely led to the subsequent suppression of convection and disappearance of the magnetic field. Further clarification of the conditions of the Martian core through observations by NASA's Mars Interior Orbiter INSIGHT is expected to verify the validity of such a scenario of Martian magnetic field formation and extinction and greatly advance our understanding of Martian history.

These ELSI's studies have revealed the mechanisms of environmental and ecological transitions that can occur on planets by exchanging information and knowledge between planetary science, geophysics, geochemistry, complex systems science, biology, and chemistry. Research targets that were previously mainly confined to early Earth have steadily expanded beyond Earth with the progress of Solar System explorations and other advances, leading to a more general understanding of planet-life system sciences.

### 3. Facilitating Interdisciplinary Research Activities

- Describe the content of measures taken by the Center to facilitate interdisciplinary research activities. For example, measures that create an environment that will facilitate doing joint research by researchers in differing fields.
- Describe the contents and results of interdisciplinary research activities yielded by the measures described above.

To facilitate interdisciplinary research activities, ELSI has conducted Study groups, PI days, and lab internships. The Study groups were organized into three interdisciplinary groups: exoplanets & life signature, magma ocean, and emergent complexity. These Study groups were given seed funding for research activities, workshops, and researcher invitations. Each Study Group also collaborates with institutions outside the ELSI and serves as the core of fusion research. For example, exoplanets & life signatures is collaborating with NAOJ, and emergent complexity is collaborating with UBI, University of Tokyo. In this way, the group is seed-funding fusion research while also acting as a link to related research institutions. From these study groups, teams applying for large research grants from the JSPS are being born. In the future, this will bring overhead to ELSI itself, which will be used to seed funds for the next study group, creating a virtuous cycle.

The PI day is a one-day event where all PIs and APIs explain current research hot topics and long-term visions and share them. From the vision shared here, new interdisciplinary study groups will be

formed and activated. For example, a new study group that was created at PI day is called folded matter. This is the study of the emergence of functional polymers that played a major role in the step from non-life to life, and their self-assembly and autocatalysis.

The lab internship is mainly for graduate students, who belong to graduate courses or Earth-Life courses in our university. These graduate students are granted a mandatory credit to intern for at least one month in a laboratory different from their own field, to promote exchange and understanding among students in the field, and ultimately to discover seeds of interdisciplinary research. In addition, laboratories in different fields voluntarily hold joint bi-weekly research seminars in an attempt to exchange more in-depth knowledge and further expand the possibilities for collaborative research. In fact, new findings are being obtained from a joint synthetic biology and planetary science research group that freeze-thaw cycles promote division and selection of primitive cells.

#### **4. Maintaining an International Research Environment**

- Describe what's been accomplished in the efforts to raise the Center's recognition as a genuine globally visible research institute, along with innovative efforts proactively being taken, including the following points, for example:
  - Efforts being developed to maintain an international research environment based on the analysis of number and state of world-leading, frontline researchers; exchanges with overseas entities
  - Proactive efforts to raise the level of the Center's international recognition
  - Efforts to make the Center into one that attracts excellent researchers from around the world (such as creating of an environment in which researchers can concentrate on their research, providing startup research funding, supporting efforts that will foster young researchers and contribute to advancing their career paths, and arranging support system for the research activities of overseas researchers.)
  - Consolidation of the administrative structures to support implementing the efforts described above
- In Appendix 3-1, describe the state of cooperation with overseas satellites, and list the main international research meetings held by the Center.

ELSI has established a research environment capable of attracting the world's best researchers in the field of the origin of Earth and life, mandating English in all communications involving ELSI researchers and required for all events, workshops, and institutional email lists, and recruited the majority of junior and senior researchers internationally. From FY2021, ~50% of all 40 ELSI researchers are world-class foreign researchers recruited from overseas, of which 2 PIs and 4 APIs are based in Tokyo full-time and 1 PI are staying in Japan 6 months per year. ELSI has pursued a targeted strategy for the international recruitment of talented researchers as PI and API from all over the world, which is unique in Japanese universities.

ELSI has continuously hosted international symposia annually, dozens of workshops, and has a vigorous visitor program to invite top scientists to spend time and collaborate at ELSI. Using the world brain exchange program of the WPI academy, ELSI continuously exchanges young and mid-career researchers per year with international centers of excellence in astrobiology on short- and mid-term exchanges. For example, a young researcher of organic chemistry went to one of the Cassini mission teams in Germany and the U.S., where they revealed the presence of biologically relevant molecules, such as nitriles, ethers, and esters, in Enceladus plumes derived from its ocean (Khawaja et al., 2025 Nature Astronomy). Through the brain exchange program, ELSI has been a core participant in top-level international researches.

Such support for this international collaborative research is further enhanced by external funding support from the JSPS RECONNECT fund (700 million yen over 6.5 years), as well as support from the university's WRH program (Figure 8). These funds are mainly used to promote long-term dispatches and collaborative research for one year or longer. In particular, ELSI is continuing to expand its international presence by collaborating with the Nice Observatory group in France on extending the pebble accretion model to the terrestrial planet-forming region (Okamoto et al., 2023 ApJ), which is important for the formation of water-bearing terrestrial planets.

In addition, ELSI has started an integrated master's and doctoral international graduate course under the Institute of Science Tokyo. This has played a major role in maintaining the internationalization of ELSI, which boasts a competitive ratio of 2.5–5 times for the maximum number of 10 students, and the level of students enrolling is high. Sixty percent of the incoming students are non-Japanese, and more than half of the non-Japanese are from Europa and America. This is an exceptional figure for a graduate school in Japan. These students have now advanced to the PhD, and after they graduate and move to research centers around the world, the international standing of the ELSI will be further enhanced.

Almost all ELSI support staff are bilingual and they provide various services to overseas researchers: daily life support, Japanese language classes, support for acquisitions of competitive funds,

pre-and post-award support of external funds, safety management training, cultural diversity training, and a confidential tool of reporting issues to the management. Laboratory safety issues are all announced in Japanese and in English.



Figure 8. Concepts and plans of the international circulation of world's best brains led by ELSI.

## 5. Making Organizational Reforms

- Describe distinctive effort in managing research operation and administrative organization, such as the strong leadership that the director is giving on the Center's operation, strong performance by the administrative director who provides the center director with strong administrative and managerial support, and division of roles and authority between the Center and its host institution.
- Describe the ripple effects that activities to disseminate experience and know-how accumulated by the Center, such as the followings, have/had on the host institution (or other research institutes, if any):
  - System reforms made through the Center's leading activities to its research operation and administrative organization
  - Experience and know-how accumulated by the Center as it have worked to establish itself as top world-level research institutes.
- Other than the above, give examples, if any, of cooperative activities by the Center and the whole WPI Program or other WPI centers, to disseminate experience and know-how accumulated by the WPI program and/or the WPI centers.

ELSI has been organized and operated along the principles of WPI; top-down operation under strong directorship and internationality. Tokyo Tech. highly evaluated this and allocated ELSI as one of the front-runners in the university innovation. After the completion of WPI center the university has set up a new organization, IRFI in 2022 and assigned ELSI as a core institute here. IRFI's target is to develop new and innovative research fields in the international environment. This is reflected by what ELSI has achieved since WPI support.

On October 1st, 2024 Tokyo Institute of Technology united with Tokyo Medical and Dental University to form Institute of Science Tokyo. The new university has aimed to be a world-class university embracing total fields of science. In the core plan ELSI is assigned as a leading agent in Institute of Future Science (IFs) which targets at innovative research towards brilliant future of human life. The university has guaranteed the same support as before. In particular, the new university will form interdisciplinary research groups with 50-100 of PIs called Visionally Initiatives (VIs) to conduct research activities that are not bound by existing disciplines, working backward from a vision of the future. ELSI is deeply involved in the Space innovation initiative, one of the six VIs, and disseminates the know-how on internationalization and interdisciplinary research acquired through the WPI to the entire university. The director of ELSI, Dr. Yasuhito Sekine, is the program director of the Space Innovation initiative, which promotes comprehensive research on human beings in space, integrating fields ranging from engineering to medicine, sports science, and social science, utilizing the heritage of the WPI.

## 6. Efforts expected to WPI Academy Center to Enhance and Amplify the Visibility and Brand of the Overall WPI Program

- Describe how the Center's outreach activities have contributed to enhancing and amplifying the visibility and brand of the WPI program. Describe the successful cases of the Center's outreach activities in Appendix 4, and enter the number of activities in Appendix 4a.
- Other than the above, describe, if any, the activities and their concrete contents that have contributed to the enhancement and amplification of the visibility and brand of the WPI program (such as holding a large international research meeting, collaborative activities with multiple WPI centers). If you have already provided this information, please indicate where in the report.

- Describe the Center's efforts in making it a place that expands and accelerates the international circulation of the world's best brains. Give their success cases and describe their concrete contents and effect in narrative.
- Describe examples, if any, of cooperative activities by the Center and the whole WPI Program or other WPI centers, to disseminate experience and know-how accumulated by the WPI program and/or the WPI centers.

ELSI's outreach efforts include an average of 20-25 press releases and research highlights per year, with media coverage of over 400. Of this media coverage, 70% is from overseas media, indicating the high level of appeal of our research activities overseas. These are exceptional in Institute of Science Tokyo, and the top 10 in the number of media coverage conducted by Science Tokyo includes multiple ELSI press releases (for example, in 2024, four of the top 10 will be from ELSI).

The ELSI also plays a central role in outreach and the scientific community in Japan: it has become one of the centers for organizing and running the Japan SciCom Forum, with over 130 participants in the 5th edition in 2024. ELSI is also involved in about 10 science communication workshops per year and hired a post-doctoral fellow for science communication in collaboration with Leiden University. The science communication activity with Leiden University goes beyond mere outreach, such as proposing a method for scientifically evaluating scientific communication and compiling it into international academic publications. ELSI also continues to collaborate with artists under the name ELSI Science-Art Residency. In this program, researchers talk with artists about the primitive earth, the origin of life, and future space exploration, and the artists, inspired by these conversations, create paintings and other works of art. We believe this is another important experiment, as it communicates the research and vision conducted by ELSI in a way that is easy to understand for the general public. In addition, ELSI receives public events and school visits, and gives talks to over 800 students and the public annually. This number is quite high within the university and allows us to continue our ideal outreach activities.

## **7. Effort to Secure the Center's Future Development over the Mid- to Long-term**

- Address each of the following items that have been done to secure mid- to long-term center development:
  - Contents of the measures taken by the host institution to support maintaining the activities of the Center (such as securing financial and personnel resources, coordination among host institution to bring together in-house researchers, in-kind provision and/or facilities afforded in terms of usage of building, lab space and other equipment, new management reform carried out after the funding period ends).
  - Actions and measures taken to sustain the Center as a world premier international research center.

To support ELSI for keeping world-top level research institute, Science Tokyo admits to allocate 8 tenure research positions, other researchers and administration staffs to support ELSI's activity including 2 full-time posts. The university declares to continue support for allocating space of research, meeting and administration office by the President's Discretionary Fund. This is a consequence of what the university has evaluated ELSI's achievements in making university's strategic strengthening plan. As for the ELSI graduate course (5 years integrated master's and doctoral program) the university supports students economically through RA expenses for 5 years. With this, ELSI can gather high-quality students over the world.

## **8. Others**

- In addition to the above 1-7, note any of the Center's notable efforts and activities.

ELSI is trying to play a role in the new university, both in promoting space exploration and in communicating it to the public to gain supporters. In this context, ELSI has started a seminar for working people called Cosmos Salon in cooperation with Fuji Television (one of the major TV companies in Japan). In this seminar, two speakers from academia and industries talk about space exploration and space developments, and then participate in a panel discussion with a reporter from the TV company. The content is recorded, edited, and made widely available to the public in an effort to increase the presence of the new university as well as ELSI.

## Appendix 1 List of Center's Major Research Achievements

### 1. List of Major Refereed Papers

\*List up to 20 papers representative of the Center's research activities during the period between FY 2021 and FY 2024, and give brief descriptions (within 5 to 10 lines) of them.

\*For each, write the author name(s); year of publication; journal name, volume, page(s) (or DOI number), and article title. Any listing order may be used as long as format is the same. If a paper has many authors, underline those affiliated with the Center.

\*If a paper has many authors (say, more than 10), all of their names do not need to be listed.

[1] Chen, C.; Yi, R.; Igisu, M.; Afrin, R.; Sithamparam, M.; Chandru, K.; Ueno, Y.; Sun, L.; Laurenzi, T.; Eberini, I.; Jia, Tony Z.; et al. Primitive homochiral polyester formation driven by tartaric acid and calcium availability. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA 2025, 122 (12), Article. DOI: 10.1073/pnas.2419554122. This paper explores how alpha-hydroxy acids (alpha HAs), like tartaric acid (TA), could have contributed to the origin of life by forming homochiral systems. These simple organic monomers could polymerize into polyesters and self-assemble into microdroplets. The study specifically investigates the role of Ca<sup>2+</sup> ions in this process. Ca<sup>2+</sup> ions exert a dual influence: first, they regulate TA monomer availability through selective crystallization, enriching the enantiomeric excess of nonracemic TA solutions. Second, they modulate polymerization, suppressing enantiopure TA polymerization while enabling DL-TA polymerization. These findings suggest that variations in inorganic ion availability, such as Ca<sup>2+</sup>, could have mediated the selection of simple organic chiral monomers and the emergence of homochirality in early protocell-forming polymers on primitive Earth.

[2] Hyodo, R.; Genda, H.; Madeira, G. Pollution resistance of Saturn's ring particles during micrometeoroid impact. NATURE GEOSCIENCE 2025, 18 (1), Article. DOI: 10.1038/s41561-024-01598-9.

This paper re-evaluates the age of Saturn's rings, challenging the hypothesis that their apparent youth (100-400 million years old) is due to darkening from micrometeoroid bombardment. Previous estimates assumed high accretion of non-icy material, but new numerical simulations show that hypervelocity impacts cause non-icy material to vaporize, forming charged nanoparticles and ions. These charged particles are subsequently removed from the rings through various mechanisms like collision with Saturn or electromagnetic drag. This efficient removal suggests a minimal accretion efficiency ( $\eta \lesssim 1\%$ ), implying that the rings' pristine appearance is due to a pollution resistance mechanism, rather than indicating a young formation age.

[3] He, D.; Adachi, K.; Hashizume, D.; Nakamura, R. Copper sulfide mineral performs non-enzymatic anaerobic ammonium oxidation through a hydrazine intermediate. NATURE CHEMISTRY 2024, 16 (10), Article. DOI: 10.1038/s41557-024-01537-6.

Anaerobic ammonium oxidation (anammox) accounts for substantial N<sub>2</sub> production in marine environments. Despite extensive biochemical research, no synthetic anammox models existed. This study reports that a copper sulfide mineral replicates the entire biological anammox pathway, catalyzed by three metalloenzymes. A copper-nitrosonium {CuNO}<sub>10</sub> complex, formed by nitrite reduction, oxidizes ammonium, leading to heterolytic N-N bond formation. N<sub>2</sub> production is mediated by the highly reactive hydrazine intermediate, similar to the biological process. We also discovered an N-N bond heterocoupling pathway forming hybrid N<sub>2</sub>O, a potent greenhouse gas. This work presents a rare non-enzymatic anammox reaction linking six redox states in the abiotic nitrogen cycle. The discovery of anammox reshaped views on ammonium activation. A single copper sulfide mineral can now replicate biological anammox.

[4] Goldford, J.; Smith, H.; Longo, L.; Wing, B.; McGlynn, S. Primitive purine biosynthesis connects ancient geochemistry to modern metabolism. NATURE ECOLOGY & EVOLUTION 2024, 8 (5), Article. DOI: 10.1038/s41559-024-02361-4.

This paper explores whether modern biochemistry's molecular complexity could have evolved continuously from simpler geochemical precursors. By simulating biosphere-scale metabolism using known biochemical reactions and primitive coenzymes, the research maps a plausible evolutionary trajectory. It identifies purine synthesis as a critical bottleneck for metabolic expansion, which is overcome by non-autocatalytic phosphoryl coupling agents. The study

reveals that early metabolic expansion phases are rich in metal-dependent and structurally symmetric enzymes, supporting existing models of early biochemical evolution. This proposed trajectory also aligns with geochemical records, suggesting a late appearance of methane metabolisms and oxygenic photosynthesis. The strong concordance between biological and geological analyses bolsters the credibility of this trajectory as a plausible history for the majority of core biochemistry.

[5] Kong, S.; Li, A.; Long, J.; Adachi, K.; Hashizume, D.; Jiang, Q.; Fushimi, K.; Ooka, H.; Xiao, J.; Nakamura, R. Acid-stable manganese oxides for proton exchange membrane water electrolysis. *NATURE CATALYSIS* 2024, 7 (3), 252-261, Article. DOI: 10.1038/s41929-023-01091-3.

This academic paper presents a significant breakthrough in developing Earth-abundant, acid-stable catalysts for the oxygen evolution reaction (OER), vital for producing hydrogen via proton exchange membrane (PEM) electrolyzers. The core innovation lies in optimizing the lattice oxygen structure of manganese oxide. By substituting pyramidal oxygen with planar oxygen, which forms a stronger Mn-O bond, the researchers effectively suppress the dissolution of manganese ions, the key deactivation bottleneck. This structural modification dramatically enhances the catalyst's durability, allowing it to sustain OER for over a month at high current densities in strong sulfuric acid. Demonstrating excellent performance in a PEM electrolyzer, this material represents a crucial step toward reducing reliance on expensive iridium, making large-scale hydrogen production more economically viable.

[6] Lee, H.; McGlynn, S.; Nakamura, R.; Okumura, T.; Ooka, H.; Adachi, K.; Hikima, T.; Hirata, K.; Kawano, Y.; Matsuura, H.; Yamamoto, M.; Yamamoto, M.; et al. Osmotic energy conversion in serpentinite-hosted deep-sea hydrothermal vents. *NATURE COMMUNICATIONS* 2024, 15 (1), Article. DOI: 10.1038/s41467-024-52332-3.

This paper reveals a fascinating parallel between cellular energy harvesting and geological processes, demonstrating how natural submarine serpentinite-hosted hydrothermal vent (HV) precipitates can convert ionic gradients into electrochemical energy. Just like cells, HVs achieve this through selective ion transport (Na<sup>+</sup>, K<sup>+</sup>, H<sup>+</sup>, and Cl<sup>-</sup>) across their intricate structures. The study highlights that layered hydroxide nanocrystals within the HV walls are radially aligned, forming confined nanopores spanning millimeters. These nanopores are unique because their surface charge changes depending on adsorbed ions, allowing the mineral to act as both a cation- and anion-selective ion transport membrane. This groundbreaking finding suggests that chemical disequilibria in geological environments, driven by flow and concentration gradients, can spontaneously generate confined nanopores capable of osmotic energy conversion, providing insights into how life might have first harnessed energy.

[7] Lu, W.; Terasaka, N.; Sakaguchi, Y.; Suzuki, T.; Suzuki, T.; Suga, H. An anticodon-sensing T-boxzyme generates the elongator nonproteinogenic aminoacyl-tRNA in situ of a custom-made translation system for incorporation. *NUCLEIC ACIDS RESEARCH* 2024, 52 (7), 3938-3949, Article. DOI: 10.1093/nar/gkaf151.

This academic paper significantly advances the "RNA world" hypothesis, investigating how ancestral ribozymes could have mimicked modern aminoacyl-tRNA synthetases (ARSs) to facilitate early peptide synthesis. Building on prior work, the study details the in vitro selection and evolution of elongation-capable T-boxzymes (eIT-boxzymes). These novel ribozymes can charge tRNAs with non-canonical amino acids, like para-azido-L-phenylalanine (PheAZ), in a sequence-specific manner, responding to their cognate anticodons. The research successfully demonstrates the translation of a PheAZ-containing peptide within an eIT-boxzyme-integrated translation system. This work collectively illustrates a compelling scenario where a series of specialized ribozymes orchestrated tRNA aminoacylation and co-evolved alongside a primitive, RNA-based translation apparatus, shedding light on a crucial step in the origin of life.

[8] Smith, E.; Smith, H.; Andersen J. Rules, hypergraphs, and probabilities: The three-level analysis of chemical reaction systems and other stochastic stoichiometric population processes. *PLOS Complex Systems*, 2024, Article, DOI: 10.1371/journal.pcsy.0000022

This academic paper investigates the complex dynamics of chemical reaction systems and their evolution, exploring how constraints on biological function arise from chemical mechanisms, network structure, and stochastic thermodynamic dynamics. Unlike previous studies that often analyze these levels in isolation, this research uniquely focuses on the inter-level relations that transmit order from fundamental chemical mechanisms up to population-level dynamics. A key

conclusion is that some universal properties in living systems, like the minimality of the Calvin cycle, are direct consequences of underlying chemical mechanisms. However, others, such as the selection of specific pathways from vast alternatives, likely reflect intricate connections between network topology and a probability measure related to dissipation. This offers a novel framework for understanding how chemical principles shape the complexity and evolution of life.

[9] Sanden, S.; Bartlett, C.; Virgo, N.; Bartlett, S.; Sekine, Y.; McGlynn, S. Rapid hydrolysis rates of thio- and phosphate esters constrain the origin of metabolism to cool, acidic to neutral environments. *ISCIENCE* 2024, 27 (11), Article. DOI: 10.1016/j.isci.2024.111088.

Universal to all life is a reliance on energy carriers such as adenosine triphosphate (ATP) which connect energy-releasing reactions to energy-consuming processes. While ATP is ubiquitously used today, simpler molecules such as thioesters and polyphosphates are hypothesized to be primordial energy carriers. Investigating environmental constraints on the non-enzymatic emergence of metabolism, we find that hydrolysis rates-not hydrolysis energies-differentiate phosphate esters and thioesters. At temperatures consistent with thermophilic microbes, thioesters are favored at acidic pH and phosphate esters at basic pH. Thioacids have a high stability across pH 5-10. The planetary availability of sulfur and phosphate is coincident with these calculations, with phosphate being abundant in alkaline and sulfur in acidic environments. Since both sulfur esters and phosphate esters are uniquely required in metabolism, our results point to a non-thermophilic origin of early metabolism at cool, acidic to neutral environments.

[10] Nakamura, T.; Matsumoto, M.; Amano, K.; Enokido, Y.; Zolensky, M.; Mikouchi, T.; Genda, H.; Tanaka, S.; Zolotov, M.; Kurosawa, K.; et al. Formation and evolution of carbonaceous asteroid Ryugu: Direct evidence from returned samples. *SCIENCE* 2023, 379 (6634), 787-+, Article. DOI: 10.1126/science.abn8671.

Samples of the carbonaceous asteroid Ryugu were brought to Earth by the Hayabusa2 spacecraft. We analyzed 17 Ryugu samples measuring 1 to 8 millimeters. Carbon dioxide-bearing water inclusions are present within a pyrrhotite crystal, indicating that Ryugu's parent asteroid formed in the outer Solar System. The samples contain low abundances of materials that formed at high temperatures, such as chondrules and calcium- and aluminum-rich inclusions. The samples are rich in phyllosilicates and carbonates, which formed through aqueous alteration reactions at low temperature, high pH, and water/rock ratios of <1 (by mass). Less altered fragments contain olivine, pyroxene, amorphous silicates, calcite, and phosphide. Numerical simulations, based on the mineralogical and physical properties of the samples, indicate that Ryugu's parent body formed similar to 2 million years after the beginning of Solar System formation.

[11] Li, Y.; Kurokawa, H.; Sekine, Y.; Nakamura, R.; Fujishima, K.; Kebukawa, Y.; Nakano, Y.; Kitadai, N.; Zhang, N.; Zang, X.; Ueno, Y.; Fujimori, G.; et al. Aqueous breakdown of aspartate and glutamate to n- $\omega$ -amino acids on the parent bodies of carbonaceous chondrites and asteroid Ryugu. *SCIENCE ADVANCES* 2023, 9 (50), Article. DOI: 10.1126/sciadv.adh7845.

Amino acids in carbonaceous chondrites may have seeded the origin of life on Earth. While Ryugu samples show similar amino acid distributions to CI chondrites, the low-temperature chemical mechanisms behind these distributions were unclear. This study reports that proteinogenic amino acids, aspartic acid and glutamic acid, decompose to beta-alanine and gamma-aminobutyric acid, respectively, under simulated geoelectrochemical conditions at 25°C. This low-temperature conversion plausibly explains the enrichment of these n- $\omega$ -amino acids in heavily water-altered CI chondrites and Ryugu's return samples. The findings suggest these samples originated from the water-rich mantle of their parent planetesimals where protein alpha-amino acids underwent decomposition.

[12] Postberg, F.; Sekine, Y.; Klenner, F.; Glein, C.; Zou, Z.; Abel, B.; Furuya, K.; Hillier, J.; Khawaja, N.; Kempf, S.; et al. Detection of phosphates originating from Enceladus's ocean. *NATURE* 2023, 618 (7965), 489-+, Article. DOI: 10.1038/s41586-023-05987-9.

This paper presents a pivotal discovery concerning the habitability of Saturn's moon, Enceladus. While a global subsurface ocean was previously confirmed and its major solutes identified, the crucial bio-essential element, phosphorus, had not been detected beyond Earth. This study utilized Cassini's Cosmic Dust Analyzer to provide the first direct evidence: sodium phosphates

were found within ice grains ejected from Enceladus's cryovolcanic plume. These observational results, supported by laboratory analogue experiments, indicate astonishingly high orthophosphate concentrations in Enceladus's ocean – at least 100 times greater than in Earth's oceans. Furthermore, geochemical modeling suggests such high phosphate abundances are plausible in Enceladus and other icy ocean worlds, potentially originating from cold seafloors or moderate-temperature hydrothermal environments. This finding significantly boosts the likelihood of life existing within Enceladus's ocean.

[13] [Li, Y.](#); [Kitadai, N.](#); [Sekine, Y.](#); [Kurokawa, H.](#); [Nakano, Y.](#); [Johnson-Finn, K.](#) Geoelectrochemistry-driven alteration of amino acids to derivative organics in carbonaceous chondrite parent bodies. *NATURE COMMUNICATIONS* 2022, 13 (1), Article. DOI: 10.1038/s41467-022-32596-3.

A longstanding question concerns the origin and transformation of organics in carbonaceous chondrites (CCs). Evidence shows amino acid abundances in CCs decrease with aqueous alteration, but the chemical processes are unclear. We simulated redox conditions, demonstrating that alpha-amino acids electrochemically alter to monoamines and alpha-hydroxy acids on FeS and NiS catalysts at 25 °C. This conversion aligns with their enrichment in heavily altered CCs compared to amino acid analogs. Our results suggest H<sub>2</sub> drives organic evolution in water-rock differentiated CC parent bodies. This process also applies to Solar System icy bodies with similar pH and redox gradients. This discovery explains the low amino acid abundances in altered carbonaceous chondrites. It deepens our understanding of Solar System chemical evolution.

[14] [Yokoo, S.](#); [Hirose, K.](#); [Tagawa, S.](#); [Morard, G.](#); [Ohishi, Y.](#) Stratification in planetary cores by liquid immiscibility in Fe-S-H. *NATURE COMMUNICATIONS* 2022, 13 (1), Article. DOI: 10.1038/s41467-022-28274-z.

Liquid-liquid immiscibility has been widely observed in iron alloy systems at ambient pressure and is important for the structure and dynamics in iron cores of rocky planets. While such previously known liquid immiscibility has been demonstrated to disappear at relatively low pressures, here we report immiscible S(+/- Si,O)-rich liquid and H(+/- C)-rich liquid above similar to 20 GPa, corresponding to conditions of the Martian core. Mars' cosmochemically estimated core composition is likely in the miscibility gap, and the separation of two immiscible liquids could have driven core convection and stable stratification, which explains the formation and termination of the Martian planetary magnetic field. In addition, we observed liquid immiscibility in Fe-S-H(+/- Si,O,C) at least to 118 GPa, suggesting that it can occur in the Earth's topmost outer core and form a low-velocity layer below the core-mantle boundary.

[15] [Nakai, H.](#); [Isshiki, K.](#); [Hattori, M.](#); [Maehira, H.](#); [Yamaguchi, T.](#); [Masuda, K.](#); [Shimizu, Y.](#); [Watanabe, T.](#); [Hohsaka, T.](#); [Matsuura, T.](#); et al. Cell-Free Synthesis of Human Endothelin Receptors and Its Application to Ribosome Display. *ANALYTICAL CHEMISTRY* 2022, 94 (9), 3831-3839, Article. DOI: 10.1021/acs.analchem.1c04714.

This paper introduces a groundbreaking high-throughput screening method for G-protein-coupled receptors (GPCRs), a vital drug target family, utilizing a reconstituted in vitro transcription-translation (IVTT) system. The study highlights the crucial role of the phospholipid POPG in nanodiscs for the de novo functional folding of human endothelin receptor type-B (ETBR) within this system. Although purified ETBR could function with various phospholipids upon reconstitution, POPG proved essential for its synthesis in vitro. The method successfully enabled the functional synthesis of ETAR and its integration, alongside ETBR, into ribosome display. Crucially, the paper demonstrates the applicability of ribosome display for GPCR gene screening using a mock library, thus opening new avenues for high-throughput screening and directed evolution of GPCRs entirely in vitro, which could significantly accelerate drug discovery efforts.

[16] [Fried, S.](#); [Fujishima, K.](#); [Makarov, M.](#); [Chereshchuk, I.](#); [Hlouchova, K.](#) Peptides before and during the nucleotide world: an origins story emphasizing cooperation between proteins and nucleic acids. *JOURNAL OF THE ROYAL SOCIETY INTERFACE* 2022, 19 (187), Review. DOI: 10.1098/rsif.2021.0641.

This paper challenges the nucleic acid-centric view of the Origins of Life, highlighting the crucial, often overlooked, role of peptides as early functional polymers. It argues that their simple synthesis, easy activation, condensation, and remarkable self-assembly capabilities make them strong candidates for primordial catalysts. Drawing on diverse scientific fields, the paper proposes

a "peptide-polynucleotide stage," where early peptides and mini-proteins acted as catalysts, compartments, and structural hubs before being encoded by polynucleotides. In essence, it illuminates the significant contributions of these simple proteins during the crucial period leading up to the "nucleotide world," underscoring their lasting impact on the unique characteristics of modern-day proteins.

[17] Seal, M.; Weil-Ktorza, O.; Despotovic, D.; Tawfik, D.; Levy, Y.; Metanis, N.; Longo, L.; Goldfarb, D. Peptide-RNA Coacervates as a Cradle for the Evolution of Folded Domains. *JOURNAL OF THE AMERICAN CHEMICAL SOCIETY* 2022, 144 (31), 14150-14160, Article. DOI: 10.1021/jacs.2c03819.

This academic paper investigates how peptide-RNA coacervates may have facilitated early protein evolution by concentrating and compartmentalizing simple biopolymers. The study specifically examined the helix-hairpin-helix (HhH) motif, an ancient nucleic acid binding element, using electron paramagnetic resonance spectroscopy (EPR). The findings demonstrate that HhH motifs form dimers, a process significantly promoted within peptide-RNA coacervates. Additionally, transient alpha-helical character consistent with a symmetric (HhH) 2-Fold was observed. These results suggest that coacervates acted as unique environments for peptide oligomerization, implying that phase-separating peptides were a crucial resource for building complex protein structures through evolutionary mechanisms like duplication and fusion. This research offers valuable insights into the origins of protein complexity.

[18] Hirose, K.; Wood, B.; Vocadlo, L. Light elements in the Earth's core. *NATURE REVIEWS EARTH & ENVIRONMENT* 2021, 2 (9), 645-658, Review. DOI: 10.1038/s43017-021-00203-6. This academic review delves into the enduring mystery of Earth's core composition, specifically identifying the "light" elements (S, Si, O, C, H) that cause its density deficit relative to pure iron. Understanding this is paramount for deciphering Earth's accretion, core formation, and the sustenance of its magnetic field. The paper meticulously synthesizes mineral physics data with cosmochemical and geochemical estimates to propose a likely range of compositions for both the liquid outer core (e.g., Fe + 5% Ni + 1.7% S + varying Si, O, C, H) and the solid inner core. While acknowledging that the exact composition remains unknown, the authors highlight that refining core temperature constraints and establishing clearer links between inner and outer core compositions are crucial next steps to pinpoint the definitive light element inventory.

[19] Matsumura, S.; Brasser, R.; Ida, S. N-body simulations of planet formation via pebble accretion: II. How various giant planets form. *ASTRONOMY & ASTROPHYSICS* 2021, 650, Article. DOI: 10.1051/0004-6361/202039210.

This academic paper numerically investigates planetary system formation through pebble accretion, specifically exploring the impact of protoplanetary disc properties (masses, dissipation timescales, metallicity). Utilizing a modified N-body code with updated planet-disc interaction and Type II migration models, it successfully reproduces the observed distributions of exoplanet semi-major axes, eccentricities, and masses. The study identifies two main giant planet formation trends: rapid formation leads to widely distributed, massive planets, whereas disc-dissipation-limited formation results in lower-mass, cold Jupiters. Crucially, the simulations also naturally explain the isolated nature of hot Jupiters and the observed eccentricity-metallicity trends, offering a comprehensive framework for giant planet evolution.

[20] Sakuraba, H.; Kurokawa, H.; Genda, H.; Ohta, K. Numerous chondritic impactors and oxidized magma ocean set Earth's volatile depletion. *SCIENTIFIC REPORTS* 2021, 11 (1), Article. DOI: 10.1038/s41598-021-99240-w

This academic paper resolves a long-standing paradox: how Earth's volatile elements (C, N, H) show depletion in the bulk silicate Earth despite chondritic delivery. Challenging prior non-chondritic source theories, the study proposes a model where continuous chondritic accretion can explain the observed pattern. It posits that carbon partitioned into the core, hydrogen was stored in the magma ocean during main accretion, and nitrogen underwent atmospheric erosion in the late accretion stage. This scenario requires a relatively oxidized magma ocean, predominant small late-stage impactors, and H/C storage in oceanic water/carbonate rocks, all consistent with Earth's formation in the habitable zone. This offers a compelling, self-consistent explanation for Earth's volatile budget.

## 2. Major Invited Lectures, Plenary Addresses (etc.)

\*List up to 10 main presentations made between FY 2021 and FY 2024 in order from most recent.

\*For each, write the date(s), lecturer/presenter's name, presentation title and conference name.

Date(s)	Lecturer/Presenter's name	Presentation title	Conference name
Aug. 2024	Tomoaki Matsuura	Artificial cells that respond to chemical and physical environmental oscillation	ArtBio2024, Aarhus, Denmark
Jun. 2024	Tetsuhiro Hatakeyama	Deciphering the Complexity in Biological Interaction (Asian Biophysical Association Young Investigator Awardee lecture)	IUPAB2024, Kyoto Japan
Apr. 2024	Naohiro Terasaka	Directed evolution of virus-like ribonucleoprotein particles	The 3rd International Symposium on Biofunctional Chemistry, Nagoya Japan
Oct. 2023	Hidenori Genda	Formation of wet Earth and its early evolution	Workshop: From Disks to Planets, Taipei, Taiwan
Oct. 2023	Shawn Erin McGlynn	Single cell anabolic rates measured by the nanoSIMS: Space, population structure, and relationships.	Advanced School on Quantitative Principles in Microbial Physiology: from Single Cells to Cell Communities; The Abdus Salam International Centre for Theoretical Physics, Trieste Italy
Jun. 2023	Ryuhei Nakamura	Prebiotic chemistry driven by geoelectricity	Kroese-Duijsters Symposium 2023, Leiden, NL
Jun. 2023	Takanori Kodama	Climate of rocky planets	ExoClimes VI, UK
May 2023	Yasuhito Sekine	Ocean World Habitability and Origin of Life	Life under extreme conditions, 26th JSPS Japanese-German Symposium, Kiel, Germany
Jun. 2022	Eric Smith	Information Gateways to Life	The 4th Information Universe Conference, Groningen, NL
Oct.2021	Yamei LI	Geo-electrocatalysis drove organic conversions for chemical evolution on Earth and icy planetesimals	2021 International Society for the Study of the Origins of Life (virtual)

**3. Major Awards**

\*List main awards received between FY 2021 and FY 2024 in order from the most recent (within 10 awards).

\*For each, write the date issued, recipient's name and the name of award. In case of multiple recipients, underline those affiliated with the Center.

Date	Recipient's name	Name of award
Jun. 2024	Tetsuhiro Hatakeyama	Young Investigator Award from the Asian Biophysics Association
Apr. 2024	Keisuke Fukunaga	Eastern Japan Branch of the Society of Biotechnology, Japan Director's Award
Feb. 2024	Yasuhito Sekine	the 40th Inoue Prize for Science
Dec. 2023	Kousuke Fujishima	The 2023 Takeda-rika Award for International Achievement from School of Life Science and Technology of Tokyo Tech
Sep. 2023	Keisuke Fukunaga	Eastern Japan Branch of the Society of Biotechnology, Japan Director's Award
Aug. 2023	Hiroya Takahashi	Best Student Poster Award from the International Association of Geochemistry
May 2023	Kei Hirose	The Royal Society (UK) Foreign Member Award
Oct. 2022	Tony Z. Jia	Best general oral presentation at the 36th Annual Meeting of the Japan Society for Biological Sciences in Space
Dec. 2022	Yasuhito Sekine	JSPS Prize
Apr. 2021	Tony Z. Jia	Yoshinori Ohsumi Fund for Fundamental Research

## Appendix 2 FY 2024 List of Principal Investigators

NOTE:

\*Underline names of principal investigators who belong to an overseas research institution.

\*Indicate newly added researchers for FY 2021-2024 in the "Notes" column.

<Principal Investigators at the end of FY 2024>							Principal Investigators Total: 14
Name	Age	Affiliation (Position title, department, organization)	Academic degree, Specialty	Effort (%)*	Starting date of participation	Status of participation (Describe in concrete terms)	Note
Yasuhito SEKINE	46	Director, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D., Planetary Science, Astrobiology, Evolution of Earth and planets	80	From June, 2018	Usually stays at the center	
Shigeru IDA	64	Professor, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D., Planetary Sciences, Planetary Physics	80	From start	Usually stays at the center	
John HERNLUND	52	Professor, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D., Geophysical Modeling, Fluid and Solid Dynamics	80	From August, 2013	Usually stays at the center	
Ryuhei NAKAMURA	48	Professor, Institute of Science Tokyo, Earth-Life Science Institute	Dr. of Science, Electrochemistry	80	From April, 2017	Usually stays at the center	
Hidenori GENDA	50	Professor, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D., Planet formation	80	From April, 2018	Usually stays at the center	
Tomoaki MATSUURA	53	Professor, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D Biotechnology	80	From September, 2020	Usually stays at the center	
Kosuke FUJISHIMA	42	Associate Professor, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D., Astrobiology	80	From June, 2021	Usually stays at the center	newly added researchers in FY 2021

<u>Mary VOYTEK</u>	66	Senior Scientist, NASA	Ph.D., Astrobiology	5	From August, 2018	Joins videoconferences from another institution	
Yuichiro UENO	50	Professor, Institute of Science Tokyo, Department of Earth and Planetary Science	Dr. of Science, Geochemistry	20	From April, 2016	Usually stays at the Department of Earth and Planetary Sciences	
Shawn McGLYNN	41	Associate Professor, Institute of Science Tokyo, Earth-Life Science Institute	Ph.D., Evolutionary biology, Microbial biochemistry	80	From April, 2016	Usually stays at the center	
<u>Eric SMITH</u>	59	Professor, Institute of Science Tokyo, Earth-Life Science Institute External Professor, Santa Fe Institute Senior Research Scientist, Georgia Institute of Technology	Ph.D., High-energy/particle Physics	50	From February, 2015	Stays at the center for Six months	
Kei HIROSE	57	Visiting Professor, Institute of Science Tokyo, Earth-Life Science Institute Professor, The University of Tokyo, Department of Earth and Planetary Science	Ph.D., High-pressure Geoscience	20	From start	Stays at the center once a week, usually stays at the University of Tokyo	
Shinji MASUDA	52	Professor, Institute of Science Tokyo, Department of Life Science and Technology	Ph.D., Photosynthesis	20	From April, 2023	Usually stays at the Department of Life Science and Technology	newly added researchers in FY 2023
Kazumi OZAKI	40	Associate Professor, Institute of Science Tokyo, Department of Earth and Planetary Science	Ph.D., Earth System Science, Biogeochemistry, Astrobiology	20	From April, 2023	Usually stays at the Department of Earth and Planetary Sciences	newly added researchers in FY 2023

**Principal Investigators resigned since FY 2021**

Name	Next Affiliation (Position title, department, Tokyo Institute of Technology,	Period of participation
Shigenori MARUYAMA	Professor emeritus, Tokyo Institute of Technology,	From start to FY2021
Joseph Lynn KIRSCHVINK	Caltech	From start to FY2021
Jack William SZOSTAK	Investigator, Howard Hughes	From start to FY2021
George HELFFRICH		From July, 2014 to FY2021
Renata WENTZCOVITCH	Professor,	From June, 2019 to FY2021
Naohiro YOSHIDA	Professor Emeritus, Earth-Life Science Institute, Tokyo Institute of Technology	From start to FY2021
Tetsuo IRIFUNE	Professor, Ehime University, Geodynamics Research Center	From start to FY2021
Piet HUT	Institute for Advanced Study, Princeton	From start to 2023.02.28
Alexis GILBERT	Assistant Professor, Utrecht University	From May, 2023 to Dec. 2024

## Appendix 3-1 Record of Center Activities (FY 2021-FY 2024)

### 1. Researchers and Center Staffs, Satellites, Partner Institutions

#### 1-1. Researchers and Center Staffs Participated in the Center's Activities

- Enter the number of researchers and center staffs affiliated with the Center in the table in Appendix 3-1a.

##### Special mention

- Describe the Center's concrete plans for the future and already-established schedules for employing researchers, particularly principal investigators.  
 - As background to how the Center is working on the global circulation of world's best brains, give good examples, if any, of how career paths are being established for the Center's researchers; that is, from which top-world research institutions do researchers come to the Center and to which research institutions do the Center's researchers go, and how long are their stays at those institutions.

- In Appendix 3-1b, describe the positions that postdoctoral researchers acquire upon leaving the Center.

- We are planning to recruit a new PI for Prof. Shigeru Ida who will retire in March 2026.
- Two more PI positions will be recruited in FY 2025. These positions will be in the fields of planetary science and systems biology/complex systems.

#### 1-2. Satellites and Partner Institutions

- List the satellite and partner institutions, both domestic and overseas, in the table below.

- Indicate newly added and deleted institutions in the "Notes" column.

##### <Satellite institutions>

Institution name	Principal Investigator(s), if any	Notes
The University of Tokyo	Kei HIROSE	
Ehime University	Tetsuo IRIFUNE	Deleted in FY2021
Harvard University	Jack SZOSTAK	Deleted in FY2021
Columbia University	Renata M. WENTZCOVITCH	Deleted in FY2021
Institute for Advanced Study, Princeton	Piet HUT	Deleted in FY2021

##### < Partner institutions >

Institution name	Principal Investigator(s), if any	Notes
JAXA		
NINS		
JAMSTEC		
Ehime University		Newly added in FY2022
NASA	Mary VOYTEK	

## 2. Status of Collaboration with Overseas Satellites

### 2-1. Coauthored Papers

- List the refereed papers published between FY 2021 and FY 2024 that were coauthored between the Center's researcher(s) in domestic institution(s) (include satellite institutions) and overseas satellite institution(s). List them by overseas satellite institution in the below blocks.
- Transcribe data in same format as in Appendix 1. Italicize the names of authors affiliated with overseas satellite institutions.

#### Overseas Satellite 1          Harvard University (Total: 5 papers)

- 1) Biasi, J.; Kirschvink, J.; *Fu, Rger*. Characterizing the Geomagnetic Field at High Southern Latitudes: Evidence From the Antarctic Peninsula. JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH 2021, 126 (12), Article. DOI: 10.1029/2021JB023273.
- 2) Fukui, A.; Korth, J.; Livingston, J.; Twicken, J.; Osorio, M.; Jenkins, J.; Mori, M.; Murgas, F.; Ogihara, M.; Narita, N.; *Collins, K.A.; Lathan, D. W.*; et al. TOI-1749: an M dwarf with a Trio of Planets including a Near-resonant Pair. ASTRONOMICAL JOURNAL 2021, 162 (4), Article. DOI: 10.3847/1538-3881/ac13a5.
- 3) Gastoldi, L.; *Ward, L.*; Nakagawa, M.; Giordano, M.; McGlynn, S. Changes in ATP Sulfurylase Activity in Response to Altered Cyanobacteria Growth Conditions. MICROBES AND ENVIRONMENTS 2021, 36 (2), Article. DOI: 10.1264/jsme2.ME20145.
- 4) Prondzinsky, P.; Berkemer, S.; *Ward, L.*; McGlynn, S. The Thermosynechococcus Genus: Wide Environmental Distribution, but a Highly Conserved Genomic Core. MICROBES AND ENVIRONMENTS 2021, 36 (2), Article. DOI: 10.1264/jsme2.ME20138.
- 5) *Ward, L.*; Li-Hau, F.; Kakegawa, T.; McGlynn, S. Complex History of Aerobic Respiration and Phototrophy in the Chloroflexota Class Anaerolineae Revealed by High-Quality Draft Genome of *Ca. Roseilinea mizusawaensis* AA3\_104. MICROBES AND ENVIRONMENTS 2021, 36 (3), Article. DOI: 10.1264/jsme2.ME21020.

#### Overseas Satellite 2          Columbia University (Total: 4 papers)

- 1) Shephard, G.; Houser, C.; Hernlund, J.; Valencia-Cardona, J.; Tronnes, R.; *Wentzcovitch, R.* Seismological expression of the iron spin crossover in ferropericlase in the Earth's lower mantle. NATURE COMMUNICATIONS 2021, 12 (1), Article. DOI: 10.1038/s41467-021-26115-z.
- 2) Umemoto, K.; *Wentzcovitch, R.* Ab initio prediction of an order-disorder transition in Mg<sub>2</sub>GeO<sub>4</sub>: Implication for the nature of super-Earth's mantles. PHYSICAL REVIEW MATERIALS 2021, 5 (9), Article. DOI: 10.1103/PhysRevMaterials.5.093604.
- 3) Zhang, N.; *Shi, S.*; Yuan, X.; Ni, W.; *Wang, X.*; Yoo, B.; Jia, T.; Li, W.; Zhang, S. A General LC-MS-Based Method for Direct and De Novo Sequencing of RNA Mixtures Containing both Canonical and Modified Nucleotides. In RNA MODIFICATIONS, HUMANA PRESS INC: 999 RIVERVIEW DR, STE 208, TOTOWA, NJ 07512-1165 USA, 2021; Vol. 2298, pp 261-277.
- 4) Zhang, Z.; Zhang, D.; Onga, K.; Hasegawa, A.; Ohta, K.; Hirose, K.; *Wentzcovitch, R.* Thermal conductivity of CaSiO<sub>3</sub> perovskite at lower mantle conditions. PHYSICAL REVIEW B 2021, 104 (18), Article. DOI: 10.1103/PhysRevB.104.184101.

#### Overseas Satellite 3          Institute for Advance Study, Princeton (Total: 1 paper)

- 1) Guttenberg, N.; Chen, H.; Mochizuki, T.; *Cleaves, H.* Classification of the Biogenicity of Complex Organic Mixtures for the Detection of Extraterrestrial Life (vol 11, 234, 2021). LIFE-BASEL 2021, 11 (6), Correction. DOI: 10.3390/life11060461.

## 2-2. Status of Researcher Exchanges

- Using the below tables, indicate the number of researcher exchanges between the Center (include domestic satellite institutions) and overseas satellite institutions during the period of FY 2021-FY 2024. Enter by institution and fiscal year.
- Write the number of principal investigator visits in the upper space and the number of other researcher visits in the lower space.

### Overseas Satellite 1:

<To overseas satellite>

	FY 2021	FY 2022	FY 2023	FY 2024	Total
Principal investigators	0	N/A	N/A	N/A	0
Other researchers	0	N/A	N/A	N/A	0
Total	0	N/A	N/A	N/A	0

<From overseas satellite>

	FY 2021	FY 2022	FY 2023	FY 2024	Total
Principal investigators	0	N/A	N/A	N/A	0
Other researchers	0	N/A	N/A	N/A	0
Total	0	N/A	N/A	N/A	0

### Overseas Satellite 2:

<To overseas satellite>

	FY 2021	FY 2022	FY 2023	FY 2024	Total
Principal investigators	0	N/A	N/A	N/A	0
Other researchers	0	N/A	N/A	N/A	0
Total	0	N/A	N/A	N/A	0

<From overseas satellite>

	FY 2021	FY 2022	FY 2023	FY 2024	Total
Principal investigators	0	N/A	N/A	N/A	0
Other researchers	0	N/A	N/A	N/A	0
Total	0	N/A	N/A	N/A	0

### Overseas Satellite 3:

<To overseas satellite>

	FY 2021	FY 2022	FY 2023	FY 2024	Total
Principal investigators	0	N/A	N/A	N/A	0
Other researchers	0	N/A	N/A	N/A	0
Total	0	N/A	N/A	N/A	0

&lt;From overseas satellite&gt;

	FY 2021	FY 2022	FY 2023	FY 2024	Total
Principal investigators	0	N/A	N/A	N/A	0
Other researchers	0	N/A	N/A	N/A	0
Total	0	N/A	N/A	N/A	0

### 3. Holding and Participating in International Research Meetings

#### 3-1. Holding international Research Meetings

- Indicate the number of international research conferences or symposiums held between FY 2021 and FY 2024, and give up to **five examples** of the most representative ones using the table below.

FY 2021: 02 meetings	FY 2022: 02 meetings	FY 2023: 03 meetings	FY 2024: 02 meetings
----------------------	----------------------	----------------------	----------------------

Major examples (meeting titles, places and dates held)	Number of participants
13th ELSI International Symposium, ELSI, 7-9 January 2025	From domestic institutions: 140 From overseas institutions: 26
6th Japan SciCom Forum conference, Kyushu University, 22-23 November 2024	From domestic institutions: 91 From overseas institutions: 36

#### 3-2. Participating in International Research Meetings

- Give up to five examples of the most representative case in which the Center, not individual researchers, participated in international research meetings to enhance the visibility and brand of the Center or of the overall WPI Program

Meeting titles, places, dates held and number of participants	Form of participation (e.g. operating a booth)	Number of participants from the Center
The 48th Annual Meeting of the Molecular Biology Society of Japan (MBSJ2025), Fukuoka, 27-29 November 2024	Operating a booth	12
JpGU conference, Chiba, 26-31 May 2024	Operating a booth, coordination of outreach activities, scientific session organization, and presentations	20
AAAS conference, Boston USA, 13-15 February 2025	Scientific session organization and supporting exhibition booth	1

#### 4. List of the Cooperative Research Agreements with Overseas Institutions

- Indicate the number of agreements concluded with overseas institutions still in effect as of the end of FY 2024 (March 31, 2025).  
Give five examples of the most representative agreements.

Number of effective agreements (as of March 31, 2025): 2

Five examples of the most representative agreements:

1. Name of an Agreement: Affiliate international Partner of the NAI  
 Dates of an Agreement: July 15, 2016  
 Counterpart of an Agreement: NASA Astrobiology Institute (NAI) with Japan Astrobiology Consortium (JABC)  
 Summary of an Agreement: ELSI launched the Japan Astrobiology Consortium in cooperation with the National Institutes of Natural Sciences' Astrobiology Center, and signed a partnership agreement with NASA's Astrobiology Institute. The mission of JABC is to develop the field of astrobiology, establish a community of researchers in astrobiology, to support especially young researchers, and to be the hub for international relationships. The partnership between NAI and JABC will focus initially in (1) the exchange of early career scientists and astrobiology summer schools; (2) the organization of Workshops Without Walls; and (3) research collaborations involving members of NAI and the JABC.
  
2. Name of an Agreement: Collaborative Research Agreement  
 Dates of an Agreement: July 5<sup>th</sup>, 2023  
 Counterpart of an Agreement: Observatoire De La Cote D'azur (OCA), Universite Cote D'az.Ur (UCA) and Centre National De La Recherche Scientifique (CNRS)  
 Summary of an Agreement: OCA, UCA, CNRS and ELSI will conduct a joint study entitled "Formation of the Earth". The Agreement aims to define the terms and conditions under which the Study will be executed, in particular the conditions of access to the Laboratory for doctoral students.

## 5. Postdoctoral Positions through Open International Solicitations

- In the columns "number of applications" and "number of selections," put the total number (upper) and the number and percentage of overseas researchers in the < > brackets (lower).
- In Appendix 3b, describe the status of employment of postdoctoral researchers.

Fiscal year	Number of applications	Number of selections
FY 2021	3	1
	<1, 33%>	<0, 0%>
FY 2022	14	2
	<13, 93%>	<1, 50%>
FY 2023	21	3
	<17, 81%>	<2, 67%>
FY 2024	2	1
	<2, 100%>	<1, 100%>

## 6. Diagram of Management System

### 6-1.

- Diagram the Center's management system within the Center in an easily understood manner.
- If any changes have been made in the Center's management system vis-à-vis that stated in the application for WPI Academy center certification, describe them. Especially describe any important changes made in such as the center director, administrative director, head of host institution, and officer(s) in charge at the host institution (e.g., executive vice president for research).

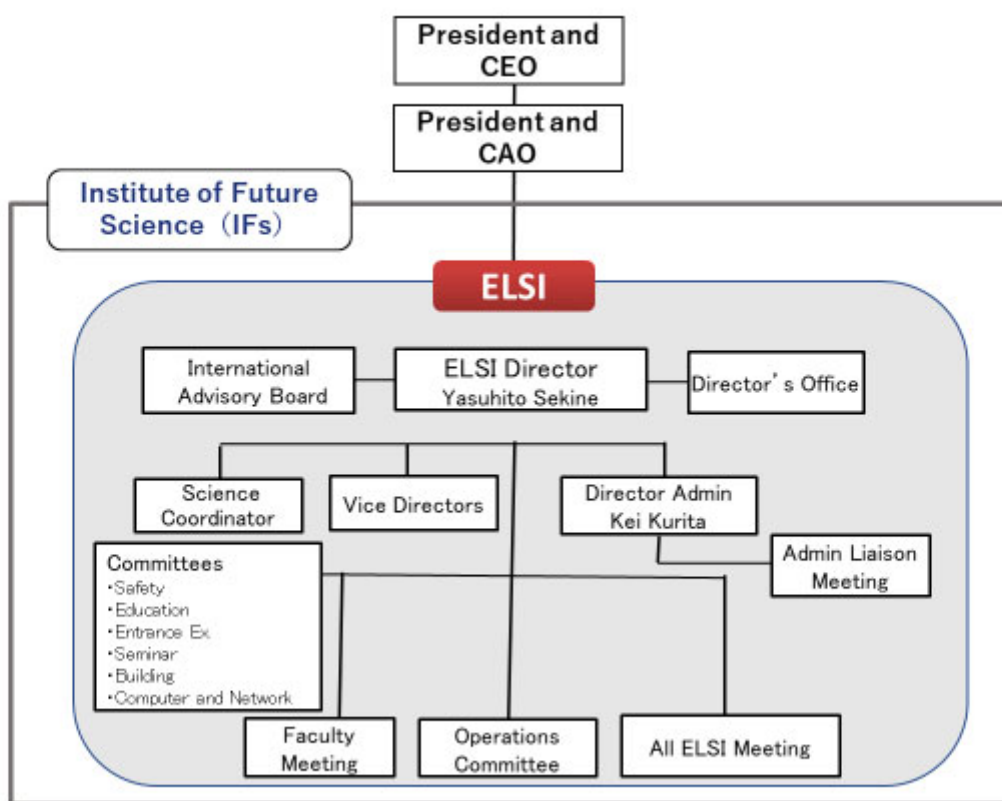
Tokyo Institute of Technology merged with Tokyo Medical and Dental University to form Institute of Science Tokyo (Science Tokyo) on October 1, 2024.

Naoto Ohtake began his duties as the inaugural president and chief executive officer (CEO).

On the same day, Ohtake appointed Yujiro Tanaka as president and chief academic officer (CAO) of Science Tokyo.

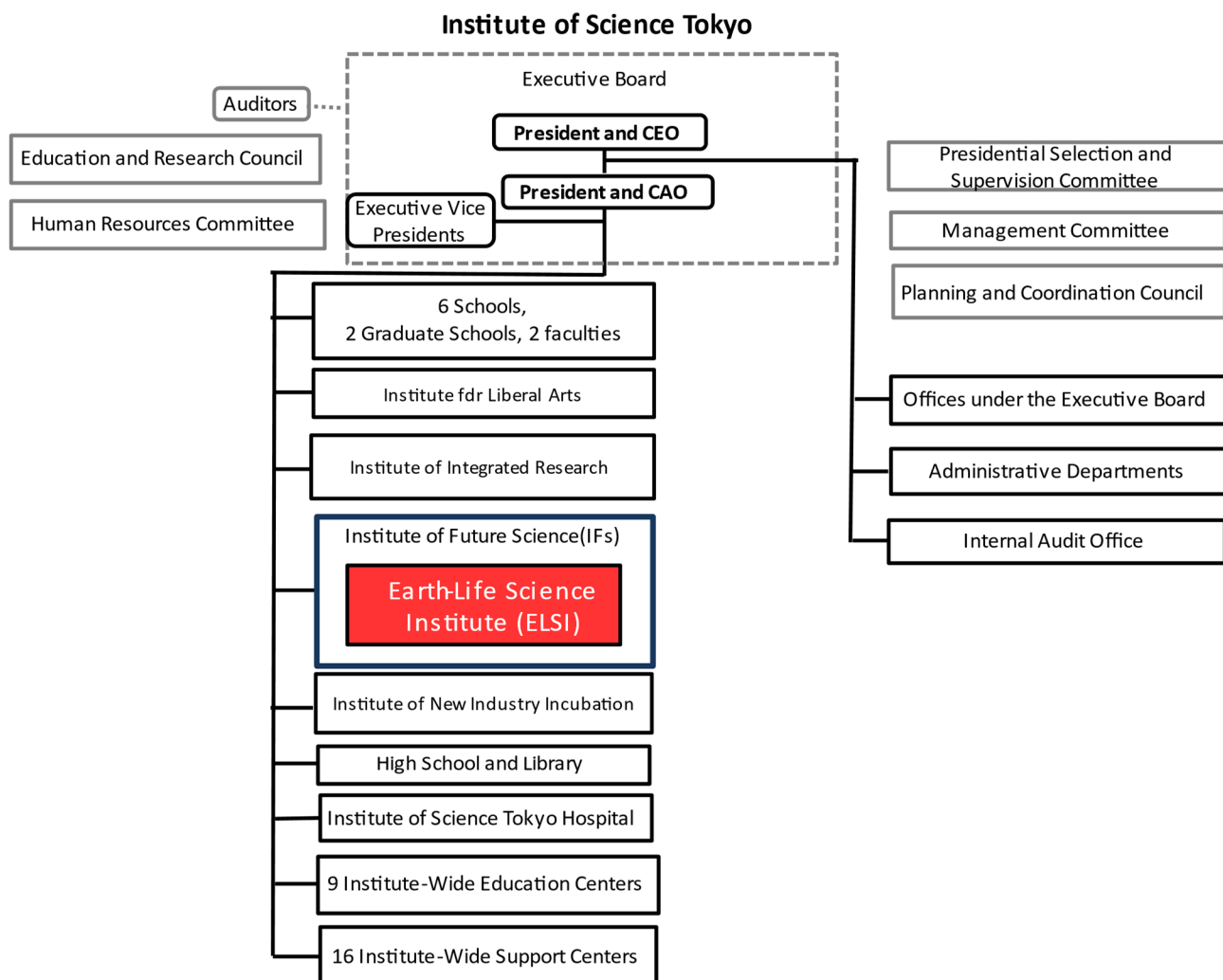
The new executive vice president for research and industry-academia-government collaboration is Mutsuko Hatano.

Science Tokyo established the Institute for Institute of Future Science(IFs) and placed ELSI in IFs.



**6-2.**

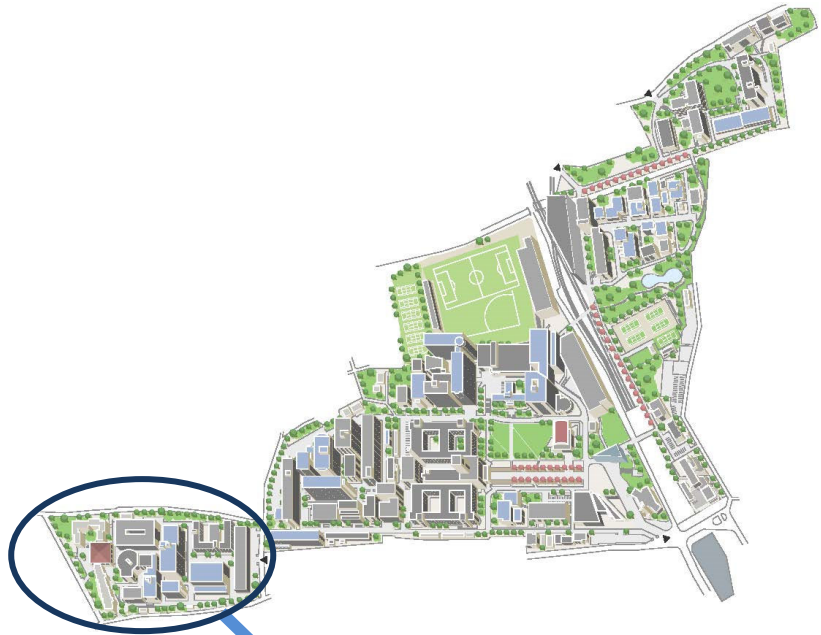
- Make a diagram of the organizational chart to show Center's position **within the host institution**.



## 7. Campus Map

- Draw a simple map of the campus showing where the main office and principal investigator(s) are located.

### Ookayama Campus Map



**Ishikawadai Area**



**Ishikawadai Bldg.7 (ELSI-1)**

- Yasuhito SEKINE
- John HERNLUND
- Tomoaki MATSUURA
- Shigeru IDA
- Ryuhei NAKAMURA
- Hidenori GENDA
- Kei HIROSE
- Shawn McGLYNN
- Kosuke FUJISHIMA
- Eric Smith

**Ishikawadai Bldg.2**

- Yuichiro UENO
- Kazumi OZAKI
- Alexis Gilbert

## Suzukakedai Campus Map



## Appendix3-1a Number of Center Personnel FY 2021-FY 2024

	FY 2021		FY 2022		FY 2023		FY 2024	
	Number of persons	%	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	50	/	35	/	42	/	42	/
Overseas researchers	22	44	14	40	20	48	17	40
Female researchers	11	22	8	23	11	26	11	26
Principal investigators (PIs)	20	/	12	/	15	/	14	/
Overseas PIs	9	45	4	33	5	33	4	29
Female PIs	2	10	1	8	1	7	1	7
Other researchers	14	/	12	/	14	/	12	/
Overseas researchers	5	36	6	50	8	57	7	58
Female researchers	3	21	2	17	4	29	4	33
Postdocs	16	/	11	/	13	/	16	/
Overseas Postdocs	8	50	4	36	7	54	6	38
Female Postdocs	6	38	5	45	6	46	6	38
Research support staffs	40	/	44	/	52	/	55	/
Administrative staffs	22	/	19	/	18	/	20	/
<b>TOTAL</b>	<b>112</b>		<b>98</b>		<b>112</b>		<b>117</b>	

Number of persons who were/have been paid using the host institution's operating budget (excluding indirect funding) among the above persons.

	FY 2021	FY 2022	FY 2023	FY 2024
Principal investigators (PIs)	4	9	12	12
Other researchers	4	12	10	11
Postdocs	0	6	2	3
Research support staffs	0	25	37	40
Administrative staffs	3	13	13	15

※ Make consistent with the number of persons reported in Appendix 3-2.

	R3		R4		R5		R6	
	FY 2021	FY 2022	FY 2023	FY 2024	FY 2021	FY 2022	FY 2023	FY 2024
	Number of persons	%	Number of persons	%	Number of persons	%	Number of persons	%
Doctoral students	0	/	0	/	0	/	10	/
Employed	0	-	0	-	0	-	10	100.0

※ The number of doctoral students indicated in the lower table can also include those in the upper table of Total numbers.

Changes vis-à-vis the Center's application for academy center certification

※ If changes have been made vis-à-vis the Center's application for academy center certification, describe the main changes and the reasons for them.

## Appendix 3-1b Career Path of WPI Postdocs

Enter the information below during the period from the start of the center through the end of FY 2024.

\* For each person, fill in the spaces to the right. More spaces may be added.

\* Leave "Position as of April 2025" blank if unknown.

### Japanese Postdocs

Employment period	Position before employed at WPI center		Next position after WPI center		Position as of April 2025*	
	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located
2013.4.1-2015.10.31	The University of Tokyo · Graduate Student · Japan	Japan	Postdoctoral Program Fellpw · NASA-GISS	USA	National Astronomical Observatory · Associate Professor	Japan
2013.4.1-2016.3.31	RIKEN · Researcher · Japan	Japan	Tokyo Institute of Technology · Research Staff · Japan	Japan		
2013.4.1-2016.3.31	Tokyo Institute of Technology · Research Staff · Japan	Japan	National Institute of Genetics · Researcher · Japan	Japan		
2013.4.1-2016.3.31	Tokyo Institute of Technology · Research Staff · Japan	Japan	Kyushu University · Researcher · Japan	Japan	Kagoshima University · Specially appointed associate professor	Japan
2013.4.1-2015.8.31	JAMSTEC · Researcher · Japan	Japan	Okayama University · Researcher · Japan	Japan		
2014.4.1-2016.3.31	Tokyo Institute of Technology · Graduate Student · Japan	Japan	Ehime University · Researcher · Japan	Japan		
2014.4.1-2015.9.30	Hiroshima University · Postdoctoral Researcher · Japan	Japan	JAMSTEC · Technical Scientist	Japan	JAMSTEC · Technical Scientist	Japan
2014.4.1-2015.7.31	Tokyo Institute of Technology · Graduate Student · Japan	Japan	The University of Tokyo · Assistant Professor · Japan	Japan	RIKEN · Research Fellow	Japan

2014.6.1-2015.3.31	Tokyo Institute of Technology · Post-doctoral fellow · Japan	Japan	Tokyo Institute of Technology · Research Staff · Japan	Japan	Kumamoto Kosen · Associate Professor	
2014.4.1-2016.3.31	Tokyo Institute of Technology · Research Staff · Japan	Japan	AIST · Researcher · Japan	Japan		
2014.4.1-2014.8.31	Tokyo Institute of Technology · Research Staff · Japan	Japan	RIKEN · Researcher · Japan	Japan		
2014.4.1-2014.8.31	Tokyo Institute of Technology · Graduate Student · Japan	Japan	Carnegie Institution for Science · Postdoctoral Researcher · USA	USA		
2015.4.1-2016.3.31	Hiroshima University · Graduate Student · Japan	Japan	Kyushu University · JSPS Postdoctoral Fellowships · Japan	Japan	Institute of Science Tokyo · Associate Professor	
2015.4.1-2015.6.30	Nagoya University · Graduate Student · Japan	Japan	Niels Bohr Institute · Postdoctoral Researcher	Denmark	Kyoto University · Assistant Professor	
2015.4.1-2015.9.30	Tokyo Institute of Technology · Graduate Student · Japan	Japan	JASRI · Researcher · Japan	Japan	Shimane University · Visiting Associate Professor	
2014.4.1-2017.3.31	Ritsumeikan University · Visiting scholar · Japan	Japan	JAMSTEC · Researcher	Japan	JAMSTEC · Researcher	Japan
2013.4.1-2016.9.30	Hokkaido University · Researcher · Japan	Japan	Osaka University · Assistant Professor · Japan	Japan	Osaka University · Assistant Professor	Japan
2015.10.1-2016.10.31	The University of Tokyo · Project Researcher · Japan	Japan	The University of Tokyo · Project Researcher · Japan	Japan		
2015.4.1-2017.8.31	Toyama University · Researcher · Japan	Japan	The University of Tokyo · Assistant Professor · Japan	Japan	The University of Tokyo · Assistant Professor	Japan
2015.7.1-2018.3.31	Tokyo Institute of Technology · Specially Appointed Assistant Professor · Japan	Japan	Tokyo Institute of Technology · Researcher · Japan	Japan	Institute of Science Tokyo · JSPS Researcher	Japan

2015.4.1-2017.7.31	Tokyo Institute of Technology · Graduate Student · Japan	Japan	JAMSTEC · Researcher · Japan	Japan	JAMSTEC · Researcher	Japan
2017.4.1-2018.3.31	YHouse · Core membr ·	USA	Ritsumeikan University · Associate Professor · Japan	Japan	Ritsumeikan University · Associate Professor	Japan
2015.10.1-2018.10.31	Riken · Senior Technical Scientist · Japan	Japan	Tokyo Institute of Technology · Specially Appointed Assistant Professor · Japan	Japan	OIST · Technician	Japan
2017.4.1-2018.7.31	Ehime University · Researcher · Japan	Japan	TADANO LTD. · Researcher · Japan	Japan	TADANO LTD. · Researcher	Japan
2018.4.1-2018.5.31	Tokyo Institute of Technology · Graduate Student · Japan	Japan	Chiba Institute of Technology · Associate Staff Scientist · Japan	Japan	Chiba Institute of Technology · Associate Staff Scientist	Japan
2018.4.1-2018.9.30	Tokyo Institute of Technology · Graduate Student · Japan	Japan	Utrecht University · Researcher ·	Netherlands	Kyoto University · Assistant Professor	Japan
2019.4.1-2019.5.31	Tokyo Institute of Technology · Graduate Student · Japan	Japan	University of Bern · Postdoctoral Researcher	Switzerland	Kagoshima University · Specially appointed assistant professor	Japan
2019.4.1-2020.3.31	Kyushu University · Post-doctoral Fellow	Japan	Kyushu University · Post-doctoral Fellow	日本	Kyushu University · Assistant Professor	Japan
2013.4.1-2020.3.31	National Astronomical Observatory · Postdoctoral Fellow	Japan	Jasco Japan	Japan	Jasco Japan	Japan
2019.4.1-2020.3.31	Nagoya University · Graduate Student · Japan	Japan	Tokyo Institute of Technology · JSPS Postdoctoral Fellow	Japan		
2021.4.1-2021.12.22	National Astronomical Observatory · Project Assistant Professor	Japan	Associate Professor, Shanghai Jiao Tong University	China	Shanghai Jiao Tong University · Associate Professor	China

2019.4.1-2022.2.26	Tokyo Institute of Technology · Graduate School Student	Japan	University of St Andrews, School of Earth and Environmental Sciences, JSPS研究員	UK	Institute of Science Tokyo · Specially Appointed Assistant Professor	Japan
2013.11.1-2022.3.31	Research Associate Professor, Department of Earth Sciences, University of Minnesota · 米国	Japan	NEC Corp.	Japan	NEC Corp. · Engineer	Japan
2013.3.1-2022.3.31	Caltech · Research Scientist	USK	Kochi University · Visiting Professor	Japan	Kochi University · Specially Appointed Professor	Japan
2022.2.16-2022.3.31	kanagawa institute of industrial science and technology · Researcher	Japan	SyntheticGestalt KK	Japan		
2021.5.1-2022.4.30	IPAG Univ. Grenoble Alpes, CNRS	France	Chiba Institute of Technology · Associate Staff Scientist	Japan	Self-employment	Japan
2014.10.1-2022.8.31	Université Blaise Pascal · Postdoctoral Fellow	France	Kobe University · Specially Appointed Associate Professor	Japan	Osaka Otani University · Lecturer	Japan
2021.4.1-2023.3.31	University of Tokyo · Graduate School Student	Japan	JAMESTEC · Young Research Fellow	Japan	JAMESTEC · Young Research Fellow	Japan
2022.7.1-2023.3.31	SyntheticGestalt KK	Japan				
2023.11.1-2024.3.31	University of Tokyo · Research Fellow	Japan	Tokyo Institute of Technology · Research Fellow	Japan		
2023.4.1-2024.3.31	Japan Advanced Institute of Science and Technology · Lecturer	Japan	Japan Advanced Institute of Science and Technology · Associate Professor	Japan	KK MAQsys · Research Manager	Japan
2024.5.1-2024.7.31	Molecure株式会社	Japan	Molecure株式会社	Japan	Molecure KK	Japan

2024.10.1-2024.12.31	JAXA · International Top Young Fellow	Japan	SpaceDATA · CSO	Japan	SpaceDATA · CSO	Japan
2019.4.1-2025.3.31	University of Tokyo · Postdoctoral Fellow	Japan	National Astronomical Observatory · JSPS Research Fellow	Japan	National Astronomical Observatory · JSPS Research Fellow	Japan
2024.4.1-2025.3.31	University of Tokyo · Ph.D. Student	Japan	Institute of Science Tokyo · JSPS Postdoctoral Fellow	Japan	Institute of Science Tokyo · JSPS Postdoctoral Fellow	Japan
2024.4.1-2025.3.31	Institute of Science Tokyo · Ph.D. Student	Japan	RIKEN · Research Fellow	Japan	RIKEN · Research Fellow	Japan

**Overseas Postdocs**

Employment period	Position before employed at WPI center		Next position after WPI center		Position as of April 2025*		Nationality
	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located	
2013.3.8-2014.3.31	The University of Arizona · Senior Research Scientist · USA	USA	The University of Tokyo · Associate Professor · Japan	USA			USA
2014.9.1-2015.7.31	University of Hawaii · PostDoctoral Researcher · USA	USA	Chief research officer · ETH · Switzerland	Germany			Germany
2013.11.1-2017.2.28	Tokyo Institute of Technology · Research Staff · Japan	Japan	Tokyo Institute of Technology · Specially Appointed Assistant Professor · Japan	France	Utrecht University · Assistant Professor	Netherlands	France
2014.8.5-2016.6.30	University of Oregon · Researcher · USA	USA	Araya Brain Imaging · Data Science Manager · Japan	USA			USA
2016.2.1-2017.2.28	Ochanomizu University · Project Assistant Professor · Japan	Japan	Ochanomizu University · Assistant Professor · Japan	France	Ochanomizu University · Associate Professor	Japan	France

2014.5.1-2017.4.30	Yokohama National University · Graduate Student · Japan	Japan	-	Malaysia	National University of Malaysia	Malaysia	Malaysia
2015.5.1-2017.6.30	Georgia Institute of Technology · Graduate Student · USA	USA	Tokyo Institute of Technology · JSPS Postdoctoral Fellowships · Japan	USA	Nanjing University · Associate Professor	China	USA
2015.9.24-2017.9.23	University of Southern Denmark · Graduate Student · Denmark	Denmark	University of Southern Denmark · Assistant Professor · Denmark	Denmark	University of Southern Denmark · Associate Professor	Denmark	Denmark
2016.2.1-2018.1.31	Max Planck Institute for Solar System Research · Postdoctoral Research Scientist · Germany	Germany	Gateway House · Fellow · India	India	Observer Research Foundation (ORF) · Fellow	India	India
2016.2.1-2018.1.31	UC San Diego · Postdoctoral fellow · USA	USA	University of California, San Diego · Assistant Teaching Professor · USA	USA	University of California, San Diego · Assistant Teaching Professor	USA	USA
2016.3.1-2018.2.28	University of Cambridge · Postdoctoral Research Associate · UK	UK	University of Cambridge · Visiting Researcher · UK	UK	Lecturer, University of Essex	UK	UK
2016.4.1-2018.3.31	University of California, Los Angeles · Graduate Student · USA	USA	Lawrence Livermore National Laboratory · Postdoctoral Research Staff · USA	USA	Lawrence Livermore National Laboratory · Postdoctoral Research Staff ·	USA	USA
2016.4.1-2018.3.31	Ecole Polytechnique · Postdoctoral Researcher · France	France	California Institute of Technology · Postdoctoral Researcher · USA	USA	California Institute of Technology · Postdoctoral Researcher · 米国	USA	UK
2016.4.1-2018.3.31	Institute of Advanced Studies, Princeton · Visiting Scholar · USA	USA	University of Naples "Federico II" · Assistant Professor · Italy	Italy	University of Naples "Federico II", Professor	Italy	Italy
2017.9.1-2018.2.28	University of Oxford · Postdoctoral Researcher · UK		University of Southampton · Research Fellow · UK	UK	University of Southampton · Research Fellow	UK	UK

2013.9.1-2018.8.31	Harvard University · Postdoctoral · USA	USA	University of New South Wales · Lecturer · Australia	USA	University of New South Wales, Senior Lecturer	Australia	USA
2017.4.1-2018.8.28	Tokyo Institute of Technology · JSPS Postdoctoral Fellowships · Japan	Japan	Nantes University · Marie Skłodowska-Curie actions Individual Fellowship fellow · France	France	Bureau Veritas (BV).	France	France
2018.10.1-2019.7.28	University Tokyo · postdoctr al fellow	Japan	University of Washington · postdoctoral fellow	USA	Research Scientist, IEH laboratories and Consulting Groups	USA	Etiopia
2018.11.19-2019.11.30	Araya Inc · Data Science Manager	Japan	Cross Compass Ltd. · Researcher	Japan			USA
2019.4.1-2020.1.31	Sony Computer Science Laboratories, Inc., Tokyo, Japan · Associate Researcher	Japan	Sony Computer Science Laboratories, Inc., Tokyo, Japan · Associate Researcher	Japan	Sony Computer Science Laboratories, Inc., Tokyo, Japan · Associate Researcher	Japan	France
2018.10.1-2020.6.30	University of Tronto · Postdoctoral researcher	Canada	National Central University · Assistant Professor	Taiwan	National Taiwan University · Assistant Professor	Taiwan	Taiwan
2019.12.1-2021.1.31	National University of Singapore · Graduate School Student	Singapore	University of Oxford · Postdoctoral researcher	UK	University of Oxford · Postdoctoral Research Associate	UK	Turkey
2017.9.11-2022.7.31	Cornell University Dept. of Astronomy, Research Associate	USA	the University of Central Florida, Department of Physics / tenure-track Associate Professor	USA	Assistant Professor, University of Central Florida, Department of Physics	USA	USA
2020.7.1-2022.3.31	California Institute of Technology, Proffessor	USA	Kochi University · JSPSFellow	Japan	Kochi University · JSPSFellow	Japan	USA
2019.11.1-2022.3.31	University of Tokyo · Research Fellow	Japan	Director of Research and Executive Officer, Cross Labs, Cross Compass Ltd.	Japan	Cross Labs, Cross Compass Ltd. · Director of Research and Executive Officer	Japan	Belgium

2019.4.17-2022.3.31	Tokyo Institut of Technology · Postdoctr I Researcher	Japan	Tokyo Institute of Technology · Research Fellow	Japan			China
2018.1.1-2022.3.31	Arizona State University Graduate School Student	USA	Rensselaer Polytechnic Institute (RPI), Assistant Professor	USA	Rensselaer Polytechnic Institute (RPI), Assistant Professor	USA	USA
2020.12.1-2022.12.31	University of Glasgow · Graduate School Student	UK					Spain
2019.9.1-2023.2.28	Shanghai Jiao Tong University	China	Shanghai Jiao Tong University	China	Shanghai Jiao Tong University · Associate Professor (China-UK Low Carbon College)	China	China
2022.4.1-2023.3.31	Tokyo Institute of Science · Graduate School Student	Japan	RIKEN Postdoctoral Fellow	Japan	RIKEN Postdoctoral Fellow	Japan	China
2023.4.1-2023/12/31	JAXA Postdoctoral Fellow	Japan	Okayama University · Associate Professor	Japan	Okayama University · Associate Professor	Japan	India
2016.2.1-2023.12.27	Tottori University · Graduate School Student	Japan	Chinese Academy of Sciences · Special Research Professor.	China	Chinese Academy of Sciences · Special Research Professor.	China	China
2023.12.1-2024/4/30	Self-employment	Japan	Self-employment	USA	Self-employment	USA	USA
2014.11.1-2024.10.31	University of Tokyo · JSPS Postdoctoral Fellow	Japan	University of Hertfordshire · Postdoctoral Research Fellow	UK	University of Hertfordshire · Postdoctoral Research Fellow	UK	UK
2021.4.1-2024.12.31	University of Pretoria, South Africa · Ph.D. Student	South Africa		Japan		Japan	India

Project Expenditures FY2024

(Thousand yens)

	Amount	Details	Operational subsidies to National University Corporations/Incorporated Administrative Agency		Funding by WPI Academy		Government Subsidies except Funding from WPI Academy		Donations		Indirect funding		Joint research projects		Competitive funding		Others		
			Total costs	Details (no. of persons)	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs
Personnel	355,369	Operational subsidies to National University Corporations/Incorporated Administrative Agency	14,893	Center director 1															
	23,440	Funding by WPI Academy	4,587	Administrative direct 1															
	-	Government Subsidies except Funding from WPI Academy	133,397	Principal investigator 11	8,086	Principal investigator 1	-	0	-	0	-	0	-	0	-	0	-	0	-
	22,773	Donations	102,289	• Full-time / Japanese 8															
	-	Indirect funding		• Concurrent / Japanese															
	16,374	Joint research projects	31,108	• Full-time / Overseas 3	8,086	1													
	56,070	Competitive funding		• Concurrent / Overseas															
	6,553	Others	79,186	Other researchers 11	15,354	Other researchers 2	-	0	-	0	-	0	-	0	-	16,318	2	-	0
			65,754	• Specially Appointed Associate professor 10	15,354	2										16,318	2		
			13,432	• Others 1															
			12,991	Postdocs 3				20,686	Postdocs 7			10,228	Postdocs 2	26,721	Postdocs 8				
			45,955	Research support staffs 40				2,087	Research support staffs 4			5,102	Research support staffs 6	3,838	Research support staffs 11	4,503	Research support staffs 5		
			64,360	Administrative staffs 15								1,044	Administrative staffs 1	9,193	Administrative staffs 3	2,050	Administrative staffs 3		
Subtotal	480,579		355,369	82	23,440	3	-	0	22,773	11	-	0	16,374	9	56,070	24	6,553	8	
Project activities	49,389	Operational subsidies to National University Corporations/Incorporated Administrative Agency	49,389	Project activities	1,028	consumables	2,818	consumables											
	1,536	Funding by WPI Academy			508	honorarium													
	2,818	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	53,743		49,389		1,536		2,818	-	-	-	-	-	-	-	-	-	-	-	-
Travel	13,240	Operational subsidies to National University Corporations/Incorporated Administrative Agency	13,240	travel expenses	101	domestic travel expenses	578	domestic travel expenses											
	9,630	Funding by WPI Academy			9,529	international travel expenses	1,102	international travel expenses											
	1,680	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	24,550		13,240		9,630		1,680	-	-	-	-	-	-	-	-	-	-	-	-
Equipment	15,394	Operational subsidies to National University Corporations/Incorporated Administrative Agency	703	Microwave Power Sources 1															
	-	Funding by WPI Academy	7,370	Energy-Dispersive Spectron 1															
	-	Government Subsidies except Funding from WPI Academy	899	Micromanipulator 1															
	-	Donations	1,125	Bioshaker 1															
	-	Indirect funding	2,992	Microplate Reader 1															
	-	Joint research projects	2,305	projector 1															
	-	Competitive funding																	
	-	Others																	
Subtotal	15,394		15,394		-		-	-	-	-	-	-	-	-	-	-	-	-	-
Research projects	-	Operational subsidies to National University Corporations/Incorporated Administrative Agency							58,976	Donations			24,723	Joint research projects	130,788	KAKENHI	31,015	Contract research expenses	
	-	Funding by WPI Academy															3,063	Consignment business expenses	
	-	Government Subsidies except Funding from WPI Academy																	
	58,976	Donations																	
	-	Indirect funding																	
	24,723	Joint research projects																	
	130,788	Competitive funding																	
	34,078	Others																	
Subtotal	248,565		-		-		-	58,976	-	-	24,723	-	130,788	-	34,078	-	-	-	-
Others	5,394	Operational subsidies to National University Corporations/Incorporated Administrative Agency	1,745	others	9	others													
	-	Funding by WPI Academy	13	consumption tax															
	-	Government Subsidies except Funding from WPI Academy	3,636	Subcontracting commission															
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	5,403		-		5,394		9	-	-	-	-	-	-	-	-	-	-	-	-
Total	828,234		433,392		40,000		4,507		81,749		-		41,097		186,858		40,631		

Operational subsidies to National University Corporations/Incorporated Administrative Agency	運営費交付金
Funding by WPI Academy	WPIアカデミー国際脳循環の加速・拡大事業
Government Subsidies except Funding from WPI Academy	機関補助金(WPIアカデミー国際脳循環の加速・拡大事業を除く)
Donations	寄付金
Indirect funding	間接経費
Joint research projects	共同研究費
Competitive funding	競争的資金
Others	その他

Project Expenditures FY2023

(Thousand yens)

	Amount	Details	Operational subsidies to National University Corporation/Incorporated Administrative Agency		Funding by WPI Academy		Government Subsidies except Funding from WPI Academy		Donations		Indirect funding		Joint research projects		Competitive funding		Others		
			Total costs	Details (no. of persons)	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs
Personnel	348,828	Operational subsidies to National University Corporation/Incorporated Administrative Agency	14,280	Center director 1															
	16,157	Funding by WPI Academy	4,323	Administrative director 1															
	-	Government Subsidies except Funding from WPI Academy	132,433	Principal investigators 11	8,041	Principal investigator 1	-	0	-	0	-	0	-	0	-	0	-	0	-
	10,883	Donations	61,628	·Full-time/Japanese 5		·Full-time/Japanese													
	-	Indirect funding	37,480	·Concurrent/Japanese 3															
	5,658	Joint research projects	23,381	·Full-time/Overseas 2	8,041	·Full-time/Over 1													
	51,484	Competitive funding	9,944	·Concurrent/Overseas 1															
	1,742	Others	81,698	Other researchers 10	8,116	Other researchers 1	-	0	-	0	-	0	-	0	-	10,119	Other researchers 3	-	0
			68,407	·Specially Appointed Associate Professor 9	8,116	·Specially Appointed Associate Professor 1										10,119	·Specially Appointed Associate Professor 3		
			13,291	·Others 1															
			12,113	Postdocs 2				8,026	Postdocs 3			4,797	Postdocs 1	27,717	Postdocs 8				
			44,274	Research support staffs 37				2,857	Research support staffs 6			861	Research support staffs 2	5,667	Research support staffs 14	1,742	Research support staffs 1		
			59,707	Administrative staffs 13										7,981	Administrative staffs 4				
Subtotal	434,752		348,828	75	16,157	2	-	0	10,883	9	-	0	5,658	3	51,484	29	1,742	1	
Project activities	59,320	Operational subsidies to National University Corporation/Incorporated Administrative Agency	59,320	project activities expense	1,625	consumables	791	consumables											
	2,187	Funding by WPI Academy			562	honorarium													
	791	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	62,298		59,320		2,187		791		-										
Travel	10,571	Operational subsidies to National University Corporation/Incorporated Administrative Agency	10,571	travel expenses	14,029	international travel expenses													
	14,029	Funding by WPI Academy																	
	-	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	24,600		10,571		14,029														
Equipment	16,345	Operational subsidies to National University Corporation/Incorporated Administrative Agency	6,919	Infrared Microscope 1	1,100	Workstation 1													
	3,970	Funding by WPI Academy	691	Switching Hub 1	1,018	PC 1													
	-	Government Subsidies except Funding from WPI Academy	1,430	Switching Hub 2	791	PC 1													
	-	Donations	1,305	Ultrapure water sy 1	1,061	Syringe Pump 2													
	-	Indirect funding	1,194	Fixed-Angle Alumini 1															
	-	Joint research projects	891	Touch Display 1															
	-	Competitive funding	1,000	Touch Display 1															
	-	Others	2,915	Audio and visual e 1															
Subtotal	20,315		16,345		3,970														
Research projects	-	Operational subsidies to National University Corporation/Incorporated Administrative Agency							28,319	Donations			15,917	Joint research projects	124,494	KAKENHI	20,708	Contract research expenses	
	-	Funding by WPI Academy															2,465	Consignment business expenses	
	-	Government Subsidies except Funding from WPI Academy																	
	28,319	Donations																	
	-	Indirect funding																	
	15,917	Joint research projects																	
	124,494	Competitive funding																	
	23,173	Others																	
Subtotal	191,903		-		-				28,319				15,917		124,494		23,173		
Others	-	Operational subsidies to National University Corporation/Incorporated Administrative Agency			21	consumption tax													
	3,657	Funding by WPI Academy			3,636	Subcontracting commission													
	-	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	3,657		-		3,657														
Total	737,525		435,064		40,000		791		39,202				21,575		175,978		24,915		

Operational subsidies to National University Corporation/Incorporated Administrative Agency	運営費交付金
Funding by WPI Academy	WPIアカデミー国際顕微鏡の加速・拡大事業
Government Subsidies except Funding from WPI Academy	機関補助金(WPIアカデミー国際顕微鏡の加速・拡大事業)
Donations	寄付金
Indirect funding	間接経費
Joint research projects	共同研究費
Competitive funding	競争的資金
Others	その他

Project Expenditures FY2022

(Thousand yens)

	Amount	Details	Operational subsidies to National University Corporations/Incorporated Administrative Agency		Funding by WPI Academy		Government Subsidies except Funding from WPI Academy		Donations		Indirect funding		Joint research projects		Competitive funding		Others		
			Total costs	Details (no. of persons)	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs
Personnel	336,612	Operational subsidies to National University Corporations/Incorporated Administrative Agency	13,349	Center director 1															
	15,036	Funding by WPI Academy	4,302	Administrative direct 1															
	-	Government Subsidies except Funding from WPI Academy	93,894	Principal investigator 8	6,994	Principal investigator 1	-	0	8,351		1	-	0	-	0	-	0	-	0
	15,472	Donations	57,698	Full-time/Japane 5															
	-	Indirect funding	13,464	Concurrent/Japa 1															
	7,614	Joint research projects	22,732	Full-time/Overseas 2															
	23,730	Competitive funding		Concurrent/Overseas 1	6,994	Concurrent/Over 1		8,351											
	16,992	Others	107,057	Other researchers 12	8,042	Other researchers 1	-	0											
			59,500	Associate professor 8	8,042	Associate professor 1													
			47,557	Assistant professor 4															
			27,161	Postdocs 6				5,696	Postdocs 1				6,876	Postdocs 2	2,695	Postdocs 1	7,238	Postdocs 2	
			34,426	Research support staffs 25			1,425	Research support staffs 3				738	Research support staffs 1	16,926	Research support staffs 15	9,754	Research support staffs 3		
			56,423	Administrative staffs 13										4,109	Administrative staffs 3				
Subtotal	415,456		336,612	66	15,036	2	0	15,472	5	-	0	7,614	3	23,730	19	16,992	5		
Project activities	122,237	Operational subsidies to National University Corporations/Incorporated Administrative Agency	122,237	project activities expenses	9,454	consumables													
	9,887	Funding by WPI Academy		433	honorarium														
	-	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	132,124		122,237		9,887														
Travel	8,826	Operational subsidies to National University Corporations/Incorporated Administrative Agency	8,826	travel expenses	4,382	domestic travel expenses	371	domestic travel expenses											
	8,517	Funding by WPI Academy		4,135	international travel expenses														
	371	Government Subsidies except Funding from WPI Academy																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	17,714		8,826		8,517		371												
Equipment	10,153	Operational subsidies to National University Corporations/Incorporated Administrative Agency	1,322	Osmium coater exclu 1															
	-	Funding by WPI Academy	978	Elix Essential UV3 Sy 1															
	-	Government Subsidies except Funding from WPI Academy	1,478	gel imager system 1															
	-	Donations	629	PC 1															
	-	Indirect funding	574	PC 1															
	-	Joint research projects	1,774	EPOCH2 NON TOUCH 1															
	-	Competitive funding	506	laptop 1															
	-	Others	543	Work station 1															
			628	Work station 1															
			990	server 1															
			731	mirrorless single lens 1															
Subtotal	10,153		10,153																
Research projects	-	Operational subsidies to National University Corporations/Incorporated Administrative Agency							9,230	Donations			9,960	Joint research projects	129,809	KAKENHI	34,401	Contract research expenses	
	-	Funding by WPI Academy															1,542	Consignment business expenses	
	-	Government Subsidies except Funding from WPI Academy																	
	9,230	Donations																	
	-	Indirect funding																	
	9,960	Joint research projects																	
	129,809	Competitive funding																	
	35,943	Others																	
Subtotal	184,942		-		-			9,230				9,960		129,809			35,943		
Others	713	Operational subsidies to National University Corporations/Incorporated Administrative Agency			1,618	others	9	others											
	6,560	Funding by WPI Academy	713	consumption tax of WPI acad	1,306	consumption tax													
	9	Government Subsidies except Funding from WPI Academy			3,636	Subcontracting commission													
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	7,282		713		6,560		9												
Total	767,671		478,541		40,000		380		24,702			17,574		153,539			52,935		

Operational subsidies to National University Corporations/Incorporated Administrative Agency	運営費交付金
Funding by WPI Academy	WPIアカデミー国際顕微鏡の加速・拡大事業
Government Subsidies except Funding from WPI Academy	機関補助金(WPIアカデミー国際顕微鏡の加速・拡大事業を除く)
Donations	寄付金
Indirect funding	間接経費
Joint research projects	共同研究費
Competitive funding	競争的資金
Others	その他

Project Expenditures FY2021

(Thousand yens)

	Amount	Details	Operational subsidies to National University Corporations/Incorporated Administrative Agencies		WPI grant		Government subsidies except WPI grant		Donations		Indirect funding		Joint research projects		Competitive funding		Others		
			Total costs	Details (no. of persons)	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	Total costs	Details	
Personnel	92,300,475	Operational subsidies to National University Corporations/Incorporated Administrative Agencies	14,897,265	Center Director 1	3,600,000	Center Director allow 0													
	355,873,245	WPI grant			7,000,000	Vice Director allowan 0													
	-	Government subsidies except WPI grant	27,640,903	Principal investigator 3	3,126,360	Administrative Direct 1													
	-	Donations	27,640,903	Principal investigator 3	116,222,495	Principal investigator 12													
	-	Indirect funding		Full-time/Japane 3	55,038,844	Full-time/Japane 5													
	-	Joint research projects		Concurrent/Japanese		Concurrent/Japanese													
	-	Competitive funding		Full-time/Overseas	61,183,651	Full-time/Overseas 7													
	-	Others		Concurrent/Overseas		Concurrent/Overseas													
			30,894,254	Other researchers 4	71,772,766	Other researchers 10													
			30,894,254	Professor 4	19,303,484	Associate professor 2													
				Others	52,469,282	Others 8													
				Postdocs	43,191,240	Postdocs 8													
				Research support staffs	32,919,501	Research support staffs 15													
			18,868,053	Administrative staffs 3	78,040,883	Administrative staffs 15													
Subtotal	448,173,720		92,300,475	Administrative staffs 11	355,873,245	Administrative staffs 71													
Project activities	50,313,907	Operational subsidies to National University Corporations/Incorporated Administrative Agencies			5,865,420	University of Tokyo Satellite Personnel Expenses													
	143,749,536	WPI grant			64,020	University of Tokyo Satellite travel expenses													
	-	Government subsidies except WPI grant			1,519,436	University of Tokyo Satellite consumables													
	-	Donations			1,581,712	University of Tokyo Satellite rental fee													
	-	Indirect funding			569,412	University of Tokyo Satellite consumption tax													
	-	Joint research projects			6,226,991	Ehime University Satellite Personnel Expenses													
	-	Competitive funding			8,172,823	Ehime University Satellite consumables													
	-	Others			754,270	Ehime University Satellite Consignment/transportation costs													
					4,045,916	Ehime University Satellite Utility costs													
			381,950	advisory board	50,929	advisory board													
			262,936	startup	2,445,720	startup													
			14,650,909	Consignment/transportation costs	14,712,853	Consignment/transportation costs													
			4,249,225	PR	4,840,337	PR													
					344,390	international symposium													
			4,482,478	Repair cost	3,901,865	Repair cost													
			18,853,229	consumables	5,717,752	consumables													
			172,536	postage	690	postage													
					82,800,000	rental fee													
					135,000	honorarium													
			7,260,644	seed fund															
Subtotal	194,063,443		50,313,907		143,749,536														
Travel	2,184,380	Operational subsidies to National University Corporations/Incorporated Administrative Agencies	2,184,380	travel expenses	1,793,158	travel expenses													
	1,793,158	WPI grant																	
	-	Government subsidies except WPI grant																	
	-	Donations																	
	-	Indirect funding																	
	-	Joint research projects																	
	-	Competitive funding																	
	-	Others																	
Subtotal	3,977,538		2,184,380		1,793,158														
Equipment	8,068,140	Operational subsidies to National University Corporations/Incorporated Administrative Agencies	834,460	Lenovo ThinkStation 1	554,840	PHC MCO-50AIC-PJ 1													
	3,537,116	WPI grant	1,343,628	Waters MassLynx Pe 1	2,189,000	HPC tech HPCTSS4X 1													
	-	Government subsidies except WPI grant	2,409,000	Fortinet Japan FortiG 1	793,276	Apple MWPFF2J/A & 1													
	-	Donations	2,409,000	Fortinet Japan FortiG 1															
	-	Indirect funding	444,000	HPC Tech HPCT WS 1															
	-	Joint research projects	628,052	science artwork 1															
	-	Competitive funding																	
	-	Others																	
Subtotal	11,605,256		8,068,140		3,537,116														
Research projects		Operational subsidies to National University Corporations/Incorporated Administrative Agencies							18,437,396	Donations	58,886,084	KAKENHI Indirect expenses	7,773,999	Joint research projects	316,526,667	KAKENHI			
		WPI grant									8,569,014	Contract research expenses	Indirect expenses		58,588,721	Contract research expenses			
		Government subsidies except WPI grant													27,152,896	Government subsidies except WPI grant			
		Donations																	
		Indirect funding																	
		Joint research projects																	
		Competitive funding																	
		Others																	
Subtotal	495,934,777		-		-				18,437,396		67,455,098		7,773,999		402,268,284				
Others		Operational subsidies to National University Corporations/Incorporated Administrative Agencies																	
		WPI grant																	
		Government subsidies except WPI grant																	
		Donations																	
		Indirect funding																	
		Joint research projects																	
		Competitive funding																	
		Others																	
Subtotal	-		-		-				-		-		-		-				
Total	1,153,754,734		152,866,902		504,953,055				18,437,396		67,455,098		7,773,999		402,268,284				

Operational subsidies to National University Corporations/Incorporated Administrative Agencies	運営費交付金
WPI grant	国際研究拠点形成促進事業補助金
Government subsidies except WPI grant	機関補助金(WPI補助金を除く)
Donations	寄付金
Indirect funding	間接経費
Joint research projects	共同研究費
Competitive funding	競争的資金
Others	その他

## Appendix 4 Outreach Activities and Their Results

List up to three of the Center's outreach activities carried out during the period between FY 2021 and 2024 that have contributed to enhancing the brand or recognition of your Center and/or the brand of the overall WPI program, and describe its concrete contents and effect in narrative style. (Where possible, indicate the results in concrete numbers.)

Examples:

- As a result of using a new OO press-release method, a OO% increase in media coverage was obtained over the previous year.
- By holding seminars for the public that include people from industry, requests for joint research were received from companies.
- We changed our public relations media. As a result of using OO to disseminate information, a OO% increase in inquiries from researchers was obtained over the previous year.
- As a result of vigorously carrying out OO outreach activity, ¥OO in external funding was acquired.

Enter a list of your outreach activities in Attachment 4a.

### Example 1: Leader in Science Communication

ELSI has positioned itself as a leader in science communication with providing skills for researchers, students, and PR staff. ELSI has hosted Japan Scicom Forum (JSF) in 2018, 2019 and 2021. And organised SciComm in Practice symposium in 2019 and 2021, including sessions for WPI institutions. Majority of the science communication efforts are conducted by external grants over the years with funding from industry (Adobe, Google, Cactus, Nature, etc.) and foundations such as Kavli, IAU, etc.

### Example 2: Astrobiology and Origins of Life and Art

ELSI launched the science and art effort in FY2016 which continues to grow as an artist in resident programme, workshops, panel discussions, and other ways. It is the only science-art project in the world that focuses on astrobiology and origins of life. The outcome art expressions are displayed in ELSI-1 building for visitors (public and scientific) as part of the ELSI tour.

### Example 3: Structured and Evaluated Outreach for School Students

ELSI has increased the number of schools visiting ELSI with about 2 schools per month. The visits are structured to engage graduate students and researchers. It is focused both on science and careers, with an exposure to what it is like to be a scientist. The visits are evaluated to get an idea of understanding and interest of the students.

## Appendix 4a State of Outreach Activities from FY 2021 to FY 2024

\* For each activity, enter the number of times that the activity was held each fiscal year.

Activities	FY 2021	FY 2022	FY 2023	FY 2024
	(number of activities, times held)	(number of activities, times held)	(number of activities, times held)	(number of activities, times held)
PR brochure, pamphlet	4	4	4	3
Lectures, seminars for general public	15	11	12	7
Teaching, experiments, training for elementary, secondary and high school students	2	8	8	9
Science café	2	8	9	9
Open house	0	0	1	1
Participating, exhibiting in events	2	2	5	4
Press releases	16	6	6	9
Publications of popular science books	0	0	0	0
Others (science communication internships, science-art project, scicom forum conference, science engagement event)	2	5	10	12

\*If there are activities that the center hasn't implemented, delete those lines. If you have other activities, list them in the space between parentheses after "Others" and state the number of times they were held in the spaces on the right. Another line under "Others" can be added, if needed.

<Notes>

## WPI Academy

### Submittal of List of Center's Research Results

Prepare the following two materials and submit them with your Activities Report.

#### 1. Refereed Papers published from 2021 to 2024 (Free format)

List only the Center's refereed papers published during the period from 2021 to 2024. (Note: The list should be for the calendar year, not the fiscal year.)

##### Divide the papers into two categories, A and B.

##### A. WPI papers

List papers whose author(s) can be identified as affiliated with the WPI program (e.g., that state "WPI" and the name of the WPI center (WPI-center name)). (Not including papers in which the names of persons affiliated with the WPI program are contained only in the acknowledgements.)

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## B.WPI-related papers

List papers related to the WPI Academy center but whose authors are not noted in the institutional affiliations as WPI affiliated. (Including papers whose acknowledgements contain the names of researchers affiliated with the WPI program.)

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