World Premier International Research Center Initiative (WPI)
FY 2019 WPI Project Progress Report

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Common instructions:
* Unless otherwise specified, prepare this report based on the current (31 March 2020) situation of your WPI center.
* So as to execute this fiscal year's follow-up review on the "last" center project plan, prepare this report based on it.
* 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 10-20 pages (excluding the appendices, and including Summary of State of WPI Center Project Progress (within 2 pages)).

Summary of State of WPI Center Project Progress (write within **2 pages**)

1. Advancing Research of the Highest Global Level

ELSI continues to publish research papers of the highest standard. In 2019 there were 184 refereed papers, of which 60 were in Nature Index Journals. They are aiming not only for the 4 goals established at the creation of ELSI (Origin of the Earth, Birth of Earth-Life system, Evolution of Earth-Life system and "Bioplanets" in the Universe) but also for the new themes (see 2.). A number of remarkable results were published in the following themes.

Impact Processes and Planet Formation: Kuwahara and Kurokawa investigated the pebble accretion model of planet formation and identified that turbulence from gas flows is an important parameter to consider (Kuwahara, Kurokawa, 2020). Hyodo and PI Genda showed through simulations that material derived from an early earth magma ocean could have been the primary source of material which eventually became the Moon [58].

Deep Planetary Mineralogy and Chemistry: Umemoto and PI Wentzcovitch advanced our mineralogical understanding of deep interiors of super Earths. Umemoto also collaborated with PI Hirose in a computational exploration of the chemical composition of the Earth's outer core (Umemoto, Hirose, 2020). These works place constraints on the partitioning of elements and the density of phases in deep planetary portions. PI Hernlund and PhD student Bonati investigated the core-mantle boundary and found the surface of the core is likely patchy, which suggests material exchange between the mantle and core could be an ongoing phenomenon [49].

Protometabolism: Kitadai, PI Nakamura, PI Yoshida et al. found that FeS minerals are converted into metallic Fe under possible geoelectrochemical conditions on the Hadean Earth [78]. Li, He and PI Nakamura's finding about the role of MoS_2 shows the importance of secondary electronic interaction with sulfur ligands to facilitate the functional evolution from mineral- to enzyme-catalyzed systems (Li et al., 2020).

Chemical Evolution or Chemical Selection: A-PI Cleaves demonstrated how simpler structures could have also performed the same functionality, considering the chemically heterogeneous and messy environment on the early Earth[20].

Microbial Geochemistry and Evolution: Nakagawa and Giovannelli, together with an international team, showed the dual importance of life and the Earth in controlling the global elemental cycles [6].

Planetary Climate and Habitability: PI Sekine et al. investigated Pluto and identified an insulation mechanism that may prevent a subsurface ocean from freezing [68]. Sekine et al. also investigated Martian mineralogy and found constraints on early Martian surface water chemistry [32].

2. Generating Fused Disciplines

ELSI proposed 4 new themes (Reference Earth Model for major nutrient cycles, Planetary combinatorial systems chemistry, Comparative planetology: from Earth to exoplanets, Universal biology: from Earth to exoplanets) in its Progress Plan in 2019. They reflect ELSI's intention to

generate interdisciplinary, fused disciplines in the fields of research ELSI tackles. There were already notable results in some subjects related to these new themes in 2019:

Deep microbial biogeochemistry: Nakagawa and Giovannelli's work attests that the microbial and geological aspects of Earth are deeply intertwined [6], [90].

Computational biochemistry and chemical evolution: A-PI Cleaves and PI McGlynn worked with computational collaborators to understand selection in biochemistry from a molecular perspective. Cleaves has explored both amino acids and nucleotides through computational approaches.

Estimating planetary mass with deep learning: Tasker, Laneuville and Guttenberg combined the Earth and Planetary sciences with artificial intelligence approaches. They tried to gain information on planetary masses through a deep learning approach (Tasker, Laneuville, Guttenberg, 2020).

3. Realizing an International Research Environment

ELSI has made strategic investments to build our international recognition and standing. ELSI continues to recruit talent from around the world and successfully acquired a new PI from Columbia University in FY2019. ELSI's Research Interactions Committee (RIC) supports researchers' exchanges, organizes workshops to develop external collaborations, and offers strategic support toward ELSI's presence at key international meetings. ELSI is also gaining recognition for its internationalization through implementing our Global Environment Team and a Code of Conduct to ensure people of all backgrounds feel safe and welcome at ELSI. These achievements have made ELSI competitive in attracting new researchers and building active global networks. Continuing its progress, ELSI intends to fortify its PR and science communication by increasing the quantity and quality of press releases in both Japanese and English.

4. Making Organizational Reforms

ELSI has advanced organizational reform within Tokyo Institute of Technology (Tokyo Tech). The following reforms have spread to the entire university or are currently under way: (1) WPI's top-down management system in which the director makes all important decisions, (2) open and flat research organization that enables interdisciplinary research, (3) internationally competitive salary system that reflects research achievements, (4) introduction of a cross appointment system that enables the employment of top-level researchers, (5) establishment of a "donation program" system which is smaller in scale and more flexible than the conventional endowed course system, (6) enhancement of international support i.e. various notices from Tokyo Tech in both Japanese and English, and establishment of a personnel consultation desk in English.

5. Efforts to Secure the Center's Future Development over the Mid- to Long-term

Tokyo Tech has been selected as a Designated National University with the long-term goal of becoming a world-leading university in science and technology. One of Tokyo Tech's steps toward achieving its goal involves expanding system reform from ELSI to the entire university. Our institute has greatly contributed to the establishment in Tokyo Tech of an international collaborative research hub where top researchers gather, and has created an environment in which both young and experienced researchers are free to pursue their ideas within new interdisciplinary research fields.

In order for ELSI to maintain its "World Premier International Research Center" status even after the end of the subsidy, Tokyo Tech will continue to provide necessary financial and facility support to maintain an internationally competitive research level and environment, which is clearly stated in the Mid-term Plan. The support covers the posts of ten full-time principal investigators including tenured faculty members, administrative staff necessary for the smooth operation of ELSI, and staff for safety and maintenance of the laboratory.

In addition, the University will further promote ELSI's participation in graduate school education. As part of these activities, Tokyo Tech applied for the WISE program (Doctoral Program for World-leading Innovative & Smart Education) in 2020, which features ELSI as a main member. Through this program, ELSI will cooperate with various schools in Tokyo Tech and provide world-level research to graduate school education.

* Describe clearly and concisely the progress being made by the WPI center project from the viewpoints below.
- In addressing the below-listed 1-6 viewpoints, place emphasis on the following:
  (1) Whether research is being carried out at a top world-level (including whether research advances are being made by fusingdisciplines).
  (2) Whether a proactive effort continues to be made to establish itself as a "truly" world premier international research center.
  (3) Whether a steadfast effort is being made to secure the center's future development over the mid- to long-term.

1. Advancing Research of the Highest Global Level

* Among the research results achieved by the center, concretely describe those that are at the world's highest level. In Appendix 1, list the center's research papers published in 2019.
* Regarding the criteria used when evaluating the world level of center, note any updated results using your previous evaluation criteria and methods or any improvements you have made to those criteria and methods.

The Earth-Life Science Institute (ELSI) aims to answer the fundamental question "when and where did life originate and how did it evolve?" In the Progress Reports submitted in previous years ELSI proposed to carry out research in order to understand the origins of life in the context of planetary environments by addressing the following four goals:

(A) Origin of the Earth: *The Formation of Planet Earth (Formation of Earth)*
Identify the key stages in the formation of Earth by answering questions such as: how are planets formed and how did the Earth emerge in the early solar system, what was the composition and internal state of the early planet, and how was water delivered to the Earth.

(B) Birth of Earth-Life system: *Early Earth-Life System (Origin of Life on Earth)*
Seek the origins of life as the emergence of a new geological system, accounting for the interactions between oceans, atmosphere, and solid Earth that are key ingredients for early chemical evolution.

(C) Evolution of Earth-Life system: *Evolution of Life on Earth (Evolution of Earth and Life)*
Investigate the co-evolution of the Earth-life system. For example, how did life modify its environment, such as by producing an oxygen atmosphere? What are the influences and feedback between the solid Earth and surface environment? What is the importance of extra-terrestrial events in the Earth-life system?

(D)"Bioplanets" in the Universe: *Life in the Universe*
Use the foundation of Earth-life science as a springboard to identify habitable environments in the universe, and thereby establish a new dialogue for studies of the origins of universal life. Answer the questions: How unique is our planet? How should we search for extraterrestrial life?

* Phrases in italic letters reflect adjustments to our original goals and are expressions used in ELSI's website and pamphlet.

In FY 2019, ELSI published 184 papers including 2 WPI-related papers which are in Appendix 1. Among these papers, 60 papers are in the Nature Index Journals. The following research results are main examples of world-leading research related to the 4 goals mentioned above. The numbers in parentheses correspond to the center's research papers published in 2019 in Appendix 1.

(A) Origin of the Earth

[Impact processes and planet formation]

Understanding the processes that led to the formation and ultimate composition of the planets in our solar system informs us about how Earth came to be habitable. Through the efforts of ELSI researchers, it has become clear that collisions between and impacts by objects of varying sizes can strongly affect both the initial formation and the final planetary compositions. ELSI has become a leader in this research area, attracting high-output researchers who are driving the field internationally. Furthermore, since planetary scientists interact with life scientists and chemists on a regular basis within the institute, their ideas cross fertilize and create more integrative research.

A-PI Brasser's work has shed new light on the formation of the Solar System by providing insight into the structure of the protoplanetary disk from which the planets were born (Brasser et al., 2020).

This work suggests the early Solar System contained multiple rings which contributed to the eventual formation of the present giant planets. Further work that Brasser was involved in provides a temporal constraint on when life may have started on Earth, by supplying information as to when the last full crust-melting event derived by impact occurred [101]. This work indicates that life may have had persistent niches since 4.4 Ga.

PI Ida's research has revealed that the ice-giant planet Uranus likely underwent a giant impact, resulting in its spin axis being tilted by 98 degrees (Ida et al., 2020). Its inclination already suggested an early giant impact, however, the disks predicted by the impact simulations had much smaller sizes than those observed today. Through modeling, Ida et al. showed that the evolution of the impact-generated disk is a major control on the final observation. N-body simulations of the condensed ices were able to reproduce the observed mass and configuration of the Uranian satellite system, a scenario which contrasts with the formation model of the Earth's moon, where much of the mass of the impactor was incorporated into the Moon.

Towards understanding the final distribution of planets after accretion, ELSI researchers Kuwahara and Kurokawa investigated the pebble accretion model of planet formation, incorporating gas flow and turbulence into their model. The work indicated that models that lack consideration of gas differ from those which do, and that turbulence from gas flows is an important parameter to consider when modeling the final architecture of a planet-star system. (Kuwahara and Kurokawa, 2020).

Together with PI Genda, A-PI Brasser and PhD student Woo conducted impact simulations of Mars and determined that a post-impact generated hydrogen-rich atmosphere could have existed for several tens of millions of years, keeping the planet warm, and also potentially supplying a reductant for early metabolism and prebiotic synthesis on that planet [164]. Thus, impactors may have contributed to habitability as well as being basic constraints on planetary composition.

Impactors help explain compositional anomalies and similarities of planetary bodies, and one dramatic case of planetary alteration which likely resulted from an impactor is Mercury. Mercury is essentially an iron ball covered with a thin rocky mantle, proportionally having far more iron than any other of our solar system's planets. Following others who guessed similarly, ELSI PI Helffrich, together with A-PI Brasser, hypothesized that Mercury lost most of its mantle rock in one or more collisions early in the life of the Solar System. From estimates of Mercury's surface composition and thermodynamic modeling, they showed that Mercury lost rock equivalent to 1.4-2.5 times its present mass during this event, and also proposed an isotopic test for detecting the meteoritic fragments it lost [47].

ELSI researchers Hyodo, and PI Genda, together with a team of researchers, have also constrained planetary moon compositions by simulating impactors. Hyodo et al. [58] studied mass delivery from the Martian surface to the Martian moons Phobos and Deimos and found that the amount of delivered Martian materials is ten to one hundred times more than previously estimated. Furthermore, in contrast to Martian meteorites which are igneous and of a limited age range, they found that the material delivered to Martian moons comprises a more substantial record on Martian geology than meteorites, motivating sample return missions from Martian moons.

Hyodo and PI Genda also found a contribution of impactors to moon formation on trans-Neptunian objects [2]. They found that molten progenitors offer the best explanation for the large observed satellites. Furthermore, this work placed a temperature constraint on these bodies, based on short-lived ^{26}Al isotope decay. The existence of magma oceans at the time of impact was also investigated by ELSI researcher Saitoh and collaborators. Their simulations show that material derived from an early Earth magma ocean could have been the primary source of material which eventually became the Moon [53].

(B) Birth of Earth-Life system

[Deep Planetary mineralogy and chemistry]

The interior of a planet harbors information about its formation, as well as its evolution. Furthermore, the degree of interaction between a planet's interior and its surface forms a control on surface chemistry that is relevant to both the origin and the evolution of life. However, the composition of planet interiors remains an open research challenge. ELSI scientists have continued their excellent track record in illuminating the mineralogy of planetary interiors. Understanding the partitioning of elements in the interior of a planet and the processes that may affect redistribution as the planet continues to evolve is essential in order to understand elemental cycling that is necessary to establish and sustain a habitable planet.

Umemoto also collaborated with PI Hirose by performing a computational exploration of the chemical composition of the Earth's outer core (Umemoto, Hirose, 2020). These works place constraints on the partitioning of elements, and the density of phases in deep planetary portions.

PI Hernlund and PhD student Bonati investigated the core-mantle boundary, and found that the structure there is unlikely to be smooth. Instead, the surface is probably patchy, in agreement with seismic observations. The equation derived in the paper allows for time-resolved understanding of ultralow velocity zones, and suggests that material exchange between the mantle and core is an ongoing phenomenon [49].

[Protometabolism]

An important question to understand the origins of life from a chemical standpoint is "Where on Earth can the chemical potentials be sufficiently insulated from one another, such that the resulting redox disequilibrium is sufficient as an energy source to drive chemical reactions?" Understanding how mineral catalysis can be driven by redox disequilibria to form the building blocks of life and help organize them into living systems could assist us in understanding where on Earth and/or on Earth-like planets primitive life could have emerged. ELSI scientists have been studying these issues using multidisciplinary approaches unique to ELSI, supported by the combined expertise of ELSI researchers in geochemistry, electrochemistry, and metabolic chemistry.

ELSI scientist Kitadai, PI Nakamura, PI Yoshida and collaborators found that FeS minerals are converted into metallic Fe under geoelectrochemical conditions which can be expected from the H_2-rich alkaline hydrothermal systems on the Hadean Earth [78]. The geoelectrochemically produced FeS-Fe(0) mineral composite promoted various reactions such as reductive amination and certain steps in the Wood-Ljungdahl (W-L) pathway and the reductive tricarboxylic acid (rTCA) cycle, with efficiencies far superior to pure FeS.

Furthermore, ELSI scientist Li and He, and PI Nakamura have investigated the conversion of nitrate to ammonia in the context of amino acid synthesis and the prebiotic nitrogen cycle. Using operando molecular spectroscopy, Li et al found that MoS_2 can generate an active intermediate which is structurally similar to the active core of biological nitrate reductase enzymes, thus allowing the mineral to catalyze ammonia synthesis in aqueous solution efficiently (Li et al., 2020). This finding highlights the importance of secondary electronic interaction with sulfur ligands to facilitate the functional evolution from mineral- to enzyme-catalyzed systems.

(C) Evolution of Earth-Life system

[Chemical evolution or Chemical selection]

Chemical evolution is the hypothesized process by which complex biomolecules arise from reactions of simple inorganic and organic compounds under chemically messy and dynamic conditions. This is fundamentally different from traditional synthetic chemistry, which uses purified molecules under controlled conditions. By utilizing the multidisciplinary approach unique to ELSI and

supported by a combined background of organic chemistry, biochemistry, and computational chemistry, ELSI scientists have been tackling the question "How were specific molecules and reaction pathways selected from chemically complex environments?". To understand the chemical selection rules before the emergence of biology, a platform in which experimentalists and theorists can work closely together is needed, and ELSI is one of the few research institutions that hashave achieved this.

Considering the above, ELSI visiting student Wataru Takahagi (U Tokyo Ph.D student) and research collaborators including A-PI Fujishima have conducted a laboratory experiment to investigate how peptides can be formed from six prebiotically common amino acids under conditions similar to those occurring at water–rock interfaces in Enceladus' ocean. After more than six months of thermal cycling (between 30 and 100°C), 28 out of the 36 possible dipeptide species were detected. The surface peptide-bond formation model assumes that chemisorption of amino acids on the rock surface facilitates peptide formation, which was further supported by elemental analysis showing carbon and nitrogen signatures on the rock surface only when amino acids were added [142]. These findings suggest that short abiotic peptides could be continuously generated on the porous minerals present in Enceladus' subsurface oceans.

ELSI A-PI Cleaves and collaborators developed a new experimental strategy to search for chemical reactions capable of self-propagation [154]. So far, such chemical reaction networks are limited to model systems such as the Belousov-Zhabotinsky reaction and related reactions, which are not considered to be especially prebiologically plausible and do not lead to organic complexification in any event. These researchers started with "messy" chemical "soups" full of simple organic and inorganic species, observed them over long periods of time and found that oscillatory behaviors were common. In a subsequent study, complex organic mixtures were subjected to multiple cycles of incubation and dilution. In the presence of certain minerals, they found that the organics in the original feed solution disappeared while other complex chemical phenomena propagated, suggesting how natural selection may have occurred due to the emergence of self-propagating chemical networks.

Furthermore, ELSI PI Mamajanov reported a seminal work on how selective polymerization can be possible despite chemically messy conditions by periodic environmental fluctuations [89]. Subjecting a mixture of citric acid and glycerol to wet-dry cycles, soluble low molecular weight hyperbranched polymers (HBPs) were formed. Initially, the HBPs were the dominant products, but operating under a continuous drying condition promoted the formation of insoluble polymers. NMR studies suggested that this drying process enriched citric acid in the HBPs which promoted cross-linking to form the insoluble glassy products. This "environment-driven selective polymerization under far-from equilibrium conditions" provides a means to control the chain growth and serves as a model for further study of the formation of functional polymers under prebiotically plausible conditions.

Compartmentalization is essential to life today. Although the membranes in modern life are based on lipid bilayers, ELSI researchers Jia, Chandru, Hongo, Afrin, Usui, Myojo, and A-PI Cleaves demonstrated how simpler structures could have also performed the same functionality, considering the chemically heterogeneous and messy environment on the early Earth. The team found that drying α-hydroxy acids leads to spontaneous polymerization and self-assembly of polyester microdroplets. Furthermore, they demonstrated that these microdroplets can compartmentalize fluorescent dyes and fluorescently labeled RNAs. α-hydroxy acids are likely to be abundant in the prebiotic environment, suggesting that a function similar to the compartmentalization of modern organisms was possible, albeit using a different set of chemical building blocks [65].

[Synthetic Biology]

An ongoing component of ELSI's research has been examining living systems from a synthetic approach. Previous work at ELSI achieved internationally visible results demonstrating artificial cell construction with some cellular functionality including protein expression and energy transduction.

One of the major energy-consuming activities of life today is in translation, which requires ~4 ATP hydrolysis events to add a single amino acid to a growing peptide chain. Where could this energy have come from before biological energy innovations such as photosynthesis originated? ELSI researchers Wang, Kuruma, Jia, A-PI Fujishima, and PI McGlynn found that polyphosphate can drive protein synthesis in a synthetic system (Wang et al. 2020). Surprisingly, the polyphosphate system showed enhanced protein production compared to the case of using conventional nucleotide triphosphates. This work suggests a flexibility in high energy esters which can be used to overcome energy barriers associated with monomer polymerization in water.

[Microbial Geochemistry and Evolution]

ELSI researchers have made significant progress in understanding the relationship of biology to geology and geochemistry and thereby are able to fill in details of the evolution of Earth's biosphere. Their work is highly international in nature, involving collaborators from top-tier universities worldwide (e.g. Harvard, Caltech), and is published in the highest ranked journals (e.g. Nature, PNAS).

As an example of this highly interdisciplinary and renowned work, ELSI researchers Nakagawa and Giovannelli, together with an international team, investigated the fate of carbon in a subduction zone [6] with isotopes, microbiology, and geological techniques. Their work indicated that around 90% of the carbon released during slab subduction became sequestered within the crust due to the formation of the mineral calcite. Furthermore, the study indicated that microbial chemolithotrophy contributed to a small but noticeable amount of carbon uptake in the system, showing the dual importance of life and the Earth in controlling the global elemental cycles. Overall, this study allows for a re-calibration of carbon cycle, as around 20% of carbon previously thought to move into the mantle is now understood to be channeled into crustal and microbial reservoirs.

Researchers Ward and PI McGlynn et al. investigated microbial genomics along a geochemical gradient that captures the transition of Earth from a low-oxygen environment to current day conditions [160]. This work explored the nature of primary productivity during the Proterozoic, the period following the first signs of oxygen in Earth's atmosphere and preceding the major proliferation of life on Earth. They found low biological productivity associated with iron- and hydrogen-oxidizing microbes near the source of the spring which mimics earlier time periods, and also found an increase in oxygen-producing cyanobacteria within a high-iron spring away from the source. The observation of abundant cyanobacteria in an iron-rich spring challenges the hypothesis that cyanobacterial primary productivity would be limited in an early ferrous ocean.

(D) "Bioplanets" in the Universe

[Planetary Climate and Habitability]

The concept of habitability drives many discussions amongst planetary scientists, however what constitutes habitability is a point of debate. ELSI researchers have considered planetary habitability for different bodies, and for different time periods. Their work highlights that multiple planetary bodies might be habitable, and/or may have once been more habitable. Through the uniqueness of the ELSI environment, these researchers interact with microbiologists and are able to directly refine and discuss their findings with an intellectually diverse array of researchers.

Work by PI Sekine and collaborators investigated Pluto and identified an insulation mechanism that may prevent a subsurface ocean from freezing [68]. Clathrate hydrates may form and prevent heat loss, and a consequence of this mechanism of insulation may be that more extensive subsurface oceans exist than has previously been thought. A striking implication of this work is that it suggests that even bodies such as Pluto, which is well outside the so called Habitable Zone of our Solar System, could have a subsurface ocean that could support life.

Related to the results of Woo et al. discussed in the previous section, ELSI researcher Ramirez investigated the energy budget of early Mars and found evidence for warm temperatures on the planet for ~10 million years (Ramirez et al., 2020). This work adds information on the possible climate of early Mars, and is consistent with the existence of large oceans early in Mars' history. In their simulations, rainfall predicted can explain geological features consistent with abundant early water on the planet.

Further work by Sekine et al. investigated Martian mineralogy in the form of smectite clays [32], giving the opportunity to reconstruct early Martian water chemistry. These observations are consistent with mild salinity and circumneutral pH of early Martian waters. Post depositional alteration during periods in which semiarid climates predominated may have raised salinity levels in surface waters, and redox disequilibria in minerals in the form of ferrous iron together with sulfate, is consistent with oxidizing fluids moving into reduced sediments. This work is a first historical reconstruction of aqueous geochemistry on Mars.

An important component of considering whether planets are or were habitable, is considering the possibility that extraterrestrial life might be returned to Earth during sample return missions. ELSI researchers Hyodo and PI Genda, together with collaborators, investigated the possibility of this type of contamination during JAXA's Martian Moons eXploration (MMX) sample return mission. They determined that the chance of delivery of microbes from those bodies is extremely small [30].

Lists of papers published in 2020 (Papers published in 2019 are listed in Appendix.1)

Brasser, R., Mojzsis, S. J., 2020. The partitioning of the inner and outer Solar System by a structured protoplanetary disk. Nature Astronomy 4, 492-499.

Ida, S., Ueta, S., Sasaki, T. et al., 2020. Uranian Satellite Formation by Evolution of a Water Vapor Disk Generated by a Giant Impact. Nature Astronomy.

Kuwahara and Kurokawa, 2020. Influences of protoplanet-induced three-dimensional gas flow on pebble accretion. Astronomy & Astrophysics 633, A81 (18).

Li. Y., He, D., Nakamura, R. et al., 2020. Enzyme Mimetic Active Intermediates for Nitrate Reduction in Neutral Aqueous Media. Angewandte Chemie-International Edition.

Ramirez et al., 2020. Climate Simulations of Early Mars With Estimated Precipitation, Runoff, and Erosion Rates. JGR Planets 125.

Tasker, E.J., Laneuville, M., Guttenberg, N., 2020. Estimating Planetary Mass with Deep Learning. The Astronomical Journal 159 (2), 41.

Umemoto, K., Hirose, K., 2020. Chemical compositions of the outer core examined by first principles calculations. Earth and Planetary Science Letters 531, 116009.

Wang, P., Fujishima, K., Berhanu, S., Kuruma, Y., Jia, T.Z., Khusnutdinova, A.N., Yakunin, A.F., McGlynn, S.E., 2020. A bi-functional polyphosphate kinase driving NTP regeneration and reconstituted cell-free protein synthesis. ACS Synthetic Biology 9(1).

2. Generating Fused Disciplines

* Describe the content of measures taken by the center to advance research by fusing disciplines. For example, measures that facilitate doing joint research by researchers in differing fields. If any, describe the interdisciplinary research/fused discipline that have resulted from your efforts to generate fused disciplines. You may refer to the research results described concretely in "1. Advancing Research of the Highest Global Level."

A key attribute of ELSI is that it allows researchers to conduct research which would not occur in traditional siloed departments. By bringing together diverse researchers into a single institute, surprising and unexpected benefits continue to occur within ELSI.

2-1. Measures taken by ELSI to advance fused research

In a common workspace which includes many chances for interaction, researchers with different skill sets often ask each other questions, and create new questions when they find that their skills complement each other's.
The following are concrete measures taken by ELSI to advance fused research.

● Study Groups: There are 4 groups within ELSI: (i) the "magma oceans" group focused on unifying planetary accretion and early geological environments, (ii) "cycles of life on planets" (CycLoPs) examines bio-geochemical cycles involving both geological and biological processes, (iii) "mineral selection" brings together organic chemists and mineralogists, while (iv) "origins of life" combines all fields represented at the institute to tackle our biggest unifying question.

● ELSI Assembly: Researchers share their most recent results to promote fusion, and to improve their work through gaining a global perspective.

● ELSI International Symposium: ELSI organizes annual international symposia to showcase our research in broadly inter-disciplinary themes. It brings world-leading scientists such as Carmen Gaina and Benedicte Menez to exchange perspectives and insights with our researchers. In FY2019, the 8th symposium was held with the theme "Extending views of catalysis". For the first time at ELSI all talks were delivered live on the internet. It was one of our best opportunities to showcase ELSI's research outcomes to global leaders. Their impressions of ELSI, shared with all of their colleagues and networks, have been a key ingredient to ELSI's recognition as a widely known inter-disciplinary institution of unprecedented breadth and scope.

2-2. Interdisciplinary research/fused disciplines that have resulted from ELSI's efforts

ELSI set 4 new research themes in the Progress Plan of 2019, which were added to ELSI's 4 original goals:

(a) Reference Earth Model for major nutrient cycles
(b) Planetary combinatorial systems chemistry
(c) Comparative planetology: from Earth to exoplanets
(d) Universal biology: from Earth to exoplanets

These themes are all interdisciplinary research/fused disciplines. Although ELSI does not have a strong thrust currently in the area of Universal Biology, ELSI has been working on the first three themes. The following are considerable achievements in FY2019 related to those three.

(a) Reference Earth Model for major nutrient cycles

[deep microbial biogeochemistry and microbial biogeochemistry]

Microbiologists and geologists speak different scientific languages and are accustomed to thinking at very different time scales. However, the microbial and geological aspects of Earth are deeply intertwined, leaving challenges for scientists to reconcile their thinking to understand the whole Earth system. The work of Nakagawa and Giovannelli [6], [90] attests to the intellectual

breadth and diversity required to fully understand the Earth system, and highlights what is possible at ELSI.

Work on microbial geochemistry within Japan has also been pursued at ELSI. Ward, Nakagawa, PI Ueno, and PI McGlynn investigated microbial genomics along a geochemical gradient that captures the transition of Earth from a low-oxygen environment to current day conditions [159]. This work explored the nature of primary productivity during the Proterozoic, the period following the first signs of oxygen in Earth's atmosphere and preceding the major proliferation of life on Earth. They found low biological productivity associated with iron- and hydrogen-oxidizing microbes near the source of the spring which mimics earlier time periods, and also found an increase in oxygen-producing cyanobacteria within a high-iron spring away from the source. The observation of abundant cyanobacteria in an iron-rich spring challenges the hypothesis that cyanobacterial primary productivity would be limited in an early ferrous ocean. These two themes are specifically related to global elemental cycling, and oxygenation of the planet by microbes.

(b) Planetary combinatorial systems chemistry and evolutionary open endedness [computational biochemistry and chemical evolution]

ELSI researchers and experimentalists A–PI Cleaves, Butch, and PI McGlynn have conducted research enlisting computational collaborators to understand selection in biochemistry from a molecular perspective. Cleaves explored both amino acids and nucleotides, and his results show that chemical traits of biologically encoded amino acids have been selected for [61].

PI McGlynn and collaborators combined expertise in [Fe-S] clusters and computational approaches to ask why only a single thiol containing amino acid is observed in the contemporary genetic code. This research also guides experimental design and interpretation, and experiments are now underway [141].

Further computational work by A-PI Cleaves and Butch shows that basic research application and interest in the origins of life also finds paths to medicinal drug design, what might be found in extraterrestrial life, and the structure of contemporary biology [20].

Working at the interfaces of machine learning and evolutionary theory, ELSI researchers Guttenberg and A-PI Virgo showed that co-evolutionary complexity and the phenomenon of open endedness can be applied to problems in machine learning. This work compares problems and techniques from both of these fields, showing that approaches from both can be synergistically utilized.

(c) Comparative planetology: from Earth to exoplanets
[Estimating Planetary Mass with Deep learning and Artificial Intelligence]

ELSI has become a location where varied, unorthodox techniques are applied towards solving diverse problems. An example of this can be seen in the congregation of researchers pursuing questions in the Earth and planetary sciences with artificial intelligence approaches.

ELSI researchers Tasker, Laneuville and Guttenberg combined forces to gain information on planetary masses through a deep learning approach. By taking advantage of expertise in both planetary science and machine learning, they were able to develop a new code that could estimate planet properties, given the other known bulk and orbital properties. By estimating missing values in the exoplanet catalog, a greater understanding of the known planets can be acquired and used to develop a better and more complete picture of how planets like our own formed (Tasker et al. 2020).

The last three decades have seen a revolution in planetary science. We have gone from knowing only the eight planets of our Solar System to discovering thousands of worlds around other stars. Yet, our knowledge of individual worlds remains sparse. Even measuring basic properties such as

mass and radius requires two independent detection techniques. There are relatively few cases in which both are possible. The result is a large but sparse catalog of planets.

This leaves scientists with a choice: either only the small subset of the catalog with measured properties is used and the rest discarded, or methods need to be developed to compute missing values. Obviously, the latter is preferable when the data set is as expensive and difficult to collect as that for exoplanet observations. However, the relationship between planetary properties that would allow an estimate of missing values is complex and high-dimensional.

Neural networks provide a method for tackling this problem, as they excel at identifying trends in high-dimensional data. They have been used to great effect in tasks such as image generation and recognition. Their potential has recently attracted attention in the scientific community, but this is the first time the technique has been applied to computing planet properties.

2-3. Acquisition of funding for inter-disciplinary research

Raising funds for inter-disciplinary research is absolutely necessary for ELSI's science. Twice, ELSI has successfully obtained a "Grant-in-Aid for Scientific Research on Innovative Areas", which offers large-scale funding for broad collaborations (involving many fields, investigators, and multiple institutions).

- *Co-evolution of the Core and Mantle Toward Integrated Deep Earth Science*, (FY2015-2020) led by ELSI-Ehime satellite Affiliate Faculty Tsuchiya as the PI (approx. 1.09 billion yen for five years). This area aims to constrain the evolution of both the core and mantle as the system that dominates the dynamics in deep Earth.
- *Aquaplanetology* (FY2017-2022) was launched under the leadership of PI Sekine. The proposal also involves members at ISAS/JAXA and aims to constrain how volatile delivery and the history of a planet/moon influences the early environment and possibilities for organic processes leading to life.

In addition to these domestic funds, ELSI has successfully been involved with grants from the US: PI Yoshida is part of a NASA NAI group, and PI McGlynn is part of an NSF Origins of life collaborative research project, which supports a Visiting Fellow at ELSI.

3. Realizing 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 in accordance with the development stage of the center, including the following points, for example:
- Efforts being developed based on the analysis of number and state of world-leading, frontline researchers (in Appendix 2); exchanges with overseas entities (in Appendix 4); number and state of visiting researchers (in Appendix 5)
- Proactive efforts to raise the level of the center's international recognition
- Efforts to make the center into one that attracts excellent young researchers from around the world (such as efforts fostering young researchers and contributing to advancing their career paths)

ELSI has made strategic investments in building our international recognition and standing. Through our programs supporting research interaction and working toward organizational excellence of an international standard, ELSI has become competitive in recruiting new researchers and building active global networks.

In FY 2019 ELSI welcomed Dr. Renata Wentzcovitch as a PI. She is a professor at Columbia University and known for her work on simulating materials at the quantum-mechanical level, including participating in the Quantum ESPRESSO project. ELSI signed a MoU with Columbia University in FY 2018 and has developed closer cooperation with the university by inviting a new PI. ELSI regularly publishes coauthored papers with Columbia University (5 papers in 2018, 6 in 2019).

ELSI's Research Interactions Committee (RIC) is a funding committee that develops and supports programs associated with hosting visitors individually and in groups, workshop organization, external collaborations, and strategic support for ELSI's presence at key international meetings important to our areas of research (83 visitors came to ELSI from overseas in FY2019 despite a

considerable number of cancellations due to COVID-19). All of these programs have created opportunities for ELSI members to develop strong ties with not only domestic, but also overseas collaborators and institutions. A tangible impact can be seen in the form of joint grant submissions in overseas proposals, in the high number of publications with international collaborators, sabbaticals to ELSI by high-caliber collaborators from around the world, and the successes in ELSI postdocs' next job placements.

In addition to such support for research opportunity development, ELSI has gained recognition as a truly international institute through our social endeavors such as our Global Environment Team, ELSI Code of Conduct, clear communication of how harassment issues are handled, and open opportunities to discuss cultural awareness issues that draw on past mandatory training. This is one example of how ELSI's hard work has led to strong gender representation among our members, our workshops and symposium invitees, all of which further raises our institute's global recognition and competitiveness.

An integral part of our internationalization progress lies in fortifying ELSI PR and science communication. ELSI has increased its quantity and quality of not only Japanese, but also English press releases (from 17 in 2018 to 32 in 2019), allowing overseas media to pick up our research stories and furthering our international recognition. Understanding our own challenges to promote our science globally using our limited PR funding and human resources, ELSI once again hosted the Japan Scicom Forum 2019—after a successful forum the previous year—which brought together communicators, writers, scientists, journalists, and selected experts to share ideas for boosting science communication in Japan. Events related to science communication increased from 1 in 2018 to 10 in 2019.

ELSI strives to achieve goals with long-lasting effects beyond our first step. Our research and organizational distinction has led to ELSI being granted USD5.6M for the ELSI Origins Network Program to create a global network for origins of life research with ELSI as the hub. It has led to ELSI being selected to host the Astrobiology Graduate Conference 2020—the leading conference for young researchers in astrobiology and origins of life related fields—outside North America and Europe for the first time.

4. Making Organizational Reforms

* Describe the system reforms made to the center's research operation and administrative organization, along with their background and results.
* If innovated system reforms generated by the center have had a ripple effect on other departments of the host institutions or on other research institutions, clearly describe in what ways.
* Describe the center's operation and the host institution's commitment to the system reforms.

A long-term goal of Tokyo Tech is to be "a world-leading university in science and technology". In March 2018, Tokyo Tech was selected as a Designated National University by the Minister of Education, Culture, Sports, Science and Technology. One of the specific methods to achieve this is by establishing in Tokyo Tech as an international global research hub for leading researchers, and building an environment in which young faculty members or researchers are free to pursue their ideas within new interdisciplinary research fields. Expanding system reform from ELSI to the entire university is regarded as an important step in Tokyo Tech attaining its long-term goals.

In addition, the university's senior executives (President, and Executive Vice Presidents for Research and for Finance) have monthly meetings with ELSI's Director, Executive Director, and Administrative Director to work closely.

The system reforms carried out by ELSI and their ripple effects are as follows.

(1) Organizational management reform

ELSI is encouraging Tokyo Tech to follow in its footsteps with its organizational management reform. The director has the authority to operate the institute, including personnel and budget execution (excluding the right to appoint himself), and employs a top-down decision-making system. Using ELSI as a model, the President of Tokyo Tech is constructing, establishing, and developing a flexible research system that is not bound by conventional rules or operating systems.

(2) Open and flat research environment, promotion of interdisciplinary research

ELSI provides an open and flat research environment, and researchers pursue original research regardless of age, gender, nationality, or background. ELSI is also actively engaged in cross-disciplinary and interdisciplinary research. As a result, ELSI has attracted highly talented researchers as new members or visitors. As the truly integrated environment of ELSI becomes widely known, the number of visiting researchers for joint projects also grows.

Tokyo Tech has incorporated the ELSI system as part of the university's reforms, and established the Institute of Innovative Research (IIR) to reorganize existing research institutes and centers. ELSI's know-how is also utilized for the establishment of the "Tokyo Tech World Research Hub Initiative (WRHI)," which aims to become a world research hub for the creation of innovative science and technology.

(3) Reform of personnel and salary system

・Cross appointment system

In order to acquire top-level researchers to drive origins and evolution of life research at ELSI, we have established a cross-appointment system and applied it for the first time at Tokyo Tech. Since then, Tokyo Tech has promoted cross appointments throughout the university.

・Performance-based salary system, research achievement evaluation system

In addition to introducing an annual salary system, ELSI established its own rules for salary levels and adopted a performance-based salary system. The Annual Evaluation Meeting is held every year to evaluate researchers' performance. Researchers with excellent research are recognized, commended, and their evaluation results are reflected in their annual salary.

(4) English-based working environment, support system for foreign researchers

ELSI uses English as its official language. In addition, full-time staff provide support for foreign researchers living in Japan, which begins even before new recruits have arrived. The staff also aid with paperwork required by Japanese public offices, such as with visa applications. The General Safety Management Section of Tokyo Tech regularly organizes a bilingual training course on the use of AED.

Inspired by these efforts at ELSI and at the request of ELSI, English translations are attached to most campus notification emails from Tokyo Tech. Tokyo Tech has also established an English-based consultation desk and counseling office within the university to strengthen the supportive environment for foreign researchers. ELSI offers a meeting room to the General Safety Management Section of Tokyo Tech and jointly organize a safety and health training course in English for laboratory staff at the university.

In addition, accommodation for foreign researchers, such as the 80th Anniversary Housing, were established. Furthermore, Tokyo Tech has opened dormitories at Senzokuike, Midorigaoka, and Minamishinagawa for both domestic and international students.

5. Efforts to Secure the Center's Future Development over the Mid- to Long-term

* Address the following items, which are essential to mid- to long-term center development:
- Future prospects with regard to the research plan, research organization and PI composition; prospects for fostering and securing of next-generation researchers
- Prospects for securing resources such as permanent positions and revenues; plan and/or implementation for defining the center's role and/or positioning the center within the host institution's institutional structure
- Measures to sustain the center as a world premier international research center after program funding ends

- Host institution’s organizational reforms carried out for the center’s autonomous administration simultaneously with the creation of the center.

5-1. Future prospects with regard to the research plan, research organization and PI composition; prospects for fostering and securing of next-generation researchers

In the coming second decade, ELSI’s scope of research will expand from "the origins of the Earth and life" to the "necessary conditions for life that can exist anywhere in the universe".

ELSI will continue to deliver world-leading research results regarding the role of planets in the emergence of life, the diversity of planets other than those in our solar system, the actual conditions of prebiotic chemistry, and the basic nitrogen cycle. ELSI's organization remains flat to maximize opportunities for collaborative and interdisciplinary research, and to encourage the creation of new ideas. In addition, researchers will be organized into four groups with respect to the goals set in the Progress Plan established in 2019.

ELSI will continue to recruit top-level researchers worldwide. ELSI has already added one PI in FY2019. One more PI is currently being selected and will be hired within FY2020. Further PI(s) will be employed from new satellite institutions and cooperating institutions with MOUs.

Regarding early-career researchers, we have been providing start-up funds so they can start research before acquiring external funds; ELSI will continue supporting their successful application to external funds in Japan, and inviting promising young researchers from participants of symposia and other events organized by ELSI. ELSI will recruit excellent graduate students from overseas institutions who can obtain a fellowship from the Japanese government, JSPS or the government of their origin country, thereby promoting internationalization of Tokyo Tech’s students.

5-2. Prospects for securing resources such as permanent positions and revenues; plan and/or implementation for defining the center's role and/or positioning the center within the host institution's institutional structure

Tokyo Tech clearly stated ELSI in its Third Mid-term Plan as a “strategic and ambitious organization”. In addition, Tokyo Tech recognized ELSI as a permanent and independent research institute, nominating it one of its “Strategic Research Hubs”, and guaranteed their support.

Moreover, ELSI is regarded as indispensable for Tokyo Tech to achieve its goals after having been selected as a Designated National University.

Tokyo Tech provides financial support and workspaces to ELSI, and allocated one new tenure position in FY2018. As of the end of FY 2019, ELSI has a total of seven tenure positions. One more position has been given to ELSI in FY2020, for which a candidate is currently being selected. In addition to this, ELSI is requesting one more position from Tokyo Tech.

This support is due to Tokyo Tech appointing ELSI as a strategic and high-priority institute for education and research that should be strengthened in the medium- to long-term perspective.

In response to the request from ELSI, Tokyo Tech has introduced a donation program to enhance education and research activity through contributions from private companies, in addition to the conventional endowed course system. Utilizing this new program, ELSI has received a donation of 24 million yen from a private company for two years (2019-2020) and established the "FirstLogic-Astrobiology Donation Program" in April 2019. ELSI will continue to increase the acquisition of research funds through donations from companies and others.

Furthermore, ELSI is actively engaged in activities aimed at obtaining research funds from overseas, based on the NPO corporation "Tokyo Tech USA" established in the United States.

5-3. Measures to sustain the center as a world premier international research center after program funding ends

Tokyo Tech positions ELSI as a front-runner in its research and system reform. Therefore, in order to maintain ELSI's "World Premier International Research Center" status even after the end of subsidies, Tokyo Tech will:

- Secure positions for 10 full-time PIs, including eight tenured professors and associate professors, and two full-time administrative staff, as well as necessary operational staff for smooth operation of the institute and safe maintenance of the laboratory.

- Allocate the budget necessary for the maintenance and operation of the World Premier International Research Center.

- Continue providing the ELSI-1 and ELSI-2 buildings.

- Continue making arrangements with various schools so that ELSI is able to effectively participate in graduate education.

In addition, Tokyo Tech has applied for a WISE program in 2020, featuring ELSI as a main contributor. Through this program, ELSI will cooperate with various schools in Tokyo Tech and provide world-level research to graduate school education.

5-4. Host institution's organizational reforms carried out for the center's autonomous administration simultaneously with the creation of the center.

ELSI is the institution directly under the President of Tokyo Tech, and is defined as one of the "Strategic Research Hubs" in the organizational management rules of the National University Corporation Tokyo Institute of Technology. ELSI is able to submit a budget request to MEXT ("Gaisan-yokyu") via Tokyo Tech, and continues to be a "World Premier International Research Center" even after the end of subsidies. President Masu has recognized the outcomes of ELSI as follows: about half of the researchers are foreigners due to international recruitment, a collaborative research network of world-class researchers has been established, and a truly international research environment has been provided. ELSI has been positioned as a first choice for Tokyo Tech to achieve its objective of becoming one of the top 10 research universities in the world by 2030.

Tokyo Tech sets out three new strategic areas to develop in addition to the three priority areas under the plans for the Designated National University. One of those strategic areas is Holistic Life Science, which pursues fundamental understanding of life phenomena, bioinformatics, and life on Earth. Tokyo Tech will promote the creation of new academic fields in this area and ELSI will be an important research hub for this endeavor.

6. Others

* Describe what was accomplished in the center's outreach activities last year and how the activities have contributed to enhancing the center's "globally visibility." In Appendix 6, describe concretely the contents of these outreach activities. In Appendix 7, describe media reports or coverage, if any, of the activities.
* In addition to the above 1-5 viewpoints, if there is anything else that deserves mention regarding the center project's progress, note it.

Among the outreach activities in 2019, one of the most important items to mention is the renewal of ELSI's pamphlet. The 24-page ELSI Prospectus, using plenty of illustrations and images, aims to introduce individual researchers and their research activities in an easy-to-understand manner in accordance with the newly established basic model of research.

In the Shingakujutsu program "Hadean Biosciences" (leader: Ken Kurokawa, National Institute of Genetics, former Vice-Director of ELSI), which ended in March 2019, the movie series "The Whole History of the Earth and Life" was produced to present research on "the origins of the Earth and

life" in a clear and simple way. The first nine chapters have already been made available on YouTube, and the last chapters (Chapters 10 to 12) were released in June 2019 to complete the series.

As one of our annual activities, the 8th ELSI Annual Public Lecture was held during the international symposium (February 4, at Tokyo Tech), and the Kavli IPMU/ELSI/IRCN Joint Public Lecture "A Quest for the Origins" was held on February 16 at Miraikan. In both events a limited number (about 300) of audience members were selected in advance after online application. As the infection of the new coronavirus had begun, there were many cancellations. Despite this, we made appropriate preparations to protect all who attended, and the events were completed safely and successfully.

7. Center’s Response to Results of Last Year’s Follow-up

* Transcribe the item from the “Actions required and recommendations” section in the site visit report and the Follow-up report, then note how the center has responded to them.
* If you have already provided this information, indicate where in the report.

Actions required and recommendations (From Follow-up Report 2019)

(1) *There are a number of research themes continuing under the original roadmap. Making clear what constitutes the successful conclusion of research and what has actually been achieved will be very important for claiming that the ELSI research on the origin of Life within the context of the origin of Earth has reached a successful stage.*

We utilize many methods to assess our success. The easiest approach, which requires minimal effort, is to tabulate the number of peer-reviewed publications that include ELSI affiliated authors, citation rates of those papers, and the number that are published in so-called "high impact journals" (Nature, Science, etc.). As shown in our annual report and application for an extension of WPI funding presented in 2019, ELSI reports exceptional numbers across all of these metrics.

However, paper counts and citations offer only a limited view of our scientific success, and do not by themselves offer any guidance on key strategic questions that inform our future plans. For example, a high citation rate could be due to production of valuable technical data that is highly cited by those who use it in a specialized field, or it could be the result of great achievements in inter-disciplinary fusion that is highly cited because it changes the course of research around the globe. Furthermore, a WPI institute has additional mandates including inter-disciplinarity and global impact, and our success in these areas is not reflected in crude data like paper counts and citations.

In order to address these shortcomings, we have collaborated with Professor Arsev Umur Aydınoğlu, a social scientist who works closely with NASA in order to develop specialized research tools to study the broader questions of scientific impact, inter-displinarity, and collaboration. These methods rely upon analysis of citation networks and additional a priori information such as author affiliations, fields of specialization, and other relevant information. We additionally examined the kind of impacts that ELSI has made beyond the publication sphere, such as our influence upon how research is conducted elsewhere in the world. Gathering this information relies upon the utilization of our global network, and reveals very important information about the institute’s impact.

ELSI has placed the majority of its contract-based researchers into permanent research or faculty jobs outside ELSI. Today, these ELSI alumni populate top departments and research institutions around the world, we have disseminated people who embrace the spirit and values of our institute, including ambitious science targets, groundbreaking inter-disciplinarity, and open cooperation in research to solve the biggest and most difficult scientific questions of all time.

(2) *More concrete strategies are thought to be necessary for universal biology projects in future plans.*

Universal biology asks fundamental questions like "what is life?" ELSI's (original) mission is to study the origin of life in the context of the origin of Earth. Recent discoveries of many planets orbiting stars will someday lead to detection of life there, which may be life of unknown form. To the other extreme are the studies on artificial cells, machine learning and artificial intelligence. ELSI's researchers have already been carrying out such studies connected to universal biology. A most visible attempt would be the 2017 symposium on universal biology, organized under the framework of the EON project. Our plan on universal biology presented in the WPI extension proposal will unfortunately not be realized in full size, but it will remain one of the central ideas for guiding our researches.

(3) *Tokyo Tech should be encouraged to hasten its support for the involvement of ELSI PIs in the university's systems, including the supervision of graduate students as well as lectures in both graduate and undergraduate classes.*

In March 2019, Tokyo Tech applied for the WISE Program (Doctoral Program for World-leading Innovative & Smart Education) by multiple schools centered on ELSI. This program is titled "Graduate program for integrated space-Earth-life professionals". In collaboration with the University of Tokyo, it aims to provide comprehensive understanding of natural phenomena from multiple perspectives ranging from a bird's-eye view of the earth and planets as a system, to observations through the lens of a microscope. Based on this approach, they aim to develop human resources to solve both fundamental problems of natural science and global issues such as the environment, climate change and depletion of resources. Eight PIs from ELSI will participate in this program.

In addition, ELSI has long been coordinating with Tokyo Tech to enable ELSI's PIs, including foreigners, to become doctoral supervisors at graduate schools. As a result, PI Hernlund was assigned as the primary supervisor at the School of Science in FY2019, and PI McGlynn will be assigned as a primary supervisor at the School of Life Science and Technology in FY2020. ELSI will continue to improve the system to enable more of ELSI's PIs to become advisors at the schools of Tokyo Tech. ELSI aims to further internationalize Tokyo Tech by attracting excellent international students from overseas and providing an environment in which Japanese students can study abroad at top-level universities.

Appendix 1 FY 2019 List of Center's Research Results and Main Awards

1. Refereed Papers

- List only the Center's papers published in 2019. (Note: The list should be for the calendar year, not the fiscal year.)

(1) 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 acknowledgements.)

B. WPI-related papers

List papers related to the WPI program 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.)

Note: On 14 December 2011, the Basic Research Promotion Division in MEXT's Research Promotion Bureau circulated an instruction requiring paper authors to include the name or abbreviation of their WPI center among their institutional affiliations. From 2012, the authors' affiliations must be clearly noted.

(2) Method of listing paper

- List only refereed papers. Divide them into categories (e.g., original articles, reviews, proceedings).
- For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is consistent. (The names of the center researchers do not need to be underlined.)
- If a paper has many authors (say, more than 10), all of their names do not need to be listed.
- Assign a serial number to each paper to be used to identify it throughout the report.
- If the papers are written in languages other than English, underline their serial numbers.
- Order of Listing

A. WPI papers
1. Original articles
2. Review articles
3. Proceedings
4. Other English articles

B. WPI-related papers
1. Original articles
2. Review articles
3. Proceedings
4. Other English articles

(3) Submission of electronic data

- In addition to the above, provide a .csv file output from the Web of Science (e.g.) or other database giving the paper's raw data including Document ID. (Note: the Document ID is assigned by paper database.)
- These files do not need to be divided into paper categories.

(4) Use in assessments

- The lists of papers will be used in assessing the state of WPI project's progress.
- They will be used as reference in analyzing the trends and whole states of research in the said WPI center, not to evaluate individual researcher performance.
- The special characteristics of each research domain will be considered when conducting assessments.

(5) Additional documents

- After all documents, including these paper listings, showing the state of research progress have been submitted, additional documents may be requested.

A. WPI papers

1. Original articles

1. Andersen, J.L., Flamm, C., Merkle, D., Stadler, P.F., 2019. Chemical Transformation Motifs-Modelling Pathways as Integer Hyperflows. IEEE-ACM Transactions on Computational Biology and Bioinformatics 16, 510-523.
2. Arakawa, S., Hyodo, R., Genda, H., 2019. Early formation of moons around large trans-Neptunian objects via giant impacts. Nature Astronomy 3, 802-807.
3. Arakawa, S., Shibaike, Y., 2019. Photophoresis in the circumjovian disk and its impact on the orbital configuration of the Galilean satellites. Astronomy & Astrophysics 629.
4. Arimoto, T., Irifune, T., Nishi, M., Tange, Y., Kunimoto, T., Liu, Z., 2019. Phase relations of MgSiO3-FeSiO3 system up to 64 GPa and 2300 K using multianvil apparatus with sintered diamond anvils. Physics of the Earth and Planetary Interiors 295.

5. Barcaro, G., Sementa, L., Carravetta, V., Yano, T.-a., Hara, M., Monti, S., 2019. Experimental and theoretical elucidation of catalytic pathways in TiO2-initiated prebiotic polymerization. Physical Chemistry Chemical Physics 21, 5435-5447.
6. Barry, P.H., de Moor, J.M., Giovannelli, D., Schrenk, M., Hummer, D.R., Lopez, T., Pratt, C.A., Alpizar Segura, Y., Battaglia, A., Beaudry, P., Bini, G., Cascante, M., d'Errico, G., di Carlo, M., Fattorini, D., Fullerton, K., Gazel, E., Gonzalez, G., Halldorsson, S.A., Iacovino, K., Kulongoski, J.T., Manini, E., Martinez, M., Miller, H., Nakagawa, M., Ono, S., Patwardhan, S., Ramirez, C.J., Regoli, F., Smedile, F., Turner, S., Vetriani, C., Yucel, M., Ballentine, C.J., Fischer, T.P., Hilton, D.R., Lloyd, K.G., 2019. Forearc carbon sink reduces long-term volatile recycling into the mantle. Nature 568, 487-+.
7. Barry, P.H., Nakagawa, M., Giovannelli, D., Maarten de Moor, J., Schrenk, M., Seltzer, A.M., Manini, E., Fattorini, D., di Carlo, M., Regoli, F., Fullerton, K., Lloyd, K.G., 2019. Helium, inorganic and organic carbon isotopes of fluids and gases across the Costa Rica convergent margin. Scientific Data 6.
8. Bartlett, S.J., Beckett, P., 2019. Probing complexity: thermodynamics and computational mechanics approaches to origins studies. Interface Focus 9.
9. Bartlett, S.J., Yung, Y.L., 2019. Boolean logic by convective obstacle flows. Proceedings of the Royal Society a-Mathematical Physical and Engineering Sciences 475.
10. Bartlett, S.J., Yung, Y.L., 2019. Convective flow in the presence of a small obstacle: Symmetry breaking, attractors, hysteresis, and information. Physical Review E 99.
11. Berhanu, S., Ueda, T., Kuruma, Y., 2019. Artificial photosynthetic cell producing energy for protein synthesis. Nature Communications 10.
12. Betts, B.H., Warmflash, D., Fraze, R.E., Friedman, L., Vorobyova, E., Lilburn, T.G., Smith, A., Rettberg, P., Joensson, K.I., Ciftcioglu, N., Fox, G.E., Svitek, T., Kirschvinck, J.L., Moeller, R., Wassmann, M., Berger, T., 2019. Phobos LIFE (Living Interplanetary Flight Experiment). Astrobiology 19, 1177-1185.
13. Beulig, F., Roy, H., McGlynn, S.E., Jorgensen, B.B., 2019. Cryptic CH4 cycling in the sulfate-methane transition of marine sediments apparently mediated by ANME-1 archaea. ISME Journal 13, 250-262.
14. Bonati, I., Lichtenberg, T., Bower, D.J., Timpe, M.L., Quanz, S.P., 2019. Direct imaging of molten protoplanets in nearby young stellar associations. Astronomy & Astrophysics 621.
15. Brasser, R., Barr, A.C., Dobos, V., 2019. The tidal parameters of TRAPPIST-1b and c. Monthly Notices of the Royal Astronomical Society 487, 34-47.
16. Breider, F., Yoshikawa, C., Makabe, A., Toyoda, S., Wakita, M., Matsui, Y., Kawagucci, S., Fujiki, T., Harada, N., Yoshida, N., 2019. Response of N2O production rate to ocean acidification in the western North Pacific. Nature Climate Change 9, 954-+.
17. Caracas, R., Hirose, K., Nomura, R., Ballmer, M.D., 2019. Melt-crystal density crossover in a deep magma ocean. Earth and Planetary Science Letters 516, 202-211.
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Leveille, R.J., Papineau, D., Rempfert, K.R., Sanchez-Roman, M., Spear, J.R., Southam, G., Stern, J.C., Cleaves, H.J., II, 2019. Deciphering Biosignatures in Planetary Contexts. Astrobiology 19, 1075-1102.

19. Charnoz, S., Pignatale, F.C., Hyodo, R., Mahan, B., Chaussidon, M., Siebert, J., Moynier, F., 2019. Planetesimal formation in an evolving protoplanetary disk with a dead zone. Astronomy & Astrophysics 627.
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21. Cuthill, J.F.H., Guttenberg, N., Ledger, S., Crowther, R., Huertas, B., 2019. Deep learning on butterfly phenotypes tests evolution's oldest mathematical model. Science Advances 5.
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23. Dekura, H., Tsuchiya, T., 2019. Lattice Thermal Conductivity of MgSiO3 Postperovskite Under the Lowermost Mantle Conditions From Ab Initio Anharmonic Lattice Dynamics. Geophysical Research Letters 46, 12919-12926.
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2. Review articles

None

3. Proceedings

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174. Brasser, R., Werner, S.C., Mojzsis, S.J., 2019. Dynamical Impact Bombardment Chronology of The Terrestrial Planets From 4.5 Ga To 3.5 Ga. Meteoritics & Planetary Science 54.
175. Cuthill, J.F.H., 2019. Resolving the evolutionary relationships of the Ediacaran biota with new quantitative methods. Palaeontology Newsletter 100, 72-75.
176. Du, W., Ohfuji, H., Irifune, T., 2019. Melting of Sahara 97072 Meteorite at High Pressure and High Temperatures. Meteoritics & Planetary Science 54.
177. Egbert, M., Kolezhitskiy, Y., Virgo, N., 2019. Steering the Growth of Adaptive Self-Preserving Dissipative Structures.
178. Guttenberg, N., 2019. Evolutionary rates of information gain and decay in fluctuating environments.
179. Kurosawa, K., Genda, H., Niihara, T., Kayama, M., Koike, M., Mikouchi, T., Sano, Y., Matsui, T., 2019. Enhancement of the degree of impact heating in pressure-strengthened rocks. Meteoritics & Planetary Science 54.
180. Smith, H.B., Kim, H., Walker, S.I., 2019. Biochemical networks display universal structure across projections and levels of organization.
181. Vincent, L., Cleaves, H.J., Baum, D.A., 2019. A Candidate Self-Propagating System Enriched by Chemical Ecosystem Selection.
182. Woo, J.M.Y., Brasser, R., Matsumura, S., Mojzsis, S.J., Ida, S., 2019. The curious case of Mars' formation. Meteoritics & Planetary Science 54.

4. Other English articles

None

B. WPI-related papers

1. Original articles

183. Chiang, Y.-R., Wei, S.T.-S., Wang, P.-H., Wu, P.-H., Yu, C.-P., 2019. Microbial degradation of steroid sex hormones: implications for environmental and ecological studies. Microbial Biotechnology.

184. Fecteau, K.M., Gould, I.R., Williams, L.B., Hartnett, H.E., Shaver, G.D., Johnson, K.N., Shock, E.L., 2019. Bulk gold catalyzes hydride transfer in the Cannizzaro and related reactions. New Journal of Chemistry 43, 19137-19148.

2. Review articles

None

3. Proceedings

None

4. Other English articles

None

2. Invited Lectures, Plenary Addresses (etc.) at International Conferences and International Research Meetings

- List up to 10 main presentations during FY 2019 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
May20, 2019	Piet Hut	History and future of scientific revolutions	Science and Buddhism
May30, 2019	Joseph .L. Kirschvink	Biomineralization in Evolution	Biomineralization in Health and Disease: From the Ocean to the land to the Stars.
Jun18, 2019	Hidenori Genda	Origin and evolution of Earth's H, C, and N	Origin and evolution of planetary atmospheres - Earth, Mars, Venus
Sep 12, 2019	Shawn McGlynn	New insights into microbial iron cycling at a marine ferrous carbonate hot spring	Marine Biotechnology Conference
Sep26, 2019	Ryuhei Nakamura	Progress on Water Splitting by Mn-based	The 4th Solar Fuel Material Workshop

		Electrocatalysts	
Oct23, 2019	Naohiro Yoshida	N_2O isotope researches from bulk ^{15}N and $^{17,18}O$ to clumped Δ458, Δ548, Δ556	N_2O isotope WS; What can we learn from N_2O isotope data
Dec09, 2019	Kei Hirose	SiO_2 and molten silicate release from the core; implications for dynamo and material transport from the core to mantle	AGU Fall Meeting 2019
Dec11, 2019	Tetsuo Irifune	Synthesis of transparent nano-ceramics under ultrahigh pressure	Materials Research Meeting-2019
Dec12, 2019	George Helffrich	Transfer of SiO_2 from the core to the mantle and its fate in the Earth in early and present times	AGU Fall Meeting 2019
Jan15, 2020	Shigeru Ida	Orbital migration, pebble vs planetesimal accretion - Implication for Observation of Exoplanet Atmosphere -	ARIEL Science conference, ESTEC, Netherlands

3. Major Awards

- List up to 10 main awards received during FY 2019 in order from the most recent.
- For each, write the date issued, the 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
Feb, 2020	Naohiro Yoshida	Clair C. Patterson Medal
Feb, 2020	Naohiro Yoshida	Geochemistry Fellow
Dec, 2019	Lana Sinapayen	11th National Visual and Auditory Illusion Contest Award
Sep, 2019	Hiroyuki Kurokawa	Outstanding Young Scientist Award, The Japanese Society for Planetary Sciences

Sep, 2019	Tony Z. Jia	European Astrobiology Network Association Astrobiology Conference Travel Award
Aug, 2019	Lana Sinapayen	International Society for Artificial Life Award for Outreach and Education
Jul, 2019	Harrison B. Smith	ALIFE 2019 Best paper

Appendix 2 FY 2019 List of Principal Investigators

NOTE:

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

*In the case of researcher(s) not listed in the latest report or, for centers selected in FY2012 in the progress report for Extension application screening, attach a "Biographical Sketch of a New Principal Investigator"(Appendix 2a).

<Results at the end of FY2019> **Principal Investigators Total: 19**

Name	Age	Affiliation (Position title, department, organization)	Academic degree, specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Center director Kei HIROSE	52	Director, Tokyo Institute of Technology, Earth-Life Science Institute Professor, The University of Tokyo, Department of Earth and Planetary Science	Ph.D., High-pressure Geoscience	90	From start	Mainly stays at the center; other than that at The University of Tokyo Satellite.	
Mary VOYTEK	61	Executive Director, Tokyo Institute of Technology, Earth-Life Science Institute Professor, Columbia University Senior Scientist, NASA	Ph.D., Biology and Ocean Science	67	From August,2018	Mainly stays at the center; other than that at Columbia University Satellite.	・Collaborative research promotion with Columbia Univ.
Shigenori MARUYAMA	70	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., Geology, Tectonics, History of Life and the Earth	80	From start	Usually stays at the center	
Shigeru IDA	59	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., Planetary Sciences, Planetary Physics	80	From start	Usually stays at the center	
Piet HUT	66	Full professor, Institute for Advanced Study, Princeton, Program of Interdisciplinary Studies Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Theoretical Astrophysics, Interdisciplinary Studies	50	From start	Stays at the center for five months; other than that at Princeton Satellite	・Accept young ELSI scientists to the Satellite (5 months, 7 months) ・Facilitate interdisciplinary research ・Organize Workshops ・Recruit young scientists
Naohiro YOSHIDA	65	Professor, Tokyo Institute of Technology, School of Materials and Chemical Technology	Doctor of Science, Environmental Chemistry, Global Change Analysis	80	From start	Stays at the center three days a week	
Tetsuo IRIFUNE	65	Professor, Ehime University, Geodynamics Research Center	Ph.D., High-pressure geosciences, Materials sciences	66	From start	Usually stays at Ehime Satellite	
Joseph Lynn KIRSCHVINK	66	Professor, California Institute of Technology, Division of Geological and Planetary Sciences Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Geobiology, Paleo-magnetism, Biophysics, Neurobiology	50	From start	Stays at the center for five months, regularly communicates with us by email	・Research fieldwork and prepare customize equipment for research
Jack William SZOSTAK	67	Investigator, Howard Hughes Medical Institute Professor of Genetics, Harvard Medical School Professor of Chemistry and Chemical Biology, Harvard University Alex. A. Rich Distinguished Investigator, Department of Molecular Biology, Massachusetts General Hospital	Ph.D., Molecular biology Synthetic biology	60	From start	Usually stays at Harvard Satellite	・Accept a young ELSI scientist to the Satellite (5 months) ・Mutual dispatch of young scientists between two institutes
John HERNLUND	47	Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Geophysical Modeling, Fluid and Solid Dynamics	100	From August, 2013	Usually stays at the center	
George HELFFRICH	67	Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Geological Sciences	85	From July, 2014	Usually stays at the center	
Eric SMITH	54	Professor, Tokyo Institute of Technology, Earth-Life Science Institute External Professor, Santa Fe Institute Senior Research Scientist, Georgia Institute of Technology	Ph.D., High-energy/particle Physics	80	From February, 2015	Stays at the center for Six months, regularly communicates with us by email	・Research fieldwork and prepare customize equipment for research
Irena MAMAJANOV	44	Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Physical Chemistry	100	From January, 2016	Usually stays at the center	
Yuichiro UENO	45	Professor, Tokyo Institute of Technology, Department of Earth and Planetary Sciences	Doctor of Science, Geochemistry	60	From April, 2016	Usually stays at the center	
Shawn McGLYNN	36	Associate Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Evolutionary biology, Microbial biochemistry	80	From April, 2016	Usually stays at the center	

Ryuhei NAKAMURA	43	Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Doctor of Science, Electrochemistry	80	From April, 2017	Usually stays at the center	
Hidenori GENDA	45	Associate Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Planet formation	80	From April, 2018	Usually stays at the center	
Yasuhito SEKINE	41	Professor, Tokyo Institute of Technology, Earth-Life Science Institute	Ph.D., Planetary Science, Astrobioloby, Evolution of Earth and planets	80	From June, 2018	Usually stays at the center	
Renata WENTZCOVITCH	63	Professor, Columbia University	Ph.D., Geophysicist	20	From June, 2019	Usually stays at Columbia Satellite	

*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

Principal investigators unable to participate in project in FY 2019

Name	Affiliation (Position title, department, organization)	Starting date of project participation	Reasons	Measures taken

Appendix 2a Biographical Sketch of a New Principal Investigator

(within 3 pages per person)

Name (Age) Renata Wentzcovitch (63)

Affiliation and position (Position title, department, organization, etc.)

Professor of Material Science and Applied Physics, and Earth and Environmental Science, Columbia University, NY, USA.

Academic degree and specialty

Ph.D., Condensed Matter Physics, University of California, Berkeley

Effort 10%

* Percentage of time that the principal investigator devote to working for the center vis-à-vis his/her total working hours.

Research and education history

Renata M. M. Wentzcovitch is a Professor of Materials Science and Engineering in the Applied Physics and Applied Mathematics Department, Earth and Environmental Sciences, and Lamont-Doherty Earth Observatory at Columbia University. She was formerly a Professor of Materials Science and Engineering in the Department of Chemical Engineering and Materials Science at the University of Minnesota where she was a member of the graduate faculties in the School of Physics and Astronomy, Department of Earth Sciences, Chemical Physics Program, and Scientific Computation Program, where she was Director of Graduate Studies. Originally from Brazil, she holds a Ph.D. in Condensed Matter Physics from UC-Berkeley. She has been a regular visiting professor at the International School for Advanced Studies (SISSA), Trieste (IT) since 1998, and at Tokyo Institute of Technology since 2002.

Achievements and highlights of past research activities

Over the past two decades her research has been focused primarily on Earth and planetary materials with special emphasis on acoustic/seismic properties of minerals including those containing iron and undergoing spin state crossovers.

Achievements

(1) International influence * Describe the kind of attributes listed below.

a) Recipient of international awards

b) Member of a scholarly academy in a major country

c) Guest speaker or chair of related international conference and/or director or honorary member of a major international academic society in the subject field

d) Editor of an international academic journal

e) Peer reviewer for an overseas competitive research program (etc.)

Dr. Wentzcovitch is a fellow of APS, AGU, MSA, AAAS, and American Academy of Arts and Sciences. She has received the Senior US Scientist Award of Humboldt Foundation and the 2016 Wilhelm Heraeus visiting professorship from University of Frankfurt. She is currently Chair-Elect of the Division of Computational Physics of the American Physical Society.

(2) Receipt of major large-scale competitive funds (over the past 5 years)

Quantum Mechanical Modeling of Major Mantle Materials, National Science Foundation (EAR), $805,227 (USD), 2014-2018.

(3) Major publications (Titles of major publications, year of publication, journal name, number of citations)

https://scholar.google.com/citations?user=gNzwHb4AAAAJ&hl=en

Citations: 28769

h-index: 61

(4) Others (Other achievements indicative of the PI's qualification as a top-world researcher, if any.)

Appendix 3-1 FY 2019 Records of Center Activities

1. Researchers and center staff, satellites, partner institutions

1-1. Number of researchers in the "core" established within the host institution

- Regarding the number of researchers at the Center, fill in the table in Appendix 3-1a.

Special mention

- Enter matters warranting special mention, such as concrete plans for achieving the Center's goals, established schedules for employing main 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.

1-2. Satellites and partner institutions

- List the satellite and partner institutions in the table below.
- Indicate newly added and deleted institutions in the "Notes" column.
- If satellite institutions have been established overseas, describe by satellite the Center's achievements in coauthored papers and researcher exchanges in Appendix 4.

<Satellite institutions>

Institution name	Principal Investigator(s), if any	Notes
Ehime University	Tetsuo IRIFUNE	
The University of Tokyo	Kei HIROSE	
Institute for Advanced Study, Princeton	Piet HUT	
Harvard University	Jack SZOSTAK	
Columbia University	Mary VOYTEK	

< Partner institutions>

Institution name	Principal Investigator(s), if any	Notes
JAXA		
NINS		
NASA		
JAMSTEC		

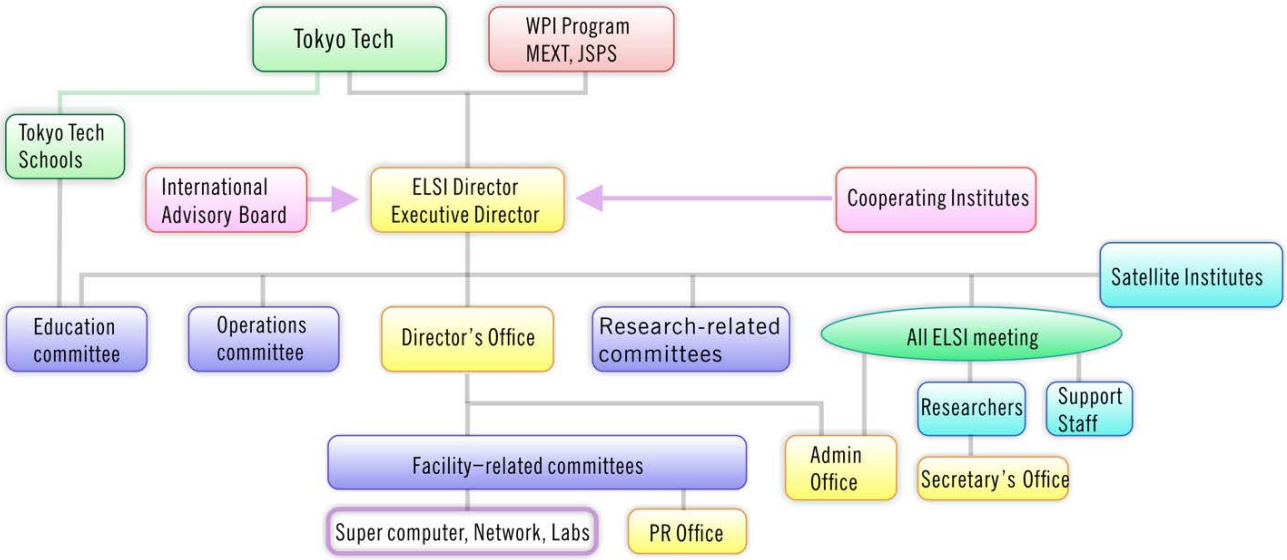
2. Holding international research meetings

- Indicate the number of international research conferences or symposiums held in FY2019 and give up to three examples of the most representative ones using the table below.

FY 2019: 7 meetings	
Major examples (meeting titles and places held)	Number of participants
8th ELSI International Symposium Digital Hall, Tokyo Institute of Technology	From domestic institutions: 72 From overseas institutions: 38
Japan Scicom Forum 2019 Mishima Hall, ELSI	From domestic institutions: 116 From overseas institutions: 6 [international attendees 46; Japanese 76]
"Fundamental Principles of Life" Meeting Komaba Campus, U. of Tokyo	From domestic institutions: 17 From overseas institutions: 16

3. Diagram of management system

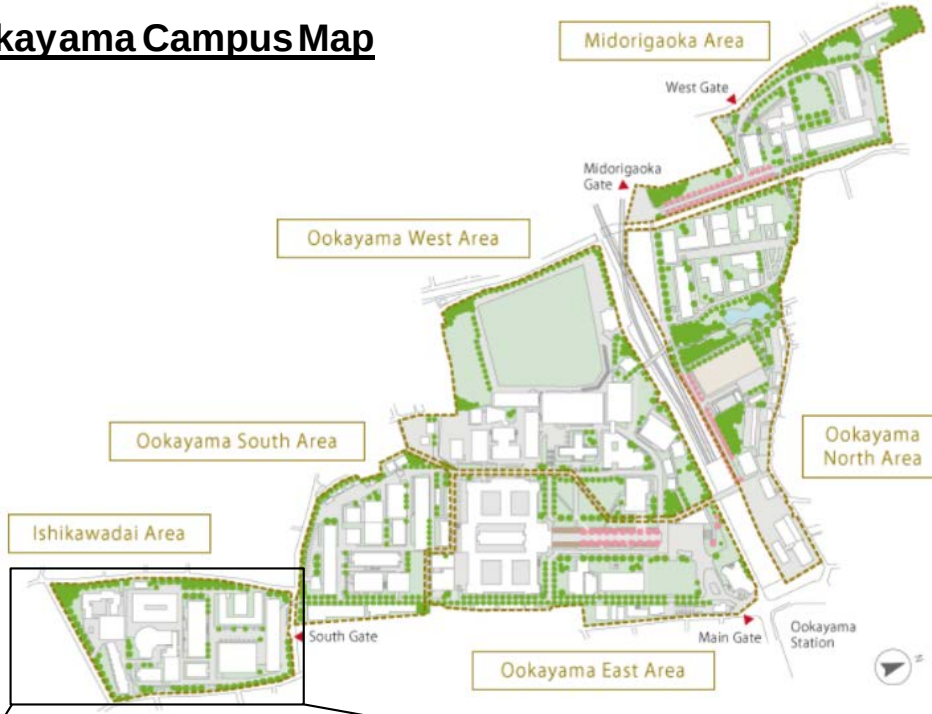
- Diagram the center's management system and its position within the host institution in an easily understood manner.
- If any new changes have been made in the management system from that in the latest "center project" last year, describe them. Especially describe any important changes made in such 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).



4. Campus Map

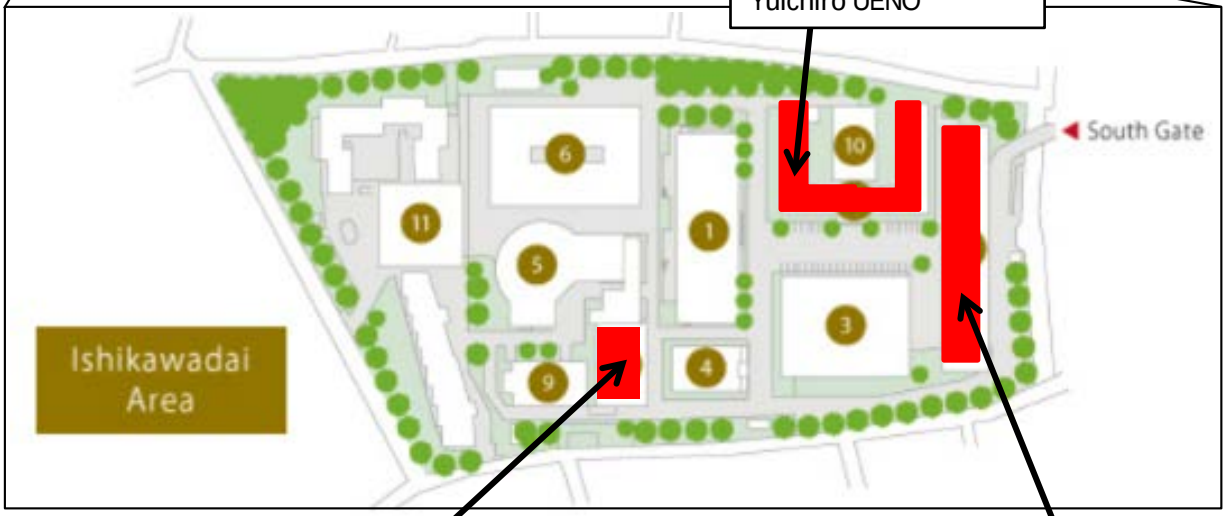
- Draw a simple map of the campus showing where the main office and principal investigator(s) are located.

Ookayama Campus Map



Ishikawadai Bldg.2

Yuichiro UENO



Earth-Life Science Institute Bldg. (ELSI-2)

Shigenori MARUYAMA
Eric SMITH
Hidenori GENDA

Earth-Life Science Institute Bldg. (ELSI-1)

Kei HIROSE
Mary VOYTEK
Shigeru IDA
Piet HUT
Joseph KIRSCHVINK
John HERNLUND
George HELFFRICH
Irena MAMAJANOV
Shawn McGLYNN
Ryuhei NAKAMURA
Yasuhito SEKINE
Naohiro YOSHIDA

Suzukakedai Campus Map

G1 Building

Naohiro YOSHISA

PIs in other institutions

Tetsuo IRIFUNE
Jack William SZOSTAK
Renata WENTZCOVITCH

5. Securing external research funding*

External research funding secured in FY2019

Total: 461,031,467 yen

- Describe external funding warranting special mention. Include the name and total amount of each grant.
* External research funding includes “KAKENHI,” funding for “commissioned research projects,” “joint research projects,” and for others. (donations, etc.)

Appendix 3-1a FY 2019 Records of Center Activities

Researchers and other center staff

Number of researchers and other center staff

* Fill in the number of researchers and other center staff in the table blow.
* Describe the final goals for achieving these numbers and dates when they will be achieved described in the last "center project."

a) Principal Investigators

(full professors, associate professors or other researchers of comparable standing)

(number of persons)

	At the beginning of project	At the end of FY 2019	Final goal (Date: March,2022)
Researchers from within the host institution	6	13	14
Researchers invited from overseas	3	5	5
Researchers invited from other Japanese institutions	4	1	1
Total principal investigators	13	19	20

b) Total members

	At the beginning of project		At the end of FY2019		Final goal (Date: March, 2022)	
	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	23		54		57	
Overseas researchers	3	13%	26	48%	28	49%
Female researchers	0	0%	13	24%	12	21%
Principal investigators	13		19		20	
Overseas PIs	3	23%	10	53%	10	50%
Female PIs	0	0%	3	16%	3	15%
Other researchers	10		15		33	
Overseas researchers	0	0%	6	40%	17	52%
Female researchers	0	0%	3	20%	8	24%
Postdocs	0		20		4	
Overseas postdocs	0	0%	10	50%	1	25%
Female postdocs	0	0%	7	35%	1	25%
Research support staffs	0		26		26	
Administrative staffs	5		22		22	
Total number of people who form the "core" of the research center	28		102		105	

Appendix 3-2 Project Expenditures

1) Overall project funding

* In the “Total costs” column, enter the total amount of funding required to implement the project, without dividing it into funding sources.
* In the “Amount covered by WPI funding” column, enter the amount covered by WPI within the total amount.
* In the “Personnel,” “Project activities,” “Travel,” and “Equipment” blocks, the items of the "Details" culumn may be changed to coincide with the project’s actual content.

(Million yens)

Cost items	Details (For Personnel - Equipment please fill in the breakdown of fiscal expenditure, and the income breakdown for Research projects.)	Total costs	Amount covered by WPI funding
Personnel	Center director and administrative director	25.4	10.5
	Principal investigators (no. of persons):12	119.9	84.8
	Other researchers (no. of persons):30	184.4	150.7
	Research support staff (no. of persons):12	63.6	63.6
	Administrative staff (no. of persons):16	75.5	55
	Subtotal	468.8	364.6
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):6	2	1.8
	Cost of dispatching scientists (no. of persons):1	3.6	3.6
	Research startup cost (no. of persons):35	7.5	3.3
	Cost of satellite organizations (no. of satellite organizations):2	28.9	28.9
	Cost of international symposiums (no. of symposiums):1	0.6	0.6
	Rental fees for facilities	83.8	83.8
	Cost of consumables	19.9	10.7
	Cost of utilities	0	0
	Other costs	82.9	26.6
	Subtotal	229.2	159.3
Travel	Domestic travel costs	6.4	0.6
	Overseas travel costs	13.4	10.9
	Travel and accommodations cost for invited scientists		
	(no. of domestic scientists):65(WPI)10(other)	21	19.5
	(no. of overseas scientists):14(WPI)6(other)	2.5	0.8
	Travel cost for scientists on transfer	0	0
	(no. of domestic scientists):0	0	0
	(no. of overseas scientists):0	0	0
	Subtotal	43.3	31.8
Equipment	Depreciation of buildings	13.2	0
	Depreciation of equipment	0.2	0
	Subtotal	13.4	0
Research projects (Detail items must be fixed)	Project supported by other government subsidies, etc. *1	0	0
	KAKENHI	179.7	0
	Commissioned research projects, etc.	48	0
	Joint research projects	0	0
	Ohers (donations, etc.)	98.7	0
	Subtotal	326.4	0
Total		1081.1	555.7

Costs (Million yens)

WPI grant in FY 2019	570.3
Costs of establishing and maintaining facilities	1
Establishing new facilities (Number of facilities: , OO m²)	0
Repairing facilities (Gallery repair work)	1
Others	0
Costs of equipment procured	8.4
Supercomputer (Number of units:3)	5.7
Name of equipment (Number of units:1)	2
Ultra Low Freezer	0.7

*1. Management Expenses Grants (including Management Enhancements Promotion Expenses (機能強化経費)), subsidies including National university reform reinforcement promotion subsidy (国立大学改革強化推進補助金) etc., indirect funding, and allocations from the university’s own resources.
*2 When personnel, travel, equipment (etc.) expenses are covered by KAKENHI or under commissioned research projects or joint research projects, the amounts should be entered in the “Research projects” block.

*1 運営費交付金(機能強化経費を含む)、国立大学改革強化推進補助金等の補助金、間接経費、その他大学独自の取組による学内リソースの配分等による財源
*2 科研費、受託研究費、共同研究費等によって人件費、旅費、設備備品等費を支出している場合も、その額は「研究プロジェクト費」として計上すること

2) Costs of satellites

(Million yens)

Cost items	Details	Total costs	Amount covered by WPI funding
Personnel	Principal investigators (no. of persons):1		
	Other researchers (no. of persons):2		
	Research support staff (no. of persons):0		
	Administrative staff (no. of persons):1		
	Subtotal	9.2	9.2
Project activities	Subtotal	12.6	12.6
Travel	Subtotal	1.3	1.3
Equipment	Subtotal	5.7	5.7
Research projects	Subtotal	93.9	0
Total		122.7	28.8

Appendix 4 FY 2019 Status of Collaboration with Overseas Satellites

1. Coauthored Papers

- List the refereed papers published in FY 2019 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.
- For reference write the Appendix 1 item number in parentheses after the item number in the blocks below. Let it free, if the paper is published in between Jan.-Mar. 2020 and not described in Appendix 1.

Overseas Satellite 1 Institute for Advanced Study, Princeton (Total: 4 papers)

1) (48) Mariscal, Carlos; *Giovannelli, Donato*; Hernlund, John; *Hut, Piet*; Nakagawa, Mayuko; Virgo, Nathaniel; *Witkowski, Olaf*; *Cleaves, H. James, II*, et al. Hidden Concepts in the History and Philosophy of Origins-of-Life Studies: a Workshop Report. ORIGINS OF LIFE AND EVOLUTION OF BIOSPHERES. 49(3):111-145. https://doi.org/10.1007/s11084-019-09580-x. 2019.

2) (64) Jia, Tony Z.; Chandru, Kuhan; Hongo, Yayoi; Afrin, Rehana; Usui, Tomohiro; Myojo, Kunihiro; *Cleaves, H. James, II*. Membraneless polyester microdroplets as primordial compartments at the origins of life. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA. 116(32):15830-15835. https://doi.org/10.1073/pnas.1902336116. 2019.

3) (73) Chan, Marjorie A.; Jia, Tony Z.; *Cleaves, Henderson James, II*, et al. Deciphering Biosignatures in Planetary Contexts. ASTROBIOLOGY. 19(9):1075-1102. https://doi.org/10.1089/ast.2018.1903. 2019.

4) (145) *Sojo, Victor*; Ohno, Aya; McGlynn, Shawn E.; Yamada, Yoichi M. A.; Nakamura, Ryuhei. Microfluidic Reactors for Carbon Fixation under Ambient-Pressure Alkaline-Hydrothermal-Vent Conditions. LIFE-BASEL. 9(1):-. https://doi.org/10.3390/life9010016. 2019.

Overseas Satellite 2 Harvard University (Total: 3 papers)

1) (34) Fukushi, Keisuke; Sekine, Yasuhito; Sakuma, Hiroshi; Morida, Koki; *Wordsworth, Robin*. Semiarid climate and hyposaline lake on early Mars inferred from reconstructed water chemistry at Gale. NATURE COMMUNICATIONS. 10():-. https://doi.org/10.1038/s41467-019-12871-6. 2019.

2) (45) *Ward, Lewis M.*; Idei, Airi; Nakagawa, Mayuko; Ueno, Yuichiro; Fischer, Woodward W.; McGlynn, Shawn E.. Geochemical and Metagenomic Characterization of Jinata Onsen, a Proterozoic-Analog Hot Spring, Reveals Novel Microbial Diversity including Iron-Tolerant Phototrophs and Thermophilic Lithotrophs. MICROBES AND ENVIRONMENTS. 34(3):278-292. https://doi.org/10.1264/jsme2.ME19017. 2019.

3) (149) Stamenkovic, V.; Kirschvink, J. L.; Kobayashi, A.; *Ward, L. M.*; Woolley, R. et al. The next frontier for planetary and human exploration. NATURE ASTRONOMY. 3(2):116-120. https://doi.org/10.1038/s41550-018-0676-9. 2019.

Overseas Satellite 3 Columbia University (Total: 6 papers)

1) (10) Umemoto, Koichiro; *Wentzcovitch, Renata M.*. Ab initio exploration of post-PPV transitions in low-pressure analogs of MgSiO3. PHYSICAL REVIEW MATERIALS. 3(12):-. https://doi.org/10.1103/PhysRevMaterials.3.123601. 2019.

2) (20) *Zhang, Ning*; *Shi, Shundi*; Jia, Tony Z.; Ziegler, Ashley; Yoo, Barney; Yuan, Xiaohong; Li, Wenjia; Zhang, Shenglong. A general LC-MS-based RNA sequencing method for direct analysis of multiple-base modifications in RNA mixtures. NUCLEIC ACIDS RESEARCH. 47(20):-. https://doi.org/10.1093/nar/gkz731. 2019.

3) (39) Del Genio, Anthony D.; Kiang, Nancy Y.; Way, Michael J.; *Amundsen, David S.*; *Sohl, Linda E.*; Fujii, Yuka; *Chandler, Mark*; *Aleinov, Igor*; Colose, Christopher M.; Guzewich, Scott D.; Kelley, Maxwell. Albedos, Equilibrium Temperatures, and Surface Temperatures of Habitable Planets. ASTROPHYSICAL JOURNAL. 884(1):-. https://doi.org/10.3847/1538-4357/ab3be8. 2019.

4) (96) *Vecchioni, Simon*; Fujishima, Kosuke; *Wind, Shalom J.*; Rothschild, Lynn, et al. Construction and characterization of metal ion-containing DNA nanowires for synthetic biology and nanotechnology. SCIENTIFIC REPORTS. 9():-. https://doi.org/10.1038/s41598-019-43316-1. 2019.

5) (123) *Qin, Tian*; *Zhang, Qi*; *Wentzcovitch, Renata M.*; Umemoto, Koichiro. qha: A Python package for quasiharmonic free energy calculation for multi-configuration systems. COMPUTER PHYSICS COMMUNICATIONS. 237():199-207. https://doi.org/10.1016/j.cpc.2018.11.003. 2019.

6) (169) van den Berg, A. P.; *Yuen, D. A.*; Umemoto, K.; Jacobs, M. H. G.; *Wentzcovitch, R. M.*. Mass-dependent dynamics of terrestrial exoplanets using ab initio mineral properties. ICARUS. 317():412-426. https://doi.org/10.1016/j.icarus.2018.08.016. 2019.

2. Status of Researcher Exchanges

- Using the below tables, indicate the number and length of researcher exchanges in FY 2019. Enter by institution and length of exchange.
- Write the number of principal investigator visits in the top of each space and the number of other researchers in the bottom.

Overseas Satellite 1: Institute for Advanced Study, Princeton

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2019	0	0	2	0	2
	5	0	0	0	5

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2019	0	1	2	0	3
	0	0	0	0	0

Overseas Satellite 2: Harvard University

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2019	0	0	0	0	0
	0	0	0	0	0

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2019	0	0	0	0	0
	1	2	1	0	4

Overseas Satellite 3: Columbia University

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2019	0	0	0	0	0
	0	0	0	0	0

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2019	0	1	0	0	1
	1	0	0	0	1

Appendix 5 FY 2019 Visit Records of Researchers from Abroad

* If researchers have visited/ stayed at the Center, provide information on them in the below table.

Total: 83

	Name	Age	Affiliation		Academic degree, specialty	Record of research activities (Awards record, etc.)	Time, duration	Summary of activities during stay at center (e.g., participation as principal investigator; short-term stay for joint research; participation in symposium)
			Position title, department, organization	Country				
1	Dennis Hoening	30	Origins Center Research Fellow, Vrije Universiteit Amsterdam	Netherland			20190401 to 20190417, 17	short-term stay for joint research
2	Sukrit Ranjan		Postdoctoral Fellow, Simons Fellow; Earth, Atmosphere and Planetary Sciences, MIT	USA	Ph.D., Astronomy & Astrophysics		20190403 to 20190406, 4	short-term stay for joint research
3	Markus Meringer		staff Scientist, German Aerospace Center	Germany	Dr. rer. nat., Mathematics and Computer Sciences		20190403 to 20190505, 33	mid-term stay for joint research
4	Jean-Sebastien Gagnon		Assistant Professor, the physics department, Castleton University	USA	Ph.D., Theoretical high-energy physics	the Castleton University Endowed Part-Time Faculty Award	20190406 to 20190420, 15	short-term stay for joint research
5	Christopher Butch		Associate Professor, Department of Biomedical Engineering, Nanjing University	USA	Ph.D., Physical organic chemistry		20190406 to 20190420, 15	short-term stay for joint research
6	Robert Craddock		Geologist, Center for Earth and Planetary Studies, National Air and Space Museum, The Smithsonian Institution	USA	Ph.D., Geology	First Prize for Educational Resources by the American Association of Museums	20190412 to 20190420, 9	short-term stay for joint research and for talks at a seminar and a conference at ELSI
7	Bakhtiyor Rasulev		Assistant Professor, Department of Coatings and Polymeric Materials, North Dakota State University	USA	Ph.D., NMR spectroscopy and Computational Chemistry of natural compounds	TOXI Young Investigators Award, 238th American Chemical Society National Meeting	20190418 to 20190503, 16	short-term stay for joint research

8	Alessandro Morbidelli	52	Researcher in Astronomy (permanent position), Observatoire de la Cote d'Azur	France	Ph. D., Mathematics	Harold Jeffreys Lecture, Royal Astronomical Society, 2018. Prix Janssen, Société Astronomique de France, 2018. CNRS Silver medal, 2019	20190422 to 20190427, 6	short-term stay for joint research and presentation at a seminar
9	Michael James Toillion		NASA Astrobiology Institute	USA			20190510 to 20190526, 17	short-term stay for media production about ELSI and other technical service
10	Douglas Lin	70	Professor of Astronomy and Astrophysics, University of California, Santa Cruz	USA	Ph.D., Astronomy, Astrophysics	Bruce Medal; Guggnheim Fellow	20190511 to 20190517, 7	short-term stay for ELSI International Advisory Board
11	Ramanarayanan Krishnamurthy		Associate Professor of Chemistry, Dpt. of Chemistry, Scripps Research Institute	USA	Ph.D., Chemistry	Member, Scientific Organizing Committee, 2017 ISSOL;	20190512 to 20190518, 7	short-term stay for ELSI International Advisory Board
12	Carl Pilcher		Research Scientist, Blue Marble Space Institute of Science	USA	Ph.D., Astrobiology	NASA Distinguished Service Medal	20190513 to 20190519, 7	short-term stay for ELSI International Advisory Board
13	Andrew Berry		Biomedical Animations Manager, WEHI.TV, The Walter and Eliza Hall Institute of Medical Research	Australia	Ph.D., biomedical animation	Honorary Doctor of Technology, Linköping University, Sweden; New York Times “If there is a Steven Spielberg of molecular animation, it is probably Drew Berry.”	20190514 to 20190519, 6	short-term stay to give a talk at Japan Scicom Forum supported by ELSI and for joint research
14	Peter Farley		Director of Communications for Research and Education, University of California, San Francisco	USA	master's degree, science and medical journalism		20190514 to 20190519, 6	presentation at Japan Scicom Forum
15	Oana-Monalisa Barbulete		Community Coordinator & Strategy Officer, The European Southern Observatory	Germany	Master Degree in Public Opinion, Marketing and Advertising		20190514 to 20190523, 10	presentation at Japan Scicom Forum and short-term stay for joint research
16	Carlos Martinez Martin		Cloud Solutions Engineer at Oracle	USA	Senior Engineer, Informatics		20190514 to 20190708, 56	mid-term stay for scientific advice of PI of ELSI
17	Robert Hazen	70	Senior Staff Scientist, Carnegie Institution of Washington	USA	Ph.D., Mineralogy, Astrobiology	Fellow of the American Association for the Advancement of Science; Roebling Medal	20190515 to 20190518, 4	short-term stay for ELSI International Advisory Board

18	Frances Westall	64	Centre de Biophysique Moleculaire, CNRS	France	Ph. D., Life & Health Sciences		20190515 to 20190518, 4	short-term stay for ELSI International Advisory Board
19	Ajay Verma		Master's Student, Department of Biology, Indian Institute of Science Education and Research	India	biology		20190519 to 20200331, 318	short-term stay for joint research
20	Sheref Samir Mansy	44	Associate Professor, Department of Cellular, Computational and Integrative Biology - CIBIO, University of Treno	Italy			20190523 to 20190601, 10	short-term stay for scientific discussion
21	Unterborn Cayman		Assistant Research Scientist, School of Earth and Space Exploration, Arizona State University	USA	Ph.D., Geological Sciences	Earth Origins Network Workshop Grant	20190605 to 20190612, 8	short-term stay for joint research
22	Gerd Steinle-Neumann		University of Bayreuth	Germany	Ph.D., Computational high pressure physics and mineralogy	Outstanding Dissertation Award, Rock and Mineral Physics Committee, American Geophysical Union; Ralph B. Baldwin Price for Astrophysics and Space Sciences, University of Michigan, Ann Arbor	20190609 to 20190611, 3	short-term stay for joint research and a talk at a seminar
23	Su Jun		Master Student, Institute of Earth Sciences, Academia Sinica	Taiwan			20190616 to 20190619, 4	short-term stay for joint research and for a Boot Camp of research
24	Vera Assis Fernandes		Marie Curie Fellow, Department of Earth and Environmental Sciences, University of Manchester	UK	Ph.D., Geology		20190716 to 20190718, 3	mid-term stay for joint research
25	Joseph Kirschvink	66	Nico and Marilyn Van Wingen Professor of Geobiology, Division of Geological and Planetary Sciences, California Institute of Technology (Caltech)	USA	Ph.D., Geology and Geophysics	the Richard P. Feynman Prize for teaching excellence at Caltech, the William Gilbert Award from the American Geophysical Union	20190829 to 20190913, 15	participation as principal investigator
26	Lewis Ward		Post-doctoral Fellow, The Johnston Group, Earth and Planetary Science, Harvard Univ.	USA	Ph.D., Earth & Planetary Science		20190829 to 20190913, 16	mid-term stay for joint research
27	Qingzhu Yin		Professor, Earth and Planetary Sciences, University of California, Davis	USA	Ph.D., Chemistry	Meteoritical Society Fellow, 2018	20190901 to 20190906, 5	short-term stay for research meeting and a talk at a seminar and a conference of ELSI

28	Mohit Melwani Daswani		Postdoctoral Scholar, Jet Propulsion Laboratory, Caltech	USA	Ph.D., Planetary Science	Lunar and Planetary Institute Career Development Award	20190901 to 20190906, 6	short-term stay for joint research and to give a talk at a seminar
29	Olaf Witkowski		director of scientific affairs and chief scientist, Cross Labs	Japan	Ph.D., Computer Science		20190907 to 20190913, 6	participation in LPI Habitability Conference
30	Vlada Stamenkovic		NASA JPL	USA	Ph.D., Earth & Planetary Science	Voyager Award, Simons Foundation's Collaboration on the Origins of Life Fellow	20190907 to 20190913, 7	short-term stay for joint research
31	Boswell Wing		Associate Professor, Geological Sciences, Univ. of Colorado Boulder	USA	Ph.D., Earth and Planetary Sciences		20190915 to 20190928, 13	short-term stay for discussion of research and give a talk at a conference at ELSI colloquium
32	Krupovic Mart		Department of Microbiology, Institute Pasteur	France	Ph.D., Archaeal Virology		20190915 to 20190928, 14	short-term stay for joint research and to attend a workshop
33	Loren D Williams		Co-Lead of the Prebiotic Chemistry and Early Earth Environment Consortium, Georgia Tech	USA	Ph.D., Physical Chemistry	the Vasser Woolley Award for Excellence in Instruction	20190930 to 20191201, 62	mid-term stay for joint research
34	Krupovic Virginija		Department of Microbiology of Paris, Institute Pasteur International Network	France	Ph.D., Archaeal Virology		20190930 to 20191201, 63	short-term stay for joint research and attend ELSI workshop
35	Joseph Kirschvink	66	Nico and Marilyn Van Wingen Professor of Geobiology, Division of Geological and Planetary Sciences, California Institute of Technology (Caltech)	USA	Ph.D., Geology and Geophysics	the Richard P. Feynman Prize for teaching excellence at Caltech, the William Gilbert Award from the American Geophysical Union	20191004 to 20191023, 19	1) participation as principal investigator 2) presentation at the 8th International Conference on Magneto-Science
36	Kimberly Chen		Post-Doctorate Fellow, Biological Sciences, College of Sciences, Georgia Institute of Technology	USA	Ph.D.		20191004 to 20191023, 20	short-term stay for research meeting for a talk at a seminar
37	Erika Flores		Senior Intern, Jet Propulsion Laboratory(JPL), Caltech	USA	Graduate Student, Chemistry		20191005 to 20191018, 13	short-term stay for joint research

38	Makarova Kira		Staff Scientist, National Center for Biotechnology Information, National Institute of Health(NIH)	USA	Ph.D., Evolutionary Biology	CRISPR–Cas systems	20191005 to 20191018, 14	field work of sampling, short-term stay for joint research and attending at a workshop at ELSI
39	Renata M. M. Wentzcovitch		Professor of Material Science and Applied Physics, and Earth and Environmental Science, Columbia University	USA	Ph.D., Computational Materials Physics	fellow of APS, AGU, MSA, AAAS, and American Academy of Arts and Sciences	20191019 to 20191030, 11	short-term stay for research meeting and for a talk at a seminar
40	Philipp Heck		Associate Professor, Department of Geophysical Sciences, University of Chicago	USA	Ph.D., Cosmochemistry	Microanalysis Society Cosslett Award	20191019 to 20191030, 12	short-term stay for research meeting and a talk at a seminar and a conference
41	Anna Wang		Scientia Fellow, School of Chemistry, UNSW Sydney	Australia	Ph.D., Applied Physics	NASA Postdoctoral Program Fellow in Astrobiology	20191113 to 20191207, 25	short-term stay for research meeting and sample analysis
42	Selene Forget		Chemistry Department, Ecole Normale Superieure de Paris	France	Graduate student		20191114 to 20200331, 139	short-term stay for research meeting
43	Joseph Kirschvink	66	Nico and Marilyn Van Wingen Professor of Geobiology, Division of Geological and Planetary Sciences, California Institute of Technology (Caltech)	USA	Ph.D., Geology and Geophysics	the Richard P. Feynman Prize for teaching excellence at Caltech, the William Gilbert Award from the American Geophysical Union	20191124 to 20191203, 10	participation as principal investigator
44	Bruce Damer		Associate Researcher, Department of Biomolecular Engineering, University of California, Santa Cruz	USA	Ph.D., Biomolecular Engineering		20191212 to 20191214, 3	participation in the origins meeting, preparation of AAM workshop and a talk at ELSI seminar
45	Daniel Duzdevich		Research Fellow in Genetics, Massachusetts General Hospital, Harvard Univ.	USA	Ph.D., Molecular Biology		20200113 to 20200116, 4	participation in ELSI Assembly and research presentation at ELSI Colloquium, research meeting with Dr. Tony Z. Jia
46	Lewis Ward		Post-doctoral Fellow, The Johnston Group, Earth and Planetary Science, Harvard Univ.	USA	Ph.D., Earth & Planetary Science		20200115 to 20200213, 30	mid-term stay for research meeting, participation in the 8th ELSI International Symposium
47	Diogo Lourenco		Postdoctoral Researcher, University of California, Davis	USA	Ph.D.,		20200115 to 20200312, 58	mid-term stay for research meeting and for a talk at ELSI seminar, participation in the 8th ELSI International Symposium

48	Georgia Gamble		MS Graduate, Deakin University	Australia			20200120 to 20200229, 41	mid-term stay for joint research and meeting
49	Joseph Kirschvink	66	Nico and Marilyn Van Wingen Professor of Geobiology, Division of Geological and Planetary Sciences, California Institute of Technology (Caltech)	USA	Ph.D., Geology and Geophysics	the Richard P. Feynman Prize for teaching excellence at Caltech, the William Gilbert Award from the American Geophysical Union	20200124 to 20200202, 10	participation as principal investigator
50	Mario Galarreta		SIY Certified Teacher, Search Inside Yourself Leadership Institute	USA	Ph.D., Neuroscience		20200124 to 20200202, 9	short-term stay for meeting and for a talk at a seminar
51	Keyron Hickman-Lewis		Researcher, CNRS Centre de Biophysique Moleculaire, Orleans	France	Ph.D.,		20200125 to 20200209, 16	short-term stay for research meeting with ELSI scientists and participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
52	Joseph Kirschvink	66	Nico and Marilyn Van Wingen Professor of Geobiology, Division of Geological and Planetary Sciences, California Institute of Technology (Caltech)	USA	Ph.D., Geology and Geophysics	the Richard P. Feynman Prize for teaching excellence at Caltech, the William Gilbert Award from the American Geophysical Union	20200127 to 20200208, 13	participation as principal investigator
53	Aaron Gronstal		graphic artist and communications specialist, NASA Astrobiology Integration Office	USA	Ph.D., Geomicrobiology		20200129 to 20200213, 16	participation in ELSI's Early Carrer Researcher Day and International Symposium
54	Petar Penev		PhD Student, Georgia Institute of Technology	USA			20200131 to 20200208, 9	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation, research meeting
55	Anton Petrov		Research Scientist, Chemistry and Biochemistry, Georgia Institute of Technology	USA	Ph.D., Physical Chemistry	Co-PI of Computational Grant: “RNA-Magnesium Assembly” NASA Advanced Supercomputing (NAS) Division, NASA	20200131 to 20200211, 12	short-term stay for research meeting
56	Carmen Gaina		Director, the Centre for Earth Evolution and Dynamics (CEED), University of Oslo	Norway	Ph.D., Geophysics	Elected Member of the Norwegian Academy of Science and Letters	20200201 to 20200208, 8	a talk at a conference as invited speaker of ELSI International Symposium
57	Toshiko Ichiye		Professor, William G. McGowan Chair in Chemistry, Georgetown University	USA	Ph.D., Biophysics		20200201 to 20200208, 8	a talk as invited speaker of the 8th ELSI International Symposium

58	Daniel Sullivan		Graduate Associate, School Of Earth and Space Exploration, Arizona State University	USA			20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
59	Kavita Matange		PhD Student, School of Chemistry and Biochemistry, Georgia Institute of Technology	USA	B.Sc., M.Sc.		20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
60	James Edward Herriman		PhD Student, Columbia University	USA			20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
61	Nan Jingbo		PhD Student, Institute of Deep sea science and engineering, Chinese Academy of Sciences	China			20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
62	Zhai Yuanyuan		PhD Student, Institute of Geology and Geophysics, Chinese Academy of Sciences	China			20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
63	Dylan Gagler		Graduate Student, School of Earth and Space Exploration, Arizona State University	USA			20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
64	Pilar Vergeli		Graduate Research Assistant, School of Earth and Space Exploration, Arizona State University	USA			20200201 to 20200208, 8	participation in ELSI's Early Carrer Researcher Day and International Symposium
65	Benjamin Carbonnier		Full Professor, Universite Paris-Est Creteil (UPEC)	France	Ph.D., Organic and Macromolecular Chemistry		20200201 to 20200209, 9	a talk at a talk as invited speaker of the 8th ELSI International Symposium
66	Shikha Dagar		Graduate Student, IISER Pune	India			20200201 to 20200209, 9	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation, research meeting
67	Susovan Sarkar		PhD Student, Department of Biology, IISER Pune	India			20200201 to 20200209, 9	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation, research meeting

68	Angel Mojarro		Graduate Student, Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology	USA			20200201 to 20200210, 10	participation in ELSI's Early Carrer Researcher Day and International Symposium, poster presentation
69	Tomas Veloz		Systemics Department Director/Postdoc, Institute of Philosophy and Complexity Sciences	Chile	Ph.D., Interdisciplinary Study	University of British Columbia Graduate Entrance Scholarship	20200201 to 20200217, 17	short-term stay for research discussion
70	Michael Toillion		Media Product Specialist, NASA Astrobiology Program	USA			20200201 to 20200223, 23	short-term stay to give technical service of internet distribution and recording at ELSI International Symposium
71	Jill McDermott		Assistant Professor, Department of Earth and Environmental Sciences, Lehigh University	USA	Ph.D., Chemical Oceanography		20200202 to 20200206, 5	a talk at a talk as invited speaker of the 8th ELSI International Symposium
72	Sheref Mansy		University of Trento/ University of Alberta	Canada	Ph.D., Chemistry	Simons Investigator	20200202 to 20200208, 7	a talk at a conference as invited speaker of ELSI International Symposium
73	Aljon Francis Koji Elegado		Researcher, The Marine Science Institute, University of the Philippines Diliman	Philippines	BS, Biology		20200202 to 20200208, 7	participation in ELSI's Early Carrer Researcher Day and International Symposium
74	Byunghwa Kang		Ph D Student, Department of Materials Science and Engineering, Pohang University of Science and Technology	Korea			20200202 to 20200208, 7	participation in ELSI's Early Carrer Researcher Day and International Symposium
75	Benedicte Menez		Institut de Physique du Globe de Paris, Universite Paris Diderot, CNRS	France	Ph.D., Geomicrobiology		20200202 to 20200209, 8	a talk as invited speaker of the 8th ELSI International Symposium
76	Joel Ager		Staff Scientist, Materials Sciences Division, Lawrence Berkeley National Laboratory	USA			20200203 to 20200208, 6	a talk at a conference as invited speaker of ELSI International Symposium
77	Yan Qiao		Institute of Chemistry, Chinese Academy of Sciences	China	Ph.D. Chemistry		20200203 to 20200208, 6	a talk as invited speaker of the 8th ELSI International Symposium

78	Hikaru Furukawa		PhD Student, School of Earth and Space Exploration, Arizona State University	USA			20200203 to 20200208, 6	participation in ELSI's Early Carrer Researcher Day and International Symposium
79	Jennifer Hoyal Cuthill		Postdoctoral Research Fellow, Institute of Analytics and Data Science (IADS), School of Life Sciences, University of Essex	UK	Ph.D., Evolutionary Biology		20200208 to 20200215, 8	short-term stay for research meeting
80	Hilairy Hartnett		Associate Professor, School of Earth & Space Exploration and School of Molecular Sciences, Arizona State University	USA	Ph.D., Oceanography	Visiting Fellow: Hanse Institute for Advanced Study (Hanse-Wissenschaftskolleg, Germany) NSF Faculty Early Career (CAREER) Development Award	20200210 to 20200214, 5	short-term stay for research meeting
81	Robert Szilagyi		Associate Professor, Department of Chemistry & Biochemistry, Montana State University	USA	Ph.D., Electronic Structure Theory, Coordination Chemistry, Bioinorganic	"Momentum" Grant (2015) , Hungarian Academy of Sciences Szent-Györgyi Call-Home fellowship (2014) , Hungarian Academy of Sciences, Nominated for Kavli Fellow (2011) Kavli Institute	20200217 to 20200221, 5	research presentation in a seminar and in a conference to ELSI scientists
82	Juan Perez-Mercader	73	Senior Research Fellow, Department of Earth and Planetary Sciences, Harvard University	USA	Ph.D., Physics	Elected Member of the International Academy of Astronautics and of the European Academy of Arts and Sciences	20200307 to 20200320, 14	short-term stay for meeting
83	Joseph Kirschvink	66	Nico and Marilyn Van Wingen Professor of Geobiology, Division of Geological and Planetary Sciences, California Institute of Technology (Caltech)	USA	Ph.D., Geology and Geophysics	the Richard P. Feynman Prize for teaching excellence at Caltech, the William Gilbert Award from the American Geophysical Union	20200311 to 20200326, 16	participation as principal investigator

Appendix 6 FY2019 State of Outreach Activities

* Fill in the numbers of activities and times held during FY2019 by each activity.
* Describe the outreach activities in the "6. Others" of Progress Report, including those stated below that warrant special mention.

Activities	FY2019 (number of activities, times held)
PR brochure, pamphlet	6
Lectures, seminars for general public	9
Teaching, experiments, training for elementary, secondary and high school students	2
Science café	1
Participating, exhibiting in events	4
Press releases	32
Others（science communication events）	10

* If there are any rows on activities the center didn't implement, delete that (those) row(s). If you have any activities other than the items stated above, fill in the space between parentheses after "Others" on the bottom with the name of those activities and state the numbers of activities and times held in the space on the right. A row of "Others" can be added, if needed.

Outreach Activities and Their Results

List the Center's outreach activities carried out in FY 2019 that have contributed to enhancing the brand or recognition of your Center and/or the brand of the overall WPI program, if any, and describe its concrete contents and effect in narrative style. (Where possible, indicate the results in concrete numbers.)

- To improve branding, graphics created specifically for SNS sites, Twitter, Facebook and LinkedIn, as a result of one branding image and consistent content production, the users increased by 60%
- ELSI Science Outreach Evaluation Framework was created and implemented at the FY2019 Annual Public Lecture. The framework aims to understand the ELSI's effect on public engagement. As a result, other WPI centres have expressed interest in adapting the framework.
- Workflow and strategy for Press Release was changed and as a result, FY2019 saw increase of almost 50% compared to FY2018.
- Science communication training for researchers and PIOs was held and as a result, many researchers show a keen interest in graphical abstracts, submitting their papers for a press release, and adding outreach as a component of their research proposals.

Appendix 7 FY 2019 List of Project's Media Coverage

* List and describe media coverage (e.g., articles published, programs aired) in FY2019.

	Date	Types of Media (e.g., newspaper, magazine, television)	Description
1	2019/4 Edition	Magazine Nikkei Science	Ultima Toure appeared -intoroducing a pypothesis on the formation of the Ultima Toure by Yasuhito Sekine
2	2019/4/11	Newspaper Nikkei Industrial News	Artificial cells that create proteine - an article based on a research paper by Yutetsu Kuruma
3	2019/4/14	Newspaper Sankei Newspaper	Getting to the origins of the solaer system from Asteroids - the article introduced Junko Kominami's calculation and comment relating to the formation of Ultima Toure Junko Kominami
5	2019/5/9	Newspaper Nikkei Industrial News	Microorganisms consume gas fields massively - an article based on a research paper by Alexis Gilbert, Naohiro Yoshira, Yuichiro Ueno et al.
8	2019/5/30	Newspaper Yomiuri Shimbun	A life on a satellite of the Saturn? - the article (in the section 'Science and Ecology') introduces Yasuhito Sekine et al.'s paper in 2015 in relation to an animation movie
9	2019/6/6	Newspaper Asahi Shimbun	An ocean on the extremely cold Pluto - the key is methane hydrate - an article based on a research paper by Yasuhito Sekine et al.
10	2019/6/6	Podcast (Internet Radio) Bilingual News	365. Special Issue: Kosuke Fujishima featured as a guest speaker
11	2019/6/14	Magazine Science	The origins of Saturn's rigns and moons. Cassini data constrain the age and history of the giant planet's rings (Insight) - An article written by Shigeru Ida
14	2019/9/30-10/3	Radio Bay FM	Love Our Bay - Yasuhito Sekine joined as the weekly guest speaker about Titan, Encerrados etc.
15	2019/10 Edition	Magazine Newton	Search for a trace of life on the satellaite of Saturn, Titan! -An article for which Yasuhito Sekine collaborated. In relation to NASA's Dragon Fly mission, Yasuhito Sekine comments on the possibility of finding a trace of life on Titan
16	2019/10 Edition	Magazine Bijutsu-Techo	What if we create an artwork in space? - In this special feature article, the art unit 'Me' proposesd various art plans in space and Yasuhito Sekine advised on them
17	2019/10/7	Book Asahi Shogakusei Shimbun	Great scientists in Japan - Kei Hirose is one of the featurerd scientists in this book targeted for school children.
18	2019/10/25	Newspaper (Online) Asahi Shimbun	Water of Mars was as salty as soya bean soup? Restoring ancient water quality - an article on a research paper by Yasuhito Sekine et al. (Articles on this paper were in many national, local and international media)
19	2019/11/4	Radio Bay FM	FM Festival 2019 - Future Lesson - Kosuke Fujishima spoke as one of the invited speakers (Talk with a brain scientist Kenichiro Mogi)
20	2019/11/10	TV NHK E-tele	Science ZERO - Japan's 'speciality', sample return The world first! To the exploration of the moon of the Mars - Hidenori Genda spoke in this program
21	2019/12/24-27(daily), 2020/1/9&17	Newspaper (Online) Nikkei Shimbun	U22 Lab visits -Hiroto Kawabata visited Kosuke Fujishima at ELSI and inverviewed him (series of six articles)
23	2020/1/30	Newspaper Yomiuri Chu-kousei Shimbun	Where is the extraterrestrical life? - An atricle for junior high and high school students on the talks by Yasuhito Sekine and Tomohiro Usui at the public lecture at Tokyo Tech in January 25
24	2020/2/20	Newspaper Mainichi Shimbun	Next exploration is to Mars 'Fobos' Jaxa launch in year 24 - In relation to the Jaxa's decision to a future mission, Hidenori Genda's resarch was mentioned
25	2020/2/24	Radio J-wave	J-WAVE special Tsuchiya Earthology - Shideru Ida was one of the guests speakers
26	2020/3/1	Newspaper Nikkei Shimbun	Earth Magnetism holds the key of the birth of life - Researches by Kei Hirose and Shigeru Ida and their comments were introduced