

World Premier International Research Center Initiative (WPI)

FY 2017 WPI Project Progress Report

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Research Center	Earth-Life Science Institute	Center Director	Kei Hirose

Common instructions:

* Unless otherwise specified, prepare this report from the timeline of 31 March 2018.

* So as to base this fiscal year's follow-up review on the "last" center project, please prepare this report from the perspective of the latest project plan.

* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.

* Please 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. Conducting research of the highest world level

In FY2017, ELSI members contributed to the publication of thematic issues in *Geoscience Frontiers* (titled "Frontiers in early Earth history and primordial life") and *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (titled "Re-conceptualizing the origins of life"), which illustrates ELSI is recognized as a leading institute in the study of the early Earth and the emergence of life on the Earth. New and original ideas, scenarios, theories, and technical advances that have been cultivated at ELSI over the past years were presented, such as messy chemistry.

The following are representative research topics and highlights that have advanced at ELSI in FY2017.

Compositional evolution of the Earth's core: PI Hirose, PI Hernlund, and PI Helffrich revealed that SiO₂ crystallization in the core is an alternative mechanism for core convection to thermal convection (Hirose et al., 2017 *Nature*; Hirose et al., 2017 *Science*).

Formation of Mars and its moons and JAXA's MMX mission: ELSI researchers published a series of papers that investigate the formation processes of the Martian moons, forming the foundation of scientific scenarios for the Mars Moon eXploration (MMX) mission led by ISAS/JAXA.

Computational chemistry: New computational concepts and methods have been developed in order to enable thorough examination of combinatorial complexity accompanied in chemical systems, such as prebiotic chemistry (Andersen et al. 2017 *Science*). EON hosted an international workshop, bringing together computational scientists and laboratory chemists to pioneer the cutting-edge developments in this area.

New mechanism for evolution: EON Postdoctoral Fellow Katie Petrie's group reported non-genetic variation that yields multiple functions with a single DNA sequence. This example of "messy" biology may represent a new mechanism for functional evolution of biomolecules in prebiotic chemistry (Petrie et al., 2018 *Science*).

Methodological development of assessing biogeochemical signatures: PI Yoshida and PI Ueno's team developed a new position-specific isotope analysis method and demonstrated that this can be applied to analyze the biotic/abiotic criteria of organic molecules, thus allowing more careful examination of evolutionary processes of biological systems (Suda et al., 2017).

2. Advancing fusion of various research fields

ELSI continues to provide a variety of opportunities including regular institutional seminars, discussion/reading groups, and ad hoc institutional strategic meetings to nurture and support interdisciplinary collaborative projects, and these efforts have promoted interactions and communications among researchers from different fields. One such project involves a microbiologist (Kameya, now assistant professor at the University of Tokyo), a planetary scientist (Laneuville), and a geochemist (Cleaves) and aims to build a global systems model to understand how nitrogen cycling would proceed on terrestrial planets with comparable geodynamic activity to the Earth, but on which life does not arise.

One of the above-mentioned strategic meetings was held in January 2017, yielding new ideas on

the origins of life study, and some discussions have developed into ongoing experiments. For instance, Katie Petrie (experimental evolution and synthetic biology) and George Helffrich (solid earth geophysics) organized a discussion group around the idea that mineral surfaces might play a role in guiding prebiotic chemistry toward organized systems of molecules rather than random, unstructured ones. Experiments are ongoing to see whether mineral surfaces might bind and “select” nucleic acids in a sequence-specific manner.

3. Establishing international research environment

Regardless of age, gender, nationality, or background, at ELSI researchers pursue original research and also actively engage in cross-disciplinary discussions and synergistic research projects in the open and flat research organization. Our institute continues to attract more talent to it in the form of either new members or visitors, and as the number of researchers who work at or visit ELSI to interact with our scientists increases, the more widely recognized ELSI’s truly integrative environment becomes. The EON project contributed enormously to ELSI’s growing visibility through their postdoc program and a number of high-quality international workshops. Foreign researchers now account for around 51 percent of all ELSI researchers. ELSI took new steps to boost research interactions and international recognition in FY2017. The first winter school targeting graduate students was held, and science communication in English between students and researchers was also enhanced.

4. Reforming the research organization

ELSI has been having a significant impact on the system reform of Tokyo Institute of Technology (Tokyo Tech), which includes ELSI’s top-down management, open and flat research environment, and introduction of the cross-appointment system. For example, Tokyo Tech has established the “Tokyo Tech World Research Hub Initiative (WRHI)” by reorganizing the existing research institutes and centers. WRHI uses ELSI as a model, equipped with an open communication space, and is promoting interdisciplinary research by inviting top-level scientists from all over the world.

Tokyo Tech is also increasing its support for foreign researchers by providing a consultation desk on contract issues and mental counseling in English.

5. Efforts to secure the center’s future development over the mid- to long-term

New members were appointed as PI (Ryuhei Nakamura, electrochemistry and mineral catalysis), A-PI, or Research Scientist based on strategic personnel decisions. In addition to new hires, enhancing human resource development is the primary focus of ELSI’s leadership. ELSI continues to provide early-career researchers with various forms of support, including assistance in obtaining competitive funds and a mentoring system for their career development. Activities in recruiting and training graduate students were boosted by holding a winter school at ELSI in January-February 2018. These efforts to nurture younger generations are critical to achieve ELSI’s missions, expand ELSI’s global network, and raise the level of the whole research community.

ELSI has established a new Satellite Center in the Department of Earth and Planetary Science (EPS) at the University of Tokyo (EPS/U.Tokyo) in April 2017, and Director Hirose himself has been leading its launch. ELSI and EPS/U.Tokyo have complementary expertise and strength in pursuing the study of the formation, evolution, and habitability of planets in solar and extrasolar systems, and the study of geology, geochemistry, and life on the early Earth. Exchange visits are facilitated by the geographical proximity of the two institutes. Our collaborations were further accelerated by the acquisition of a large collaborative Kakenhi (MEXT Grant-in-Aid for Scientific Research on Innovative Areas “Aqua Planetology”) for FY2017-FY2021, securing the progress of the initiated collaborations.

ELSI is clearly mentioned in the mid-term goals and plans of Tokyo Tech in its section for “Research Goals”. Tokyo Tech ensures that ELSI will continue to be an international top-level research center after the WPI subsidy ends by providing funding, research spaces and support for foreign researchers. In 2018, two new tenured positions will be assigned to ELSI.

In March 2018, Tokyo Tech was awarded the Designated National University status. In the proposed plan, ELSI is given a position to lead international research activities at Tokyo Tech and will therefore be assured strong support from Tokyo Tech.

In 2017, Tokyo Tech established the non-profit organization “Tokyo Tech USA” in the US. The organization has started activities to obtain donations from companies, institutions and funding agencies in the US that will support the research activities of Tokyo Tech.

Please describe clearly and concisely the progress being made by the WPI center project from the viewpoints below.

- In addressing the below-listed 1-6 criteria, please 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 fusing fields).
- (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. Conducting research of the highest world level

* Regarding the criteria used when evaluating the world level of center, please note any updated results using your previous evaluation criteria and methods or any improvements you have made to those criteria and methods.

Throughout FY2017, ELSI PIs and researchers successfully disseminated research findings, defined and proposed conceptual frameworks, developed advanced methodologies, and secured competitive funds. From these achievements, ELSI is undoubtedly placed as the world-leading institute. Following are representative research topics and highlights that have advanced in FY2017.

[Chemical and thermal evolution of the Earth]

PI Hirose's group revealed the high thermal conductivity in the Earth's core (Gomi et al., 2013 PEPI; Ohta et al., 2016 Nature), which indicates that it is difficult to sustain the geodynamo by thermal convection since early Earth. The team performed crystallization experiments on alloy liquids Fe-Si-O at core pressures, and through numerical model simulations, PI Hernlund and PI Helffrich revealed that SiO₂ crystallization in the core is an alternative mechanism for core convection (Hirose et al., 2017 Nature). The SiO₂ crystallization is a natural consequence of metal (core) – silicate (mantle) separation at high temperatures, and considerable amounts of silicon and oxygen are dissolved into metal at high temperatures and then exsolved as SiO₂ upon secular cooling. SiO₂ crystallization proposed by Hirose et al. (2017) was followed up by a couple of papers, which argued its further consequences. The SiO₂ crystallization not only has played a key role in generating core dynamo and geomagnetic field but also produced mid-lower mantle seismic scatterers (Helffrich et al., 2018). PI Hirose's group has been working on the melting experiments on Fe binary systems such as Fe-Si (Ozawa et al., 2016 EPSL) and Fe-S (Mori et al., 2017 EPSL). The team started to examine more diverse combinations of Fe binary alloys in order to constrain the possible compositional range of trace elements in the core as well as the Earth's accretion scenario including the timing of water delivery.

The progress and discussion at ELSI during the first five years converged on "magma ocean" processes as a point of focus, and ELSI researchers aim to understand how the magma ocean phase connects early formation/differentiation processes of the Earth to conditions when life emerged. PI Hernlund started a discussion group "Magma Oceans" in FY2017 to exchange ideas and initiate new collaborative projects around this theme. The magma ocean phase is followed by the core-mantle separation, and understanding this complex phenomenon is the major goal of a large KAKENHI grant "Interaction and Coevolution of the Core and Mantle – Towards Integrated Deep Earth Science (MEXT Grant-in-Aid for Scientific Research on Innovative Areas)," which is led by Prof. Taku Tsuchiya, affiliated researcher to ELSI at the Ehime Satellite in the Geodynamics Research Center (GRC), Ehime University. Collaboration between ELSI and the Ehime Satellite has been reinforced by this grant, and in FY2017, ELSI and GRC co-hosted an international workshop, "Crust to Core 2017." The workshop was built on discussion that began during the "First Crust Aftershop" following the 5th ELSI International Symposium in January 2017 and explored issues regarding how the early planetary crusts evolved from a dynamical and seismological perspective in terms of what we can model and what we can observe today.

- Helffrich G, Ballmer MD, Hirose K. Core-Exsolved SiO₂ Dispersal in the Earth's Mantle. *Journal of Geophysical Research-Solid Earth*. 2018;123(1):176-88.
- Hirose K, Morard G, Sinmyo R, Umemoto K, Hernlund J, Helffrich G, et al. Crystallization of silicon dioxide and compositional evolution of the Earth's core. *Nature*. 2017;543(7643):99-.
- Mori Y, Ozawa H, Hirose K, Sinmyo R, Tateno S, Morard G, et al. Melting experiments on Fe-Fe₃S system to 254 GPa. *Earth and Planetary Science Letters*. 2017;464:135-41.

[Impact processes during planet formation]

Collisions are ubiquitous in the solar system and have been one of the major research interests at ELSI and the new Satellite Center in the Department of Earth and Planetary Science, the University of Tokyo (EPS/U.Tokyo). A-PI Hidenori Genda's group developed an impact erosion model during

planet formation (Genda et al., 2017), which can be used in many N-body simulations. Collaborative project between ELSI and the EPS/U.Tokyo Satellite revealed that the dark and reddish area found on Pluto by New Horizons corroborates Charon-forming giant impact (Sekine et al., 2017).

A-PI Genda, Research Scientist Brassler, and colleagues investigated the Earth's late veneer impact and found that materials added at the very last stage of Earth formation contained metallic iron (Genda et al., 2017), which should drastically change the Earth's surface environment to very reduced conditions. Reduced conditions are more reactive and favorable for the emergence of life.

A-PI Genda will be promoted to a tenured A-PI from April 2018, and Associate Professor Yasuhito Sekine in the EPS/U.Tokyo will join ELSI early in FY2018 as PI. Genda and Sekine will lead the study into impact processes through synergistic interactions with other ELSI members.

- Genda H, Brassler R, Mojzsis SJ. The terrestrial late veneer from core disruption of a lunar-sized impactor. *Earth and Planetary Science Letters*. 2017;480:25-32.
- Genda H, Fujita T, Kobayashi H, Tanaka H, Suetsugu R, Abe Y. Impact erosion model for gravity-dominated planetesimals. *Icarus*. 2017;294:234-46.
- Genda H, Iizuka T, Sasaki T, Ueno Y, Ikoma M. Ejection of iron-bearing giant-impact fragments and the dynamical and geochemical influence of the fragment re-accretion. *Earth and Planetary Science Letters*. 2017;470:87-95.
- Matsumura S, Brassler R, Ida S. N-body simulations of planet formation via pebble accretion I. First results. *Astronomy & Astrophysics*. 2017;607:20.
- Sekine Y, Genda H, Kamata S, Funatsu T. The Charon-forming giant impact as a source of Pluto's dark equatorial regions. *Nature Astronomy*. 2017;1(2):6.
- Shibaike Y, Okuzumi S, Sasaki T, Ida S. Satellitesimal Formation via Collisional Dust Growth in Steady Circumplanetary Disks. *Astrophysical Journal*. 2017;846(1):10.

[Formation of Mars and its moons and JAXA's MMX mission]

PI Ida and Research Scientist Brassler show that the nucleosynthetic isotopic differences between Earth and Mars indicate that the latter should have formed in the asteroid belt. This work successfully combined cosmochemistry and N-body simulations to gain a deeper understanding of how the terrestrial planets formed.

ELSI is responsible for forming the foundation of scientific scenarios for the Mars Moon (Phobos/Deimos) eXploration (MMX) mission led by ISAS/JAXA. The MMX mission combines the exploration and sampling of Mars satellites like Phobos and Deimos (i.e. the Phobos/Deimos mission) with our knowledge from material evidences, which will help advance comparative satellite studies and understanding towards the origin and evolution of Mars itself. In FY2017, ELSI researchers continued their investigations into the formation processes of the Martian moons and published a series of papers. These findings enable making predictions to refine the targets of the MMX mission, and ELSI is clearly the world-leading institute in this research field.

- Brassler R, Mojzsis SJ, Matsumura S, Ida S. The cool and distant formation of Mars. *Earth and Planetary Science Letters*. 2017;468:85-93.
- Brassler R, Mojzsis SJ. A colossal impact enriched Mars' mantle with noble metals. *Geophysical Research Letters*. 2017;44(12):5978-85.
- Hyodo R, Genda H, Charnoz S, Rosenblatt P. On the Impact Origin of Phobos and Deimos. I. Thermodynamic and Physical Aspects. *Astrophysical Journal*. 2017;845(2):8.
- Hyodo R, Rosenblatt P, Genda H, Charnoz S. On the Impact Origin of Phobos and Deimos. II. True Polar Wander and Disk Evolution. *Astrophysical Journal*. 2017;851(2):9.

[Frontiers in early Earth history and primordial life]

PI Shigenori Maruyama assembled two special issues of "Geoscience Frontiers" entitled "Frontiers in Early Earth History and Primordial Life," where ELSI researchers made state-of-the-art contributions that provide insights into planetary formation, Earth's early history and primordial life. These achievements have been strongly promoted by the MEXT Kakenhi, Scientific Research on Innovative Areas "Hadean Bioscience," which started in FY2014 and is led by ELSI Fellow Ken Kurokawa. ELSI and the Hadean Bioscience project hosted an international workshop "Reconstructing the Phenomenon of Life -To Retrace the Emergence of Life -" in May 2017 (Appendix 3-1). PI Jack Szostak (Harvard Satellite) and Prof. David Deamer gave keynote presentations, and

the participants and Hadean Bioscience team members held intense discussions regarding the model for the emergence of first life and future directions in this field. Based on the latest research findings and highlights from the Hadean Bioscience project, a documentary “The Whole History of the Earth and Life” was published (<https://www.youtube.com/channel/UCCToEEPIF7ur1m0efQTHG4g>). This consists of a series of videos that portrays the birth of the solar system, the birth of the Earth, and the emergence and evolution of life on Earth in a plain way. To target broad audiences, both Japanese and English versions are available.

- Maruyama S, Santosh M. *Frontiers in early Earth history and primordial life - Part I. Geoscience Frontiers*. 2017;8(2):211-3.

[Re-conceptualizing the origins of life]

A theme issue entitled “Re-conceptualizing the Origins of Life” appeared in *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, where ELSI researchers present their current thinking and latest results in studies into the origins of life. Six out of eighteen articles were contributed by ELSI researchers, illustrating that ELSI is leading the field of the origins of life study. In this special issue, PI Mamajanov published two articles both centered around the idea of messy chemistry that is being developing at ELSI. The “messy chemistry” theory can be briefly described as evolving complexity. Prebiotic reaction network may have started as a complex system that changed and evolved under environmental or inherent selective pressures into a complex system that is modern biochemistry. As a part of this effort, PI Mamajanov analyzed the selective pressures provided by wet/dry cycling and the functionality of messy polymers; Research Scientist Nathaniel Virgo studied autocatalysis and selectivity in artificial chemistry systems, which will be tested in long term prebiotic polymerization experiments.

- Adam ZR, Zubarev D, Aono M, Cleaves HJ. Subsumed complexity: abiogenesis as a by-product of complex energy transduction. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):12.
- Andersen JL, Flamm C, Merkle D, Stadler PF. An intermediate level of abstraction for computational systems chemistry. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):10.
- Guttenberg N, Virgo N, Chandru K, Scharf C, Mamajanov I. Bulk measurements of messy chemistries are needed for a theory of the origins of life. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):6.
- Kacar B, Guy L, Smith E, Baross J. Resurrecting ancestral genes in bacteria to interpret ancient biosignatures. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):17.
- Mamajanov I, Cody GD. Protoenzymes: the case of hyperbranched polyesters. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):10.
- Meringer M, Cleaves HJ. Exploring astrobiology using in silico molecular structure generation. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):12.

[Computational chemistry]

A central question about the origin of life is whether its metabolic pathways are likely to reflect accidents from ancient molecular evolution, or instead are unique responses to chemical stresses on a young planet, which could have been conserved from early geochemistry into present life. In order to answer this question, it is necessary to assemble knowledge about many reaction mechanisms into networks of all possible synthetic chemistry that can result, and to analyze these networks for properties that make biochemistry special. The combinatorial complexity in a problem of this kind requires new computational concepts and methods.

ELSI PI Eric Smith and Research Scientist James Cleaves worked to develop an EON program on computational chemistry, including EON Postdoctoral Fellow Jakob Andersen, and colleagues who are world leaders in process-based methods at U. Southern Denmark and U. Vienna, and in molecular state-space modeling at the German Aerospace Center in Bavaria. The work by Andersen et al. (2017) advanced the state of the art in graph-grammar generation of networks to include molecular stereochemistry, which will soon be extended to enable modeling of catalytic metal centers.

Smith, Andersen, and Cleaves directed a workshop in 2017 "Computational Chemistry: from Components to Systems and Back", which was the first of its kind to bring together leading workers in network and other discrete methods with quantum and dynamical systems modeling approaches, machine learning, and the incorporation of chemical big-databases, jointly with laboratory chemists studying the emergence of cyclic pathways in realistic small-molecule chemistry. These modeling efforts are synergistic with ELSI's newly initiated efforts in electrochemistry and mineral catalysis. PI Ryuhei Nakamura and Research Scientists Yamei Li and Kristin Johnson joined ELSI in FY2017 with their expertise in these areas.

- Andersen JL, Flamm C, Merkle D, Stadler PF. An intermediate level of abstraction for computational systems chemistry. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):10.

[The theory of stochastic chemical reaction networks]

Chemical reaction systems of the size and complexity that can be generated with modern computational methods are still too large to search exhaustively for dynamical features (including life-like features) of interest. Therefore a leading problem in the analysis of chemical reaction systems is to constrain or predict dynamical properties from topological characteristics of networks, which can be searched and identified more efficiently.

In two papers in 2017, PI Eric Smith derived new relations between topology and fluctuation moments in stochastic chemical reactions, extending classical theorems from the 1970s for deterministic systems into the domain of small molecule numbers relevant to studies of both cellular biochemistry and possibly small reaction environments in early geochemistry. These results pave the way for general relations between dynamics and statistical inference about reaction systems, and also for a variety of problems in population statistics with a similar mathematical structure.

- Krishnamurthy S, Smith E. Solving moment hierarchies for chemical reaction networks. *Journal of Physics a-Mathematical and Theoretical*. 2017;50(42):15.
- Smith E, Krishnamurthy S. Flows, scaling, and the control of moment hierarchies for stochastic chemical reaction networks. *Physical Review E*. 2017;96(6):29.

[Paleoenzymology]

A strength of ELSI's work on early molecular biology is in the biochemistry of early carbon-fixing enzymes. This has included the work by Research Scientist Masafumi Kameya (now assistant professor at the University of Tokyo) on the enzymes of the reductive Citric Acid Cycle for carbon fixation, and by ELSI A-PI Betül Kacar (Harvard Satellite) on enzymes in the Calvin cycle.

Kacar et al. (2017) highlights her work on the enzymes RuBisCO and Carbonic Anhydrase, describes the criteria for model organisms and model proteins that make the resurrection of ancient proteins inferred from bioinformatic methods most informative about the physiologies and evolutionary potentials of the earliest forms of life. PI Smith is engaged in ongoing work with EON postdoctoral fellow Donato Giovannelli and colleagues at Rutgers University, Stanford University, and Georgia Tech to develop genetic systems and model organisms from the Epsilonproteobacteria, which can serve as hosts for reconstructed proteins from ancient carbon fixation and bioenergetic pathways including those studied at ELSI.

- Kacar B, Guy L, Smith E, Baross J. Resurrecting ancestral genes in bacteria to interpret ancient biosignatures. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):17.

[New mechanism for evolution]

EON Postdoctoral Fellow Katie Petrie and colleagues reported their discovery of an unexpected mechanism for evolutionary innovation. This new mechanism expands our understanding of how evolution occurs today, and how it might have occurred during the origin of life.

The new mechanism violates the 'one-sequence, one-structure' dogma of molecular biology: instead of a DNA sequence which is translated into a polypeptide that adopts a single, stable protein fold with a particular function, we discovered a DNA sequence that produces a polypeptide which probabilistically folds into two different proteins, each with different functions. This DNA sequence was from a model organism undergoing an evolutionary transition - it is capable of a new, innovative

function, but because it makes two versions of the protein, it maintains its ability to carry out the old function, solving a key dilemma often faced in explaining the origin of evolutionary novelty.

Even though this discovery was made in a modern organism, the mechanism of using non-genetic variation to explore multiple functions with a single sequence may be especially important for the first biomolecules of life, which were likely constrained in their length and complexity. This example of 'messy' biology, where there is an imperfect sequence-function relationship, illustrates how 'messiness' - the mistakes and side-products that are often considered a problem to be solved in prebiotic chemistry - may actually be an opportunity to exploit.

- Petrie KL, Palmer ND, Johnson DT, Medina SJ, Yan SJ, Li V, et al. Destabilizing mutations encode nongenetic variation that drives evolutionary innovation. *Science*. 2018;359(6383):1542-5.

[Methodological development for the assessment of biogeochemical signatures]

PI Naohiro Yoshida and PI Yuichiro Ueno are leading a team to develop position-specific isotope analysis (PSIA) of inorganic/organic molecules of biogeochemical interests. ELSI members apply PSIA to study biogeochemical signatures in their studies into the origin and evolution of the Earth and life. The team has been working on C₂ and C₃ compounds and their site specific ¹³C distribution. These ongoing work will set a new stage for the biotic/abiotic criteria of organic metabolites and the evolution of biological systems. Suda et al. (2017) already applied this approach to abiogenic hydrocarbons produced in the hot spring and reported promising results. In FY2017, PI Yoshida secured a Grant-in-Aid for Scientific Research, Kakenhi, (S) for the coming five years to advance the isotopologue origin analysis vigorously.

- Suda K, Gilbert A, Yamada K, Yoshida N, Ueno Y. Compound- and position-specific carbon isotopic signatures of abiogenic hydrocarbons from on-land serpentinite-hosted Hakuba Happo hot spring in Japan. *Geochimica et Cosmochimica Acta*. 2017;206:201-15.

2. Advancing fusion of various research fields

Since its launch, ELSI has provided various opportunities to initiate and carry out interdisciplinary collaborations among researchers with different backgrounds and cultures. These efforts include discussion/reading groups, institutional seminars and meetings, as well as social gatherings to open up conversation more casually.

Given below are examples of interdisciplinary studies at ELSI that explore key features during the transition from geochemistry to biochemistry. ELSI Research Scientist Matthieu Laneuville presented the earlier version of his ideas at the Site Visit in 2016, and his collaborative project with other ELSI researchers started to bear fruit. The second project has originated from the ELSI All-Hands Institutional Strategy Meeting, which was held in January 2017. Promoting interdisciplinary collaborations is a long and challenging process; however, ELSI researchers have been pushing this forward steadily. ELSI will continue to provide strategic support for their successful collaborations.

[Earth without life: A systems model of a global abiotic nitrogen cycle]

Nitrogen is the major component of Earth's atmosphere and plays important roles in biochemistry. Biological systems have evolved a variety of mechanisms for fixing and recycling environmental nitrogen sources, which links them tightly with terrestrial nitrogen reservoirs. However, prior to the emergence of biology, all nitrogen cycling was abiological and this cycling may have set the stage for the origin of life.

To study this, a microbiologist (Kameya, now assistant professor at the University of Tokyo), a planetary scientist (Laneuville), and a geochemist (Cleaves) came together to build a global systems model to understand how nitrogen cycling would proceed on terrestrial planets with comparable geodynamic activity to the Earth, but on which life does not arise. We constructed a kinetic mass-flux model of nitrogen cycling in its various major chemical forms (e.g., N₂, reduced (NH_x) and oxidized (NO_x) species) between major planetary reservoirs (the atmosphere, oceans, crust and mantle), and including inputs from space. The total amount of nitrogen species which can be accommodated in each reservoir and the ways fluxes and reservoir sizes may have changed over

time in the absence of biology were explored. Given a partition of volcanism between arc and hotspot types similar to the modern ones, our global nitrogen cycling model predicts a significant increase in oceanic nitrogen content over time, mostly as NH_x, while atmospheric N₂ content could be lower than today. The transport timescales between reservoirs are fast compared to the evolution of the environment, thus atmospheric composition is tightly linked to surface and interior processes.

- Laneuville M, Kameya M, and Cleaves HJ (2018) Earth without life: A systems model of a global abiotic nitrogen cycle. *Astrobiology* <http://doi.org/10.1089/ast.2017.1700>

[Role of early-Earth minerals in prebiotic polymer evolution]

An idea emerged out of a brainstorming workshop that ELSI organized in early 2017: that mineral surfaces might play a role in guiding prebiotic chemistry towards organized systems of molecules rather than random, unstructured ones. Katie Petrie (experimental evolution and synthetic biology) and George Helffrich (solid earth geophysics) organized a discussion group around this theme, culminating in an experiment to see whether mineral surfaces might bind and 'select' nucleic acids in a sequence-specific manner. They made a library of short DNA molecules with every possible permutation of the 4 bases, and incubated it with minerals to see if some sequences were more likely to bind than others. The minerals produced by rock-forming reactions change with time as the ambient planetary conditions change, so a variety of rocks need to be tested as the preferred sequence type could vary. However, there are many individual mineral types comprising any given rock, so screening several minerals at once is relatively easy. The first round of experiments on serpentine are awaiting detailed analysis.

3. Establishing 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; number and state of visiting researchers; exchanges with overseas entities
- Proactive efforts to raise the level of the center's international recognition
- Efforts to make the center into one that attracts excellent young researchers from around the world (such as efforts fostering young researchers and contributing to advancing their career paths)

(1) Efforts being developed based on the analysis of number and state of world-leading, frontline researchers; number and state of visiting researchers; exchanges with overseas entities

15 ELSI principal investigators are all world-leading experts in their own research fields and are leading and developing interdisciplinary collaborations at ELSI and with other researchers worldwide. In FY2017, ELSI Director Hirose and PI Irifune (Ehime Satellite) were elected for Japan Geoscience Union (JpGU) Fellow, and PI Helffrich was elected as a Fellow of the American Geophysical Union (AGU) as listed in Appendix 1.

To advance ELSI's scientific goals to study the origin and evolution of planets and life, ELSI appointed 12 researchers in FY2017, and 5 of them are of foreign nationality.

Research interactions at academic conferences in and outside of ELSI serve as good opportunities to showcase ELSI's research activities and raise its profile worldwide. ELSI researchers of all career stages are very active in attending international conferences, convening conference sessions, delivering invited or keynote presentations (Appendix 1), attracting more interest as well as many prominent visitors to ELSI (Appendix 5). In addition, the EON project postdoctoral fellows working at both ELSI and affiliated overseas institutes and carrying out joint researches have contributed to the growth of ELSI/EON's research network. The ELSI/EON was involved in hosting ten academic meetings in FY2017 (Appendix 3-1). PI Szostak, Prof. Deamer, Prof. Chen, and Prof. Rajamani gave keynote lectures at the International Workshop held at ELSI "Reconstructing the Phenomenon of Life -To Retrace the Emergence of Life -," and active discussions were held among participants about the hierarchical dynamics in life and a universal principle that is common to life. Under the initiative of Vice Director Hernlund, ELSI has been sponsoring major international conferences on research topics relevant to ELSI's scientific mission, which has contributed significantly to the growing visibility.

(2) Proactive efforts to raise the level of the center's international recognition

In order to achieve ELSI's mission of scientific leadership and globalization, it is vital for us to disseminate ELSI's research activities and the WPI program goals to global audience. ELSI thus is committed to fostering English-language science communication and outreach in Japan. For example it will host and support the Japan SciCom Forum 2018, which will be held in April 2018. Japan Scicom Forum is a scheme to bring together communicators, writers, scientists, and journalists from abroad to network, learn new skills, and bring new energy to the science communication community in Japan. When news of the research carried out in Japan can be communicated more effectively to the world, not only ELSI but the whole national science community will benefit.

In addition to the efforts described above, the public relations office has been preparing to enhance ELSI's website in the coming years for more effective communication to various targets including prospective students and both domestic and international donors. ELSI hosted a science journalist as a long-term visitor, and interviews he made with many ELSI researchers combined with pictures taken by ELSI's in-house graphics specialist crystallized into a book form, which was entitled "ELSI RISING" and was distributed at the 6th ELSI International Symposium.

(3) 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)

Through ELSI's growing visibility and reputation and the public relations efforts to advertise, 74% of the applicants in the most recent recruitment of ELSI Research Scientists were non-Japanese. As of the end of the 2017 academic year (Appendix 3-1), foreign researchers account for 51 percent of the researchers at ELSI, and 8 out of 15 principle investigators are non-Japanese. ELSI is not just seen as an attractive career path to early-career researchers, but ELSI researchers are successful in building their career. Three young ELSI researchers took up new positions as associate/assistant professor or research scientist in FY2017. In order to maintain and raise career development success, a mentoring system was introduced in FY2016. This system continued in FY2017 with further improvement to ensure constructive relationships between mentors and early-career researchers.

(4) Others

ELSI continues to provide strong day-to-day support to foreign researchers. University research administrators with rich experience in assisting applications and implementation of research funding have supported researchers, and more researchers of foreign nationality are successful in obtaining competitive research funding. Bilingual life advisor and secretaries are also essential in supporting foreign researchers and their families in a variety of ways, ranging from administrative support to language support in daily life.

4. Reforming the research organization

* 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.

* Please describe the center's operation and the host institution's commitment to the system reforms.

(1) Top-down decision-making

A system has been set up so that the Director of ELSI makes decisions about the Institute's management and operations, including personnel and budget implementation. At Tokyo Tech, ELSI has been designated as a strategic research hub: a pioneering institute of research reform specially approved and led by the President. Tokyo Tech is promoting the university's reform, aiming to spread across disciplinary boundaries, and carrying out its own internationally top-class science to strengthen the university's research capabilities and create a research center similar to ELSI.

(2) Enhancement of a "global research hub" to conduct international research activities

Tokyo Tech has implemented institute-wide research reforms. It founded the Institute of Innovative Research (IIR) by consolidating four affiliated laboratories and other research centers in April 2016, establishing a leading organization in cutting-edge science and technology. In addition, the Tokyo Tech World Research Hub Initiative (WRHI) was established within IIR as an organization to promote worldwide interaction among top international researchers in different fields, and will serve as a world research hub that strives to produce innovative scientific technology. WRHI invites

excellent researchers from overseas to conduct joint research with IIR's researchers and engage in cross-disciplinary interactions.

The IIR and WRHI are promoting interdisciplinary exchanges and carrying out integrated research by establishing open communication spaces and inviting the finest foreign researchers.

(3) System reforms for international research efforts

The reforms that ELSI has adopted to promote internationally competitive research and attract outstanding researchers from around the world — including a merit-based salary system, the provision of incentives based on performance appraisals, making English the common language, and a full range of support for foreign researchers — have given significant impacts on Tokyo Tech's reforms.

- New personnel system

Tokyo Tech is introducing a cross-appointment system and a merit-based salary system, which have been adopted for the first time at ELSI. It has also expanded the rules for evaluating and appropriately reflecting the performance of faculty members often dictated previously by the seniority system to the whole university.

- English language support

English is used as the common language at ELSI, and notices of Tokyo Tech addressed to all university staff are now made in both English and Japanese. Tokyo Tech set up an assistance service on general campus affairs in FY2016, providing full-time staff that could handle inquiries in English by phone, email, or in person.

In 2017, an English-language counseling service was initiated.

- Expanded lodging facilities

Lodging facilities for foreign researchers have been provided in the Tokyo Tech 80th Anniversary Hall so far, and in 2017, Senzokuike House and Midorigaoka House were newly opened. In 2018, the Minami-shinagawa House will be opened.

5. Efforts to secure the center's future development over the mid- to long-term

* Please 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 the 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 the fostering and securing of next-generation researchers

(1) Research plan

The research goals and scopes set out in the revised WPI center project were explored in more detail and expanded at topical meetings and workshops held at ELSI (Appendix 3-1). These are valuable opportunities to incorporate new ideas and skills from outside experts into ELSI's own improvement. Within ELSI, the ELSI Assembly series started from March 2017 and is a regular event for ELSI researchers to present their latest findings and research progress, and to exchange ideas with colleagues. ELSI continues to hold this series in FY2018 to bring members together and achieve ELSI's long-term missions. Securing a large amount of research funding is essential to substantiate ELSI's new and original ideas into solid research projects and to sustain vigorous research activities. ELSI researchers have been successful in obtaining competitive grants. For instance, PI Shawn McGlynn succeeded in acquiring a collaborative NSF grant (2017 Origin of Life – A Joint Ideas Lab Activity Between NSF and NASA, NSF 16-570, USD 2.25 million to five PIs). This project combines geochemistry, microbiology, and isotope analysis and aims to obtain a synthetic view of ancient sulfur metabolism and its implication on the early evolution of life. Another success is described

below.

[New collaborative project started to explore the existence of life beyond Earth]

MEXT Kakenhi, Scientific Research on Innovative Areas “Aqua planetology” has started under the initiative of Prof. Yasuhito Sekine (EPS/U.Tokyo Satellite; he will join ELSI as PI in FY2018). This project aims to explore the possibility of the existence of life beyond Earth and integrates two approaches: one is to develop a theory of water and material cycles on solar system bodies, and the other is to verify this theory based on observations and analyses of samples collected by the sample-return mission of Hayabusa2. The project is made of a diverse team of theorists and experimentalists in geoscience and planetary science, soliciting interdisciplinary collaborative efforts. Their specific goals are 1) to elucidate water and material cycles in planetesimals in order to understand the determining factor of the amount of water on Earth and 2) to constrain the evolution of aquatic environments on both Mars and icy moons and to predict biospheres based on the energy theory.

(2) Research organization

A monthly ELSI Faculty meeting started in FY2017, and full-time PIs and A-PIs discuss various important issues at ELSI and support the Director’s decisions for strategic development of ELSI.

As a global research hub, it is important for ELSI’s strategic development to establish Satellite Centers at key institutes and to form firm relationships with them. In April 2017, ELSI launched a new Satellite Center at the Department of Earth and Planetary Science (EPS) at the University of Tokyo (EPS/U.Tokyo). Director Hirose promotes his own research on the formation and early evolution of our planet in collaboration with experts in geochemistry and thermal evolution modeling at the EPS/U.Tokyo, and leads collaborative research between ELSI and EPS/U.Tokyo. The EPS/U.Tokyo has strong research groups in astrobiology, planetary science, solar system exploration, early Earth geochemistry, and the evolution of life. Importantly, their research is complementary to that of current ELSI members. Director Hirose leads joint research between ELSI and the EPS/U.Tokyo Satellite Center in the study of the formation, evolution, and habitability of planets in solar and extrasolar systems and the study of geology, geochemistry, and life on the early Earth. Exchange visits are facilitated by the geographical proximity of the two institutes.

Collaborations between ELSI and the Ehime Satellite were further enhanced through the April 2017 hire of a new ELSI Research Scientist who had previously worked at the Ehime Satellite. PI Tetsuo Irifune and other WPI-employed researchers at the Ehime Satellite stay at ELSI from time to time, present their research activities, and engage in collaborative projects with ELSI members.

(3) PI composition

Ryuhei Nakamura joined ELSI as a new PI in April 2017 (Appendix 2a). With his strong expertise in electrochemistry and electrocatalysis, he is seeking to create a new research field by integrating electrochemistry, microbiology, and geology, and will answer one of the most fundamental questions in science – how life emerged on earth – with PIs and researchers at ELSI.

PI Ueno’s study of the early Earth atmosphere has provided important constraints to prebiotic chemistry, and his group’s research is essential to understand the transition from geochemistry to early biochemistry. He has been one of the central researchers at ELSI from its beginning and was appointed as a tenured full professor of Tokyo Tech in September 2017. This ensures that he will continue to lead the origin of life studies at ELSI in the coming years.

ELSI appointed three new associate PIs (A-PIs) in FY2017. Two of them were promoted from ELSI Research Scientists through vigorous evaluation processes. Yuka Fujii (characterization of exoplanets, biosignatures), Tomohiro Usui (Geo-/cosmochemistry, Mars exploration), and Albert Fahrenbach (organic chemistry, abiotic synthesis of life’s building blocks) bring in additional strengths and expertise to those of ELSI PIs.

Through open recruitment, ELSI appointed Yasuhito Sekine (astrobiology, currently associate professor at the EPS/U.Tokyo Satellite) as a new PI, and he will join ELSI in FY2018. He will further promote collaborations between ELSI and the EPS/U.Tokyo Satellite. Conducting research of the highest world level, A-PI Genda will be promoted to a tenured A-PI from April 2018. The 16 PIs of complementary strength and expertise will lead interdisciplinary studies at ELSI.

(4) Fostering and securing of next-generation researchers

ELSI recruits Research Scientists through open international solicitations. Their academic independence is guaranteed at ELSI, and they work on their research by collaborating with other researchers within and outside ELSI. An annual budget of 500,000 yen is allocated to young researchers hired with WPI expenditures to cover their startup costs. This funding is to ensure that young researchers who join ELSI can start their research smoothly. It is intended as support until they acquire external funds. Research administrators provide assistance to them when applying to Tokyo Tech or external funding programs.

Each early-career researcher chooses his/her mentor, and mentors provide support and guidance for their career development. In addition, the Directors regularly communicate with Research Scientists, exchange opinions on, and discuss future directions for his or her research. Early-career researchers at ELSI have been successful in finding and moving on to new positions, which include 6 associate/assistant professor or research scientist positions in FY2016/2017.

ELSI receives frequent visits from internationally distinguished researchers, either for the purpose of research collaborations, or as symposium/workshop speakers or participants (Appendix 5). These visits not only promote valuable scientific discussion, but also serve as excellent opportunities for early-career researchers to get stimulated, inspired, or guided in their career development through interactions with leading scientists.

More graduate students started their PhD programs at ELSI. ELSI researchers will also participate in teaching classes and working toward setting up an international educational program. By doing so, such PhD students and supervisors will simultaneously develop interdisciplinary research both at ELSI and other departments. ELSI is eager to recruit more prospective PhD 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 mentioned in the section "Research Goals" of its mid-term goals and plans that "the Earth-Life Science Institute, a global top level research center, shall focus on the Earth in its early stages, seeking to mutually link and elucidate the origins and evolution of Earth and life, with full support from discretionary resources provided by the President" and designates ELSI as a "highly strategic and ambitious project".

Tokyo Tech has stipulated that ELSI is a strategic research hub specially approved by the President ("Kenkyu Tokku") defined in the National University Corporation Tokyo Institute of Technology Organization Management Regulations.

In addition to the financial support and space allocation, Tokyo Tech gave ELSI one more tenured principal investigator's post, which makes a total of 7 tenured PIs at ELSI. The President announced that there will ultimately be one more post.

Tokyo Tech established the non-profit organization "Tokyo Tech USA" in the US in 2017. It serves as an overseas base to obtain donations and research funds from overseas companies, institutions and funding agencies.

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

Tokyo Tech positions ELSI in a leadership role in research and system reform, and is taking the following measures to ensure that ELSI remains a top global research hub even after the WPI subsidies end:

- Arrangements will be made to secure ten full-time equivalent principal investigators – including eight tenured PIs and the necessary administrative staff – as well as the continued support required for the management of the institute, including discretionary funding and research space from the President.
- We will continue to provide a full-scale research environment in which the research staff can concentrate on scientific activities, supervise graduate students and other young researchers, interact with the world's greatest researchers, and pursue interdisciplinary research.

- We will continue to support foreign researchers in daily life so that they are able to focus on their research by assigning a life advisor to them, expanding the housing services, etc.
- Collaborating with the Office of Research and Innovation, the Office of Public Engagement of Tokyo Tech as well as with other WPI centers, we will maintain and expand various kinds of expertise acquired through this program to ensure that our top-level global research hub continues.
- The ELSI Director meets every month with the President and the two Executive Vice Presidents to discuss the steps required to ensure that ELSI remains a top-level global research hub.

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

President Mishima completed his term in March 2018, but he declared that active support of ELSI will be of maximum benefit to Tokyo Tech, and clearly stated that his successor will continue to support ELSI even after its WPI program funding ends.

In March 2018, Tokyo Tech was awarded the Designated National University status. This means that its educational and research activities are considered to be of the top level in the world. With this, Tokyo Tech announced its plans to promote international joint research and to create innovative science and technology as a world research hub by assembling world-class researchers. In that plan, Tokyo Tech stated that the existence of ELSI is one of the university's strengths on the long run toward establishing the leading status in research in the world.

To accomplish its goals as the Designated National University and for Tokyo Tech to "become a member of the world's top ten research universities by 2030", it is crucial that ELSI is not only supported and reinforced, but also that it can contribute to the reform and enhancement of the university's research system. Tokyo Tech will make practical plans to accomplish these system reforms by carefully considering the current organizational structures of the university.

6. Others

* In addition to the above 1-5 evaluation items, only if there is anything else that deserves mention regarding the center project's progress, please note it.

6th ELSI International Symposium (January 9-11, 2018): One way in which ELSI aims to advance Origin of Life research is to introduce more systematic ways to reason about chemical and physical mechanisms, and about how components assemble into systems, in the context of very incomplete scenarios. Recent progress in such methods, at all scales from fundamental chemistry to molecular biology and evolution, were the topic of the 6th ELSI International Symposium, titled "Building Bridges from Earth to Life: From Chemical Mechanism to Ancient Biology." The symposium drew recognized world leaders in organic- and geochemistry, microbiology, geology, and evolution, as well as computer science, molecular engineering, and even medicine, to identify what the participants judge to be the strongest steps in a bridge from Earth to Life, and the areas of greatest opportunity in the coming 5-50 years. Keynote presentations were given by Prof. George Whitesides (Harvard University), Prof. Haruyuki Atomi (Kyoto University), and Prof. Paul Falkowski (Rutgers University), and 152 participants from major institutes around the world joined the symposium. The meeting yielded fruitful dialogues to move past scenarios to build a systematic science that connects planetary chemistry to the origin of life and early evolution. In conjunction with the symposium, public lectures were given by Prof. Hisayoshi Yurimoto (Hokkaido University; Japan Aerospace Exploration Agency, JAXA) and Dr. Elizabeth Tasker (JAXA; ELSI Affiliated Scientist) and well received by the audience.

2018 EON-ELSI Winter School (January 22-February 2, 2018): EON/ELSI hosted a short intensive course targeted at undergraduates, graduate students, and early-career researchers. ELSI researchers designed the curriculum that covered important topics in the wide breadth of the field of Earth-Life science. This interdisciplinary training course consisted of not only lectures but also hands-on projects and tutorials and was designed to be incorporated into a student's active thinking. Taking advantage of ELSI's strength in geology and good access to unique local geological sites, a short field trip was made to visit hot springs, geysers, plate boundaries, and volcanoes. ELSI received 227 applications from all 6 populated continents, and the students were a diverse group from all

different research fields. Graduate students from the Harvard and EPS/UT Satellites were also enrolled. The school successfully opened up attendees' views, provided them with an integrated perspective and new tools and concepts to apply in their own research. This was a great achievement in fostering next-generation researchers and expanding an international research network.

Outreach activities – ELSI Origins I: Space Dust to Sentience (September 30, 2017): ELSI held a special public event “ELSI Origins I: Space Dust to Sentience” at ELSI Hall. At this all-day event, ELSI researchers spoke to the public audience about what they work at ELSI in plain words. The audience included local residents as well as attendees from a distance and have animated conversations with researchers during the Q & A sessions.

Coordination with another WPI Center – ELSI/Kavli IPMU Joint Public Lecture “Quest for Origins” (January 21, 2018): ELSI co-hosted a public event with Kavli IPMU, another WPI Center, at Kuramae Hall, Tokyo Tech. Shigeru Ida (ELSI), Naoshi Sugiyama (Kavli IPMU), and Asa Ito (Aesthetics and Contemporary Art; Institute for Liberal Arts, Tokyo Tech) delivered lectures on the terrestrial life, the origin of the universe, and the origin of the form, respectively, and gave a tripartite talk about the human quest for “Origins” from their own viewpoints. This was the third joint public event co-hosted by ELSI and Kavli IPMU.

7. Center's response to the follow up results in last year

* Transcribe the item from the “Advice/ recommendations” section in the site visit report and “Actions required and recommendations” in the Follow-up report, then note how the center has responded to them.

* For the center launched in FY 2017, please describe the status of response to the pointed items in “Major points that need to be improved” of “The screening result for WPI centers launched in FY 2017.”

* However, if you have already provided this information, please indicate where in the report.

- (1) *It is highly evaluated that in ELSI the number of female researcher is increasing (now 26%). We would like to ask ELSI to maintain this high level while making further effort in the same direction.*

Diversity is one of the shared values at ELSI, and ELSI has been striving to improve gender awareness and balance. The Director and Vice-Directors are promoting ELSI's top-level research environment and future prospects at various opportunities. ELSI solicits applications for the Research Scientist positions in open recruitment, which is vigorously advertised through the web-based job-posting systems, academic societies, and female researchers' communities. In our most recent recruitment of new ELSI Research Scientists, 5 out of 8 candidates in the shortlist were female. In FY2017, ELSI appointed 12 new researchers, and 6 of them are female and 6 male. Newly-appointed female researchers include one A-PI (Yuka Fujii) and one Lab Manager (Yayoi Hongo) with more responsibilities in institutional management.

It is also notable that ELSI received applications with a gender ratio of about 50 percent women and 50 percent men to enroll the 2018 EON-ELSI Winter School. Engaging younger generations in ELSI's efforts to promote gender balance is of particular importance as they could make lasting changes. Their great enthusiasm and interest, together with ELSI's commitment to further advance the gender balance, should bring about a positive outcome.

- (2) *Dr. Hirose reported that he is now cross-appointed with the University of Tokyo under an effort ratio of 80% for Tokyo Tech and 20% for U. Tokyo. The effort ratio should not merely be indicative of the physical length of stay. What we would like to know is if his effort at Tokyo Tech is commensurate with what's desired by the ELSI members and the working group. Of course, we expect good outcomes from joint research with the new U. Tokyo Satellite.*

The role of Director Hirose in heading and managing the institute remains the same and is understood by ELSI members as such. He devotes all his effort to promote ELSI as the international hub of the research into the origin and evolution of planets and life. It is vital to clarify the roles of the Satellite Centers and enhance their functions in ensuring progressive development of ELSI and its global network. Director Hirose, therefore, spent adequate time to set up the new U. Tokyo Satellite in its launch in FY2017. His leadership both at ELSI and the U. Tokyo Satellite, as well as the large collaborative grant centered at the U. Tokyo Satellite and ELSI (Aqua Planetology, MEXT Grant-in-Aid for Scientific Research on Innovative Areas for FY2017-FY2021), should yield a synergistic outcome.

- (3) *We are pleased that a few ELSI foreign PIs have acquired tenured positions at Tokyo Tech. Now, we expect that they will be able to directly educate more graduate students at Tokyo Tech in the near future.*

Since 2016, foreign ELSI faculty members have been supervising Tokyo Tech graduate students in conjunction with other Tokyo Tech departments. More prospective students have contacted ELSI faculty members to apply for full-time Master's and PhD degree program at Tokyo Tech. Organizing and hosting the 2018 EON-ELSI Winter School generated more interest in ELSI worldwide, which will contribute to more success in student recruitment.

- (4) *ELSI has established a new mentor system for young researchers within its open and flat organization, as required by the WPI Program Committee. The Committee looks forward to this new system helping young researchers in their career development while maintaining independence in conducting their research.*

ELSI would like to emphasize that nothing has changed by introducing a new mentoring system in FY2016 with regard to ELSI's basic policy of ensuring the open and flat research organization in carrying out research activities. Each researcher independently pursues their own research interests and seeks for productive collaborations both in and outside of ELSI. In the mentoring system, the primary role of mentors is to provide sound, candid advice on the researcher's performance towards his or her career goals. Mentors and mentees discuss together for improvement and about career development throughout the year. Young ELSI researchers were indeed successful in building up their career and obtaining tenured/tenure-track positions outside of ELSI in FY2016/FY2017. Success in young researchers' career development, in turn, should contribute to ELSI's reputation and the growth of its research network.

ELSI now attracts quite a few visitors of various levels in the career development and with different backgrounds or cultures. A variety of opportunities to interact with them have contributed to the opening up of young ELSI researchers' eyes in thinking of their career development plan, complementing their close relationships with mentors.

- (5) *It is highly evaluated that within ELSI the number of female researchers is increasing (now at 24%). The Committee would like to ask ELSI to maintain this high level of female participation while making further effort.*

Gender equality at ELSI goes beyond recruitment. In addition to the efforts described in the response to the comment (1), the Gender Equality Team (GET) was organized voluntarily at ELSI and has been striving towards further improvement. The team consists of both female and male and both Japanese and non-Japanese ELSI members. GET members research into the ideas and practices for promoting and maintaining gender equality in ELSI's daily activities and give suggestions to ELSI members when they organize workshops or invite visitors, for instance. The GET also monitors the female participation throughout various ELSI activities and report it to all ELSI members to share the information for further awareness and improvement. Through these in-house efforts, ELSI will continue to promote gender equality.

- (6) *Once the new Satellite at the University of Tokyo has started operation, it is expected that Dr. Hirose will continue his earnest efforts as the ELSI center director and as the PI of the Satellite.*

Please refer to the response to the comment (2).

Appendix 1 FY2017 List of Center's Research Results and Main Awards

1. Refereed Papers

- List only the Center's papers published in 2017. (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 the name of his/her WPI center). (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. As some WPI-affiliated authors of papers published up to 2011 may not be aware of this requirement, their papers are treated as "WPI-related papers." From 2012, however, the authors' affiliations must be clearly noted and only category A papers will be basically listed.

(2) Method of listing paper

- List only referred 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 the same. (The names of the center researchers do not need to be underlined.)

- If a paper has many authors (say, more than 20), all of their names do not need to be listed.

- If the papers are written in languages other than English, divide them into paper's categories when listing them.

- Assign a serial number to each paper to be used to identify it throughout the system.

- Order of Listing

A. WPI papers

1. Original articles

2. Review articles

3. Proceedings

4. Other English articles

5. Articles written in other than English

B. WPI-related papers

1. Original articles

2. Review articles

3. Proceedings

4. Other English articles

5. Articles written in other than English

(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 in FY 2017.

- 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.

WPI papers

1. Original articles

1. Adam ZR, Zubarev D, Aono M, Cleaves HJ. Subsumed complexity: abiogenesis as a by-product of complex energy transduction. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):12. doi: 10.1098/rsta.2016.0348. PubMed PMID: WOS:000415086500009.
2. Afrin R, Saito M, Watanabe-Nakayama T, Ikai A. Membrane wound healing at single cellular level. *Nanomedicine-Nanotechnology Biology and Medicine*. 2017;13(7):2351-7. doi: 10.1016/j.nano.2017.07.011. PubMed PMID: WOS:000411954200026.
3. Andersen JL, Flamm C, Merkle D, Stadler PF. An intermediate level of abstraction for computational systems chemistry. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):10. doi: 10.1098/rsta.2016.0354. PubMed PMID:

WOS:000415086500014.

4. Arai T, Maruyama S. Formation of anorthosite on the Moon through magma ocean fractional crystallization. *Geoscience Frontiers*. 2017;8(2):299-308. doi: 10.1016/j.gsf.2016.11.007. PubMed PMID: WOS:000396639500008.
5. Asanuma H, Fujisaki W, Sato T, Sakata S, Sawaki Y, Aoki K, et al. New isotopic age data constrain the depositional age and accretionary history of the Neoproterozoic-Ordovician Mona Complex (Anglesey-Lleyn, Wales). *Tectonophysics*. 2017;706:164-95. doi: 10.1016/j.tecto.2017.03.017. PubMed PMID: WOS:000402447000012.
6. Azuma S, Katayama I. Evolution of the rheological structure of Mars. *Earth Planets and Space*. 2017;69:13. doi: 10.1186/s40623-016-0593-z. PubMed PMID: WOS:000391209100008.
7. Azuma S, Yamamoto S, Ichikawa H, Maruyama S. Why primordial continents were recycled to the deep: Role of subduction erosion. *Geoscience Frontiers*. 2017;8(2):337-46. doi: 10.1016/j.gsf.2016.08.001. PubMed PMID: WOS:000396639500011.
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9. Baccouche A, Okumura S, Sieskind R, Henry E, Aubert-Kato N, Bredeche N, et al. Massively parallel and multiparameter titration of biochemical assays with droplet microfluidics. *Nature Protocols*. 2017;12(9):1912-32. doi: 10.1038/nprot.2017.092. PubMed PMID: WOS:000408997500006.
10. Ballmer MD, Houser C, Hernlund JW, Wentzcovitch RM, Hirose K. Persistence of strong silica-enriched domains in the Earth's lower mantle. *Nature Geoscience*. 2017;10(3):236-41. doi: 10.1038/ngeo2898. PubMed PMID: WOS:000395791400018.
11. Ballmer MD, Lourenco DL, Hirose K, Caracas R, Nomura R. Reconciling magma-ocean crystallization models with the present-day structure of the Earth's mantle. *Geochemistry Geophysics Geosystems*. 2017;18(7):2785-806. doi: 10.1002/2017gc006917. PubMed PMID: WOS:000407477800023.
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3. Proceedings

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4. Other English articles

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5. Articles written in other than English

None

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

- List up to 10 main presentations during FY2017 in order from most recent.
- For each, write the lecturer/presenter's name, presentation title, conference name and date(s)

- 1) Shigenori Maruyama, "Ophiolites through geological time", GSA Annual Meeting 2017, October 22-25, 2017.
- 2) George Helffrich, "Evolution and Structure of an Outer Core Crystallizing SiO₂", Goldschmidt Conference, August 13-18, 2017.
- 3) Hidenori Genda, Origin of Earth's Oceans: An Assessment of the Total Amount, History and Supply of Water, Goldschmidt Conference 2017, August 13-18, 2017.
- 4) Tomohiro Usui, "Exploration for the Origin, Delivery and Distribution of Volatiles in the Solar System", 50th ISAS Lunar Planetary Symposium, August 3-4, 2017.
- 5) Ramon Brasser, Oort Cloud and Scattered Disc Formation During a Late Dynamical Instability in the Solar System, Asia Oceania Geosciences Society (AOGS) annual meeting, 6-11 Aug. 2017.
- 6) Jim Cleaves, Computational Exploration of the Chemical Space of Nucleic Acid-Like Compounds, 18th ISSOL Meeting, La Jolla, July 16-21, 2017.
- 7) Albert Fahrenbach, Radiolytic Synthesis of Some RNA Precursors (or How I learned to Love Prebiotic Chemistry). A Golden Age For Chemistry, June 25–28, 2017. (Invited Talk)
- 8) Kei Hirose, "Chemical Evolution and the Present-day Composition of the Liquid Outer Core", Gordon Research Conference on the Interior of the Earth, June 4-9, 2017.
- 9) Marine Lasbleis, Inner core dynamics: combining seismic studies and geodynamical models, Gordon Research Conference on the Earth Interior, June 4-9, 2017.
- 10) Yutetsu Kuruma, "Construction of an artificial cell for the study of early cells", International Conference The Origin of Life synergy among the RNA, Protein, and Lipid worlds, May 29, 2017.

3. Major Awards

- List up to 10 main awards received during FY2017 in order from the most recent.
- For each, write the recipient's name, name of award, and year issued.
- In case of multiple recipients, underline those affiliated with the center.

- 1) Tetsuo Irifune, Ehime Shinbun Prize, 2018.
- 2) Tony Z. Jia, Best Young Researcher Presentation, Annual Meeting on Biopolymers and Drug Delivery Systems, 2017.
- 3) Jim Cleaves, Elected Fellow of the International Society for the Study of the Origins of Life (ISSOL), 2017.
- 4) Hidenori Genda, Geochemical Journal Award, 2017.
- 5) George Helffrich, American Geophysical Union Fellow, 2017.
- 6) Rehana Afrin, Best poster award at the XVIIIth International Conference on the Origin of Life (ISSOL) Meeting, 2017.
- 7) Kei Hirose, JpGU Fellow, 2017.

8) Tetsuo Irifune, JpGU Fellow, 2017.

Appendix 2 FY 2017 List of Principal Investigators

NOTE:

- Underline names of principal investigators who belong to an overseas research institution. Place an asterisk (*) by names of investigators considered to be ranked among world's top researchers.
- In case of researchers not listed in the latest report, attach "Biographical Sketch of a New Principal Investigator".

		<Results at the end of FY2017>				Principal Investigators Total: 15	
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	50	Director, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., High-pressure Geoscience	90	From start	Main stays at the center, other than that, at Tokyo University Satellite.	
Shigenori MARUYAMA	68	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	57	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	65	Full professor, Institute for Advanced Study, Princeton, Program of Interdisciplinary Studies Professor, Earth-Life Science Institute, Tokyo Institute of Technology	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	63	Professor, Department of Chemical Science and Engineering, Tokyo Institute of Technology	Doctor of Science, Environmental Chemistry, Global Change Analysis	80	From start	Stays at the center three times a week	
Tetsuo IRIFUNE	63	Professor, Geodynamics Research Center, Ehime University	Ph.D., High-pressure geosciences, Materials sciences	66	From start	Usually stays at Ehime Satellite	
Joseph Lynn KIRSCHVINK	64	Professor, Division of Geological and Planetary Sciences, California Institute of Technology Professor, Earth-Life Science Institute, Tokyo Institute of Technology	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

John HERNLUND	45	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., Geophysical Modeling, Fluid and Solid Dynamics	100	From August, 2013	Usually stays at the center from August 2013	
Jack William SZOSTAK	65	Professor of Genetics, Harvard Medical School	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
George HELFFRICH	65	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., Geological Sciences	85	From July, 2014	Usually stays at the center from July 2014	
Eric SMITH	52	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., High-energy/particle Physics	85	From February, 2015	Usually stays at the center from February 2015	
Irena MAMAJANOV	42	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., Physical Chemistry	100	From January, 2016	Usually stays at the center from January 2016	
Yuichiro UENO	43	Professor, Department of Earth and Planetary Sciences, Tokyo Institute of Technology	Doctor of Science, Geochemistry	60	From April, 2016	Usually stays at the center from April 2016	
Shawn McGLYNN	34	Associate Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Ph.D., Evolutionary biology, Microbial biochemistry	80	From April, 2016	Usually stays at the center from April 2016	
Ryuhei NAKAMURA	41	Professor, Earth-Life Science Institute, Tokyo Institute of Technology	Doctor of Science, Electrochemistry	80	From April, 2017	Usually stays at the center from April 2017	

*Percentage of time that the principal Investigator will devote to his/her work for the center vis-à-vis his/her total working hours (total time for whole working activities including education, medical services, and others as well as research).

Researchers unable to participate in project in FY 2017

Name	Affiliation (Position title, department, organization)	Starting date of project participation	Reasons	Measures taken
Junichiro MAKINO (54)	Team Leader, Particle Simulator Research Team, RIKEN Advanced Institute for Computational Science	From start	5 years have passed after the establishment of ELSI and the management system was improved so that external PIs contribute to the research activities than involvement in the administrative management.	Appointment to a ELSI fellow to continue the research collaboration
Ken KUROKAWA (48)	Professor, Center for Information Biology National Institute of Genetics	From start	5 years have passed after the establishment of ELSI and the management system was improved so that external PIs contribute to the research activities than involvement in the administrative management.	Appointment to a ELSI fellow to continue the research collaboration
Masaki FUJIMOTO (52)	Professor, Department of Solar System Sciences, Institute of Space and Astronautical Science, Japan Aerospace Exploration	From start	5 years have passed after the establishment of ELSI and the management system was improved so that external PIs contribute to the research activities than involvement in the administrative management.	Appointment to a ELSI fellow to continue the research collaboration
Ken TAKAI (47)	Program Director, Institute for Biogeosciences and Precambrian Ecosystem Laboratory, Japan Agency for Marine-Earth Science and Technology	From start	5 years have passed after the establishment of ELSI and the management system was improved so that external PIs contribute to the research activities than involvement in the administrative management.	Appointment to a ELSI fellow to continue the research collaboration
Hitoshi KUNINAKA (56)	Professor, Lunar and Planetary Exploration Program Group, Institute of Space and Astronautical Science, Japan Aerospace Exploration	From start	5 years have passed after the establishment of ELSI and the management system was improved so that external PIs contribute to the research activities than involvement in the administrative management.	Appointment to a ELSI fellow to continue the research collaboration

Appendix 2a Biographical Sketch of Principal Investigator

(within 3 pages per person)

Name (Age) Ryuhei Nakamura (41)

* Place an asterisk (*) by the name of the principal investigators who are considered to be ranked among the world's top researchers.

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

Position: Professor

Department: Earth-Life Science Institute

Organization: Tokyo Institute of Technology

Academic degree and specialty

Doctor of Science, Electrochemistry

Effort 80 %

* Percentage of time that the PI will devote to his/her work for the center vis-à-vis his/her total working hours (total time for whole working activities including education, medical services, and others as well as research).

Research and education history

2002-2005: Division of Chemistry, Graduate School of Engineering Science, Osaka University (Dr. Sci.)

2005-2006: JSPS Postdoctoral fellow (PD), Lawrence Berkeley National Laboratory, US

2006-2013: Assistant Professor, Department applied chemistry, the University of Tokyo

2013-present: Team Leader, RIKEN Center for Sustainable Resource Science, Biofunctional catalyst research team

2017- present: Professor, Earth-Life Science Institute (ELSI) at Tokyo Institute of Technology

Achievements and highlights of past research activities

* Describe the PI's qualifications as a top-caliber researcher if s/he is considered to be ranked among the world's top researchers.

Ryuhei Nakamura received his Dr. Degree in Science in 2005 from Osaka University, where he studied photo-electrochemistry of TiO_2 under the supervision of Prof. Yoshihiro Nakato. After working as a JSPS postdoctoral fellow with Dr. Heinz Frei in Lawrence Berkeley National Laboratory (LBNL), he joined the University of Tokyo as an assistant professor in 2006 and worked on electromicrobiology with Prof. Kazuhito Hashimoto. In 2013, he was appointed to Team Leader (PI) in RIKEN Center for Sustainable Resource Science (CSRS). In RIKEN, his group has been working on developing bio-geologically inspired catalysts, as well as employing robust energy management in the deep sea environment to develop novel materials and systems necessary to manage renewable energy sources. Through these projects, he reported the novel concept of "electrical current generation across a black smoker chimney" as a new type of energy propagation at the deep sea hydrothermal environments. Soon after the proposal, he identified for the first time the bacteria that can live off electricity termed "Electrolithoautotroph" as the 3rd type of autotrophic carbon fixation mechanism other than photosynthesis and chemosynthesis. Furthermore, he has proposed the novel scenario about "the origin of life with electricity" as the possible life-first engine to drive CO_2 fixation. In 2017, he concurrently serves as a Professor of Earth Life Science Institute (ELSI) at Tokyo Institute of Technology, which is assigned to the World Premier International Research Center Initiative (WPI) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). In ELSI, he has intended to create the new field by integrating electrochemistry, microbiology, and geology to seek one of the vital questions of general science, how was life emerged on the earth?

Based on his achievements about electrocatalysis and deep-sea electrochemistry, he was awarded "The first Honda-Fujishima Prize (2005)", "The First NAGASE Prize (special prize) (2011)" and "The Young Scientist's Prize 2016" Minister of Education, Culture, Sports, Science and Technology (MEXT) in 2016. Also, in 2016, he was invited to "24th Solvay Conference on Chemistry: Catalysis in Chemistry and Biology" (Brussels, Belgium), which is one of the most prestigious conference in Chemistry, as a speaker in the session of catalysis in extreme

environments.

Achievements

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

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

Since 2005, he was invited by 36 and 53 international and domestic conference, respectively. And in 2016, he was invited to “24th Solvay Conference on Chemistry: Catalysis in Chemistry and Biology” (Brussels, Belgium), which is one of the most prestigious conference in Chemistry, as a speaker in the session of catalysis in extreme environments.

- b) Member of a scholarly academy in a major country

N/A

- c) Recipient of international awards

N/A

- d) Editor of an influential journal, etc.

N/A

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

Grant-in-aid for specially promoted research (24000010) from the Japan Society for Promotion of Science (JSPS). “Study on biological electron transfer based on bacterial extracellular electron transfer” JPY 66,300,000 (FY2012-2016)

(3) Article citations (Titles of major publications, number of citations)

Number of citations searched using Web of Knowledge

Times cited

1. R. Nakamura, T. Tanaka, Y. Nakato, Mechanism for visible light responses in anodic photocurrents at N-doped TiO₂ film electrodes, *J. Phys. Chem. B*, 2004, 108, 10617-10620. **Citation 538**
2. Y. Zhao, R. Nakamura, K. Kamiya, S. Nakanishi, K. Hashimoto, Nitrogen-doped carbon nanomaterials as non-metal electrocatalysts for water oxidation, *Nat. Commun.*, 2013, 4:2390. **Citation 337**
3. R. Nakamura, Y. Nakato, Primary intermediates of oxygen photoevolution reaction on TiO₂ (rutile) particles, revealed by in situ FTIR absorption and photoluminescence measurements, *J. Am. Chem. Soc.*, 2004, 126, 1290-1298. **Citation 278**
4. T. Takashima, K. Hashimoto, R. Nakamura, Mechanisms of pH-dependent activity for water oxidation to molecular oxygen by MnO₂ electrocatalysts, *J. Am. Chem. Soc.*, 2012, 134, 1519-1527. **Citation 178**
5. A. Okamoto, K. Hashimoto, K. H. Neelson, R. Nakamura, Rate enhancement of bacterial extracellular electron transport involves bound flavin semiquinones, *Proc. Natl. Acad. Sci. U.S.A.*, 2013, 110, 7856-7861. **Citation 117**

Total citation: 5515

H-index: 37

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

Appendix 3-1 FY 2017 Records of Center Activities

1. Researchers and center staffs, satellites, partner institutions

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

- Regarding the number of researchers at the Center, please 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.

ELSI appointed Associate Professor Yasuhito Sekine (Department of Earth and Planetary Science, The University of Tokyo) as new PI, and he plans to join ELSI on June 1st, 2018. Prof. Sekine is an expert on planetary science and is internationally recognized as a leading pioneer of astrobiology with a clear, long-term vision. His major achievements include his fundamental work on hydrothermal systems on Enceladus, a moon of Saturn, and surface chemistry observed on Pluto and its moon Charon. He is renowned for the breadth of research areas that he works on and can address and his excellence in combining theoretical and experimental programs, making him an ideal ELSI PI to promote interdisciplinary studies to the origin and evolution of the atmosphere and oceans on stellar bodies and the achieve ELSI's missions. As an affiliated faculty at the EPS/U.Tokyo Satellite, he has already started research collaborations with ELSI members.

Associate PI (A-PI) Hidenori Genda will be promoted to tenure A-PI from April 2018. He has been very productive in disseminating research activities in high-profile journals and obtaining research fund. Last but not least, it should be noted that he has been very actively engaged in collaborating with researchers inside and outside ELSI on a wide range of topics, such as planet formation theory, giant impact simulations, physics of cooling a magma ocean, and volatile delivery. His interdisciplinary and highly original work on the early evolution of planets is widely recognized. He has successfully recruited and been supervising young and talented postdocs at ELSI.

Sekine and Genda have been engaged in collaborations for years. Their synergistic collaborations at ELSI should bring in more talents to ELSI. They are also very active in public outreach activities and will contribute to raise ELSI's recognition by both academic communities and the general public.

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, 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	
Institute for Advanced Study in Princeton	Piet Hut	
Harvard University	Jack W. Szostak	
The University of Tokyo	Kei HIROSE	

< Partner institutions >

Institution name	Principal Investigator(s), if any	Notes
Astrobiology Center, National Institute of Natural Sciences (NINS)		
California Institute of Technology	Joseph L. Kirschvink	
NASA Astrobiology Institute		
Columbia University		

2. Securing external research funding*

External research funding secured in FY2017

Total: 818,184,807 yen

- Describe external funding warranting special mention. Include the name and total amount of each grant.

* External research funding includes "Grant-in-Aid for Scientific Research," funding for "commissioned research projects," and for "joint research projects" as listed under "Research projects" in Appendix 3-2, Project Expenditures.

3. International research conferences or symposiums held to bring world's leading researchers together

- Indicate the number of international research conferences or symposiums held in FY2017 and give up to three examples of the most representative ones using the table below.

FY 2017: 10 meetings	
Major examples (meeting titles and places held)	Number of participants
International Workshop "Reconstructing the Phenomenon of Life – To Retrace the Emergence of Life –" Tokyo Institute of Technology May 31, 2017 http://www.elsi.jp/en/research/activities/workshops/2017/05/20170531_ws.html	From domestic institutions: 57 From overseas institutions: 7
EON Workshop "Sensors, Motors and Behaviour at the Origin of Life" Tokyo Institute of Technology July 26-28, 2017 http://eon.elsi.jp/eon-workshop-sensors-motors-and-behaviour-at-the-origin-of-life/	From domestic institutions: 19 From overseas institutions: 26
6th ELSI International Symposium "Building Bridges from Earth to Life: From Chemical Mechanism to Ancient Biology" Tokyo Institute of Technology January 9-11, 2018 https://elsi6sympo.com	From domestic institutions: 80 From overseas institutions: 72

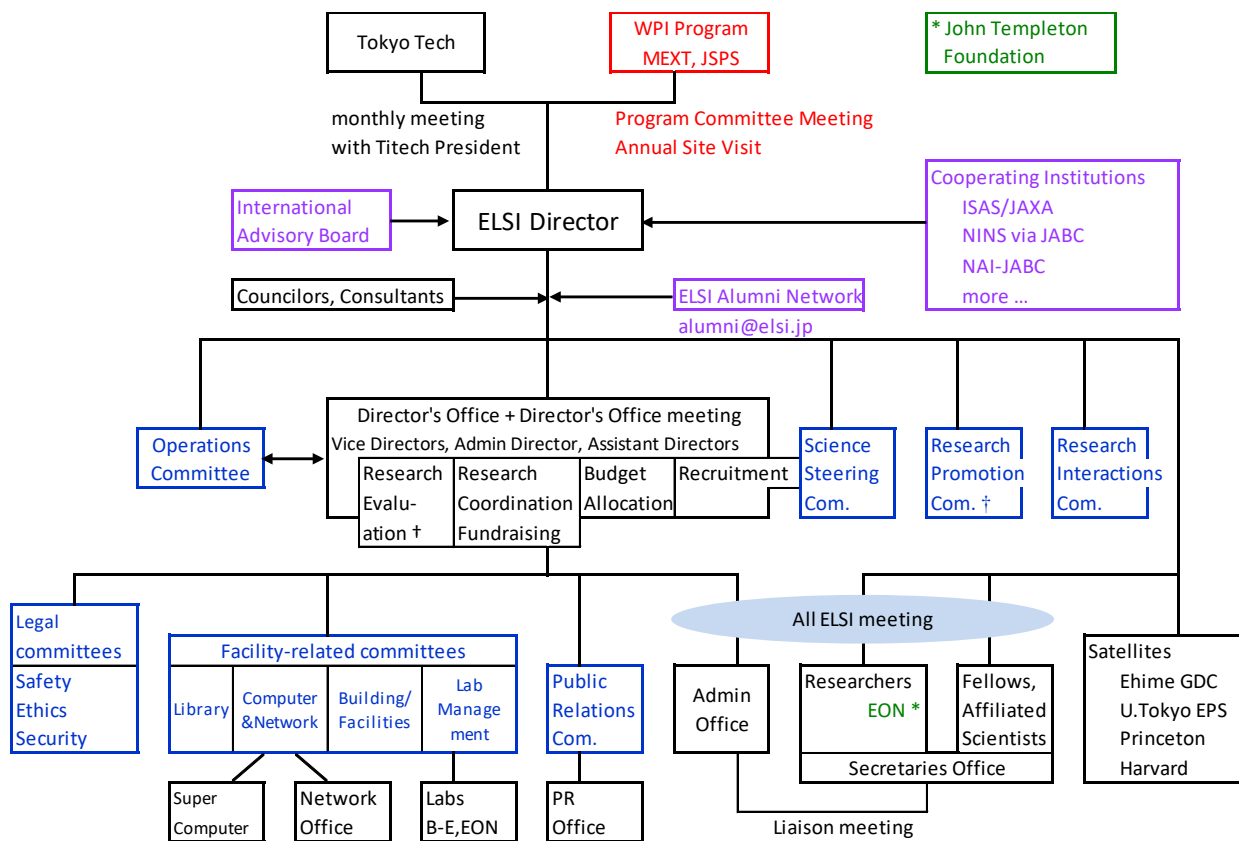
4. Center's management system

- Please diagram management system in an easily understood manner.
- If any changes have been made in the management system from that in the latest "center project," please describe them. Please describe any important changes made in such as the center director, administrative director, administrative director, head of host institution, and officer(s) in charge at the host institution (e.g., executive vice president for research).

- New satellite at the University of Tokyo

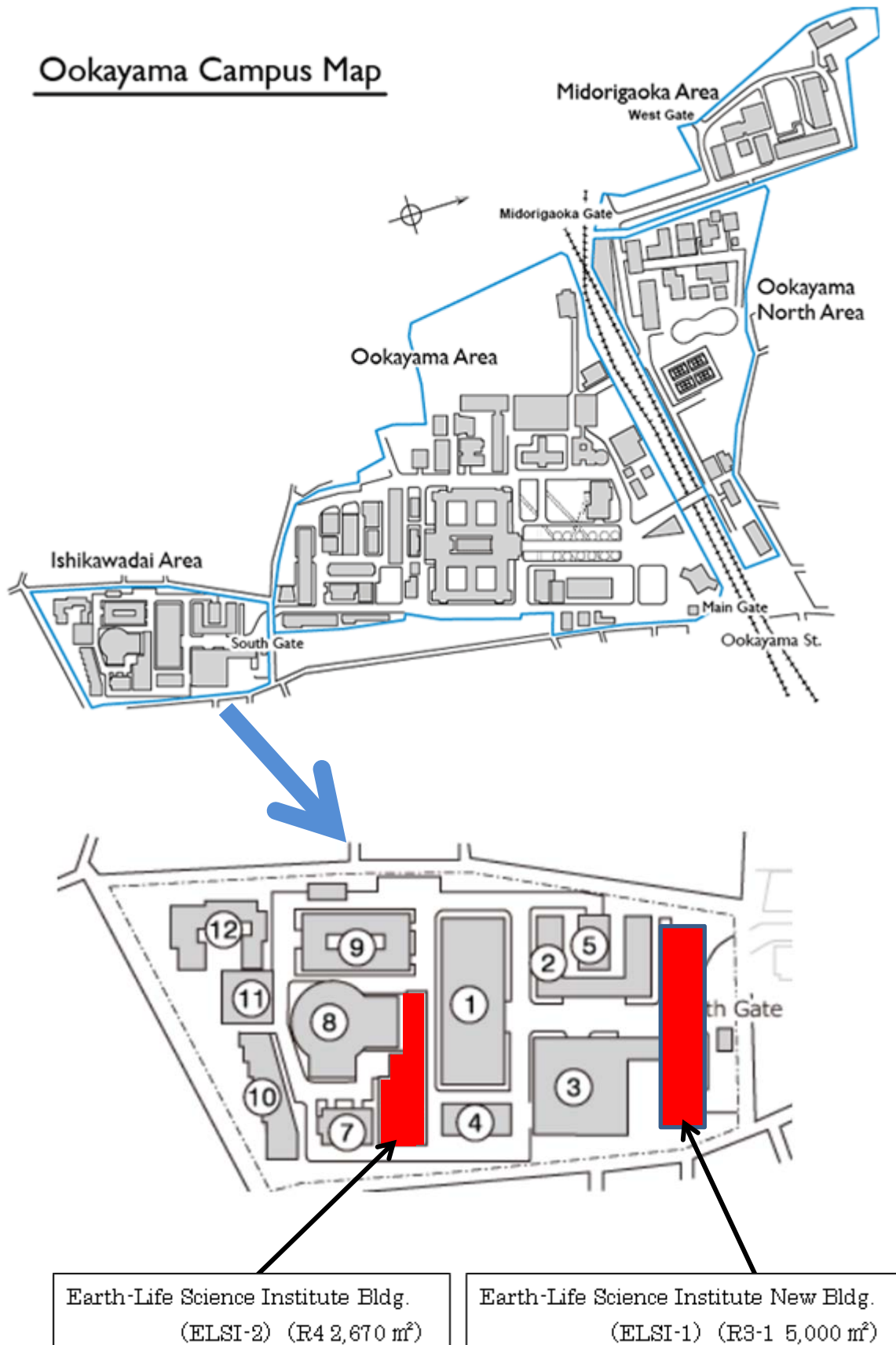
ELSI signed the contract with the department of Earth and Planetary Science (EPS), the University of Tokyo, in order to promote cooperative researches on the formation, evolution, and habitability of planets and satellites in the Solar System and other stellar environments, and geological, geochemical and biological researches on the early history of the Earth. The satellite office of ELSI is established in the University of Tokyo in April 2017.

- ELSI Organization chart:



5. Campus Map

- Please draw a simple map of the campus showing where the main office and principle investigator(s) are located.



Appendix 3-1a FY 2017 Records of Center Activities

1. Researchers and other center staffs, satellites, partner institutio

1-1. Number of researchers and other center staffs

* Please fill in the number of researchers and other center staffs in the table blow.

* Please describe the final goals for achieving these numbers and dates when they will be achieved.

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

(persons)

	At beginning of project	At end of FY 2017	Final goal (Date: 10 month, 2019 year)
Researches from within the host institution	6	11	13
Foreign researchers invited from abroad	3	3	3
Researchers invited from other Japanese institutions	4	1	1
Total principal investigators	13	15	17

b) Total members

	At beginning of project		At end of FY2017		Final goal (Date: 10 month, 2019 year)	
	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	23	/	55	/	70	/
Overseas researchers	3	13%	28	51%	35	50%
Female researchers	0	0%	7	13%	16	23%
Principal investigators	13	/	15	/	16	/
Overseas PIs	3	23%	8	53%	9	56%
Female PIs	0	0%	1	7%	1	6%
Other researchers	10	/	42	/	54	/
Overseas researchers	0	0%	20	48%	27	50%
Female researchers	0	0%	6	14%	15	28%
Research support staffs	0	/	19	/	29	/
Administrative staffs	5	/	23	/	25	/
Total number of people who form the "core" of the research center	28	/	97	/	124	/

World Premier International Research Center Initiative (WPI)

Appendix 3-2 6. Project Expenditures (the exchange rate used: 1USD= 100JPY)

1) Overall project funding

Cost Items	Details	Costs (Ten thousand dollars)	Costs (Ten thousand dollars)	
			WPI grant	600
Personnel	Center director and Administrative director	21		
	Principal investigators (no. of persons):9	84	Costs of establishing and maintaining facilities	1
	Other researchers (no. of persons):35	235	Establishing new facilities	0
	Research support staffs (no. of persons):14	51		
	Administrative staffs (no. of persons):16	61	Repairing facilities	1
	Total	452		
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):30	1	Others	0
	Cost of dispatching scientists (no. of persons):2	4		
	Research startup cost (no. of persons):23	3	Cost of equipment procured	6
	Cost of satellite organizations (no. of satellite organizations):2	30	Prominence UFLC	6
	Cost of international symposiums (no. of symposiums):1	1		
	Rental fees for facilities	118	Number of units:1	
	Cost of consumables	21		
	Cost of utilities	0	Others	6
	Other costs	63		
	Total	241		
Travel	Domestic travel costs	1		
	Overseas travel costs	20		
	Travel and accommodations cost for invited scientists (no. of domestic scientists):113 (no. of overseas scientists):21	39		
	Travel cost for scientists on secondment (no. of domestic scientists):0 (no. of overseas scientists):2	1		
	Total	61		
	Equipment	Depreciation of buildings	11	
Depreciation of equipment		156		
Total		167		
Other research projects	Projects supported by other government subsidies, etc.	35		
	Commissioned research projects, etc.	17		
	Grants-in-Aid for Scientific Research, etc.	341		
	Total	393		
Total		1314		

2) Costs of Satellites and Partner institutions

Cost Items	Details	Costs (Ten thousand dollars)
Personnel	Principal investigators (no. of persons):1	/
	Other researchers (no. of persons):12	
	Research support staffs (no. of persons):0	
	Administrative staffs (no. of persons):0	
	Total	
Project activities		7
Travel		2
Equipment		0
Other research projects		150
Total		179

Tokyo Institute of Technology -2

Earth-Life Science Institute (ELSI)

Appendix 4 FY 2017 Status of Collaboration with Overseas Satellites

1. Coauthored Papers

- List the refereed papers published in FY 2017 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. 2018 and not described in Appendix 1.

Overseas Satellite 1: Interdisciplinary Program, Institute of Advanced Study (IAS) in Princeton (Total: 0 papers)

Overseas Satellite 2: Origin of Life Initiative, Harvard University (Total: 3 papers)

- 1) [1] *Adam ZR*, Zubarev D, Aono M, Cleaves HJ. Subsumed complexity: abiogenesis as a by-product of complex energy transduction. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*. 2017;375(2109):12. doi: 10.1098/rsta.2016.0348. PubMed PMID: WOS:000415086500009.
- 2) [122] Tam CP, Fahrenbach AC, Bjorkbom A, Prywes N, Izgu EC, *Szostak JW*. Downstream Oligonucleotides Strongly Enhance the Affinity of GMP to RNA Primer-Template Complexes. *Journal of the American Chemical Society*. 2017;139(2):571-4. doi: 10.1021/jacs.6b09760. PubMed PMID: WOS:000392459300002.
- 3) [135] Zhang W, Tam CP, Walton T, Fahrenbach AC, Birrane G, *Szostak JW*. Insight into the mechanism of nonenzymatic RNA primer extension from the structure of an RNA-GpppG complex. *Proceedings of the National Academy of Sciences of the United States of America*. 2017;114(29):7659-64. doi: 10.1073/pnas.1704006114. PubMed PMID: WOS:000405662300068.

2. Status of Researcher Exchanges

- Using the below tables, indicate the number and length of researcher exchanges in FY 2017. 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 of Advanced Study (IAS) in Princeton

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2017	0	0	0	0	0
	2	4	3	1	10

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2017	0	1	1	1	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
FY2017	0	0	0	0	0
	1	0	1	0	2

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2017	3	0	0	0	3
	0	2	0	0	2

Appendix 5 FY 2017 Visit Records of World Top World-level Researchers from Abroad

* If top world-level researchers have visited/ stayed at the Center, please provide information on them in the below table.
 * To determine whether the researcher is a "top world-level researcher," please see the standard stipulated in the Application Guideline.

Total: 45

	Name	Age	Affiliation (Position title, department, organization)	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)
1	Norman Packard		Protolife	Ph.D. Physics	External faculty and science steering committee of the Santa Fe Institute	2017/04/01 to 2017/04/07	Research meeting
2	Giovanna Tinetti		University College London	Ph.D. Exoplanets	Moseley Medal & Prize, IOP Institute of Physics, UK, 2011 NASA Group Achievement Award, with Mark Swain and Gautam Vasishth (US, 2009) Edward Stone Award, with Mark Swain and Gautam Vasishth (JPL, US, 2009) SIF Award for best young Italian physicist, Italian Society of Physics (Pavia, Oct. 1999). ENEA Award for best MSc thesis, Italian National Agency for Energy & Environment (Turin, 1998).	2017/04/24 to 2017/04/25 2017/11/22 to 2017/11/30	Research meeting
3	Douglas Lin		University of California Santa Cruz	Ph.D. Astronomy and Astrophysics	Guggenheim Fellow, Otto Schmidt Medal, von Humboldt Fellow Sackler Fellow, Member of American Academy of Arts and Sciences Director, Kavli Institute for Astronomy and Astrophysics	2017/05/21 to 2017/05/25 2017/08/26 to 2017/09/01 2017/10/29 to 2017/11/01	Research meeting
4	Jack W. Szostak		Harvard University	Ph.D. Biochemistry	United States National Academy of Sciences Award in Molecular Biology Hans Sigrist Prize, University of Bern, Switzerland Genetics Society of America Medal The 2006 Lasker Award for Basic Medical Research The 2008 Dr H.P. Heinen Prize for Biochemistry and Biophysics, Royal Netherlands Academy of Arts and Sciences The 2009 Nobel Prize for Physiology or Medicine The 2011 Oparin Medal	2017/05/28 to 2017/06/01	Participation in ELSI Symposium, Research meeting
5	Tom Froese		National Autonomous University of Mexico	Ph.D. Cognitive Science	Editor-in-Chief, Adaptive Behavior Editorial Board, The Journal of Mind and Behavior Editorial Board, Constructivist Foundations Reviewer Editorial Board, Frontiers in Psychology (Section Cognitive Science) Reviewer Editorial Board, Frontiers in Psychology (Section Consciousness Research) Reviewer Editorial Board, Frontiers in Robotics and AI (Section Evolutionary Robotics) Reviewer Editorial Board, International Journal of Signs and Semiotic Systems Advisory Board, Avant: Journal of the Philosophical-Interdisciplinary Vanguard	2017/05/31 to 2017/07/30	Research meeting
6	Vladimir Airapetian		NASA/GSFC & Catholic University of America	Ph.D. Theoretical Astrophysics		2017/06/13 to 2017/06/30	Research meeting
7	Wei Liu		Nanjing University of Science and Technology	Ph.D.	2015: Distinguished Young Scholars of Jiangsu Province. Selected by the European Research Council (ERC) to participate in the 63rd Lindau Nobel Laureate Meeting, held from Jun. 30 to Jul. 5, 2013, Lindau, Germany. Apr. 2013: Nominated Award of the National Excellent Doctoral Dissertation, 2012. May 2012: Excellent Doctoral Dissertation of Jilin Province, 2012 (45 winners in total in 2012). Feb. 2011-Feb. 2013: Alexander von Humboldt Research Fellow, Germany.	2017/07/17 to 2017/07/31	Research meeting
8	Karen Ottemann		University of California, Santa Cruz	Ph.D.	Selected Publications: Abbeduto, S., J. Castellon, K. Johnson, K.D. Collins, and K.M. Ottemann. (2017) Cooperation of two distinct coupling proteins creates chemosensory network connections. Proc Natl Acad Sci U S A. 14:2970-2975. Rohlf AS, Carter JE, Ottemann KM. (2011) Bacterial chemotaxis modulates host cell apoptosis to establish a T-helper cell, type 17 (Th17)-dominant immune response in Helicobacter pylori infection. Proc Natl Acad Sci U S A. 108:19749-54.	2017/07/22 to 2017/07/29	Research meeting
9	Inman Harvey		University of Sussex	Ph.D.	Book: Vargas, Patricia A, Di Paolo, Ezequiel A, Harvey, Inman and Husbands, Phil, eds. (2014) The horizons of evolutionary robotics. Intelligent Robotics and Autonomous Agents - MIT Press, Cambridge, MA, USA. ISBN 9780262026765	2017/07/23 to 2017/07/29	Participation in Workshop
10	Simon Poulton		University of Leeds	Ph.D.	Bigsby Medal, Geological Society, 2018 Robert Berner Lecture, European Association of Geochemistry/Geochemical Society, 2018 Leverhulme Research Fellowship (2016-2019) 'Dynamics of the Great Oxidation Event' Royal Society Wolfson Research Merit Award (2016-2021) 'Nutrient controls on Earth's oxygenation history' NERC Fellowship (2005-2008) 'Chemical evolution of the Proterozoic biosphere' Marie Curie Fellowship (2002-2004) 'Oceanic phosphorus cycling in modern and ancient metalliferous sediments'	2017/07/26 to 2017/08/24	Research meeting
11	Pablo Marquet		Pontifical Catholic University of Chile	Ph.D. Biology	Books: Bradshaw, G.A. & P.A. Marquet (eds) (2003). How Landscapes Change: Human disturbance and ecosystem fragmentation in the Americas. Springer-Verlag, New York. Storch, D. P.A. Marquet & J.H. Brown (eds) (2007) Scaling Biodiversity. Cambridge University Press, Ecological review Series.	2017/08/18 to 2017/08/27	Research meeting Participation in Workshop
12	Douglas Erwin		Smithsonian Institution	Ph.D.	Chair of the Faculty at the Santa Fe Institute. Member of the Editorial Board for Current Biology. Books: Extinction: How Life on Earth Nearly Ended 250 Million Years Ago in 2006 The Great Paleozoic Crisis: Life and Death in the Permian in 1993	2017/08/20 to 2017/08/26	Participation in Workshop Research meeting
13	Michael Travisano		University of Minnesota	Ph.D.	Selected Publications: Ratcliff WC, Denison RF, Borrello M, Travisano M. 2012. Experimental evolution of multicellularity. PNAS. Greig D, Louis EJ, Borts RH, Travisano M. 2002. Hybrid speciation in experimental populations of yeast. Science 298:1772-5. Rainey PB, Travisano M. 1998. Adaptive radiation in a heterogeneous environment. Nature 394:69-72. Travisano M, Mongold JA, Bennett AF, Lenski RE. 1995. Experimental tests of the roles of adaptation and population structure in speciation.	2017/08/21 to 2017/08/26	Research meeting
14	Paul Turner		Yale University	Ph.D. Microbial Ecology & Evolution	E.F. Foxman, J.A. Storer, M.E. Fitzgerald, B.R. Wasik, L. Hou, H. Zhao, P.E. Turner, A.M. Pyle, A. Iwasaki. 2015 Temperature-dependent innate defense against the common cold virus limits viral replication at warm temperatures in mouse airway cells. Proceedings of the National Academy of Sciences USA 112(3):827-32. B.R. Wasik, P.E. Turner. 2013 On the Biological Success of Viruses. Annual Review of Microbiology. doi:10.1146/annurev-micro-090113-103822	2017/08/21 to 2017/08/26	Participation in Workshop
15	Carl Pilcher		NASA Astrobiology Institute	Ph.D.	NASA Exceptional Achievement Medal, Group Achievement Awards, and an Ames Honor Award NASA Astrobiology Institute Director (2006-2013)	2017/08/21 to 2017/08/29	Participation in Workshop, Research meeting
16	David Lynn		Emory University	Ph.D.	2013, ACS Herty Award 2010-, Fellow, American Association for the Advancement of Science 2002-, Howard Hughes Medical Institute Professor 2000-, Asa Griggs Candler Professor of Chemistry and Biology	2017/08/22 to 2017/08/26	Participation in Workshop
17	Alvaro Moreno		University of Basque	Ph.D.	led the project for the creation of the Museum of Science in San Sebastian (Spain)	2017/09/03 to 2017/09/05	Research meeting
18	Mary Voytek		NASA	Ph.D. Astrobiology	USGS Superior Service Award (2005). Invited scholar, German-American Frontiers of Science (1997 and 2001). Distinguished paper in phycology (1993). Board member of the American Geophysical Union	○2017/09/09 to 2017/09/17 ○2018/01/02 to 2018/01/13	○Research meeting ○Participation in Workshop ○Participation in ELSI Symposium, Research meeting
19	John Spear		Colorado School of Mines	Ph.D.		2017/09/10 to 2017/09/17	Participation in Workshop Research meeting
20	Jack Farmer		Arizona State University	Ph.D.	Charter member of the Executive Council of NASA's Astrobiology Institute (NAI) from 1998-2003. Chairperson of the NAI Mars Focus Group (2000-2003) and of the community-based Mars Exploration Program Analysis Group (MEPAG) in 2003. Geological Society of America (GSA) Geobiology/Geomicrobiology Division's 2012 Award for Outstanding Contributions to the fields of Geobiology and Geomicrobiology. Sequoyah Fellow of the American Indian Science and Engineering Society (AISES)	2017/09/10 to 2017/09/18	Participation in Workshop Research meeting
21	Penelope Boston		NASA Ames Research Center	Ph.D.	Director of NASA's Astrobiology Institute (NAI)	2017/09/10 to 2017/09/18	Research meeting Participation in Workshop

	Name	Age	Affiliation (Position title, department, organization)	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)
22	Robert Hazen		Carnegie Institution	Ph.D. Mineralogy, Earth Science	*Finalist, Royal Society (London) Science Book Prize (2013) *Plenary Lecturer, Society of Economic Geology(2014) Nobel Symposium Lecturer, *Stockholm, Sweden (2013) *Linus Pauling Lectures, Portland, Oregon (2013) *Qualline Lecture, University of Texas (2013) *Naff Symposium Lecturer, University of Kentucky (2013) *Plenary Lecturer, Goldschmidt Conference (2013) *Nobel Symposium, Royal Academy, Stockholm (2013)	2017/09/11 to 2017/09/16	Research meeting
23	Gordon Southam		University of Queensland	Ph.D. Microbiology	Vale-UQ Chair in Geomicrobiology	2017/09/12 to 2017/09/16	Participation in Workshop
24	Penelope King		Australian National University	Ph.D.	ANU VC's Staff Excellence Award - Clara Burton Award for Equity and Diversity 2017 Senior Fellow, Higher Education Academy 2017 ARC Future Fellowship 2014-18 NASA Group Award, MSI, (Mars Science Laboratory) APXS (Alpha particle X-ray spectrometer) Instrument Development and Science Team 2013 Mineralogical Society of America Distinguished Lecturer 2005 Premier's Research Excellence Award (Dorset) 2002 Canada Foundation for Innovation (New Steps) & Ontario Innovation Trust awards 2000	2017/09/12 to 2017/09/17	Participation in Workshop
25	Martin Schoell		GasConsult International Inc.	Ph.D.	2018 ALFRED TREIBS AWARD (Geochemical Society) AAPG (American Association of Petroleum Geologists) Distinguished Lecturer in 1996 1995 AAPG best paper award	2017/09/29 to 2017/11/30	Research meeting
26	Kishore Paknikar		Agharkar Research Institute	Ph.D.	Visiting Professor at Louis Pasteur University, Strasbourg, France and Wayne State University, School of Medicine, Detroit, USA; Advisor at the National Nanotechnology Centre, Bangkok, Thailand; Marico Industries Visiting Fellow, Institute of Chemical Technology, Mumbai	2017/10/02 to 2017/10/08	Research meeting
27	Andrew Steele		Carnegie Institution of Washington	Ph.D. Biotechnology	2009 – 2013 – Visiting Research Scientist – Smithsonian Natural History Museum, Washington DC. 2012 – Royal Society UK - Wolfson Professorial award. 2007 – 2009 - Visiting Adjunct Professor – University of Maryland Center for Marine Biotechnology.	2017/10/03 to 2017/10/07 2018/01/03 to 2018/01/13	Participation in Workshop
28	Shivaji Sisinthy		Center for Cellular and Molecular Biology	Ph.D.		2017/10/04 to 2017/10/07	Participation in Workshop
29	Aviv Bergman		Albert Einstein College of Medicine	Ph.D. aging-research	Harold and Muriel Block Chair in Systems & Computational Biology. External Professor, Santa Fe Institute. International Scientific Committee, Frontiers in Life Sciences, University of Paris.	2017/10/08 to 2017/10/14	Participation in Workshop
30	Paul Falkowski		Rutgers University	Doctoral degree in biology and biophysics	A.G. Huntsman Award for Excellence in the Marine Sciences (1998) G. Evelyn Hutchinson Award (2000) European Geosciences Union Vernadsky Medal (2005) ECI Prize (2010). [19] In 2018, Paul Falkowski was nominated as a recipient of the Tyler Prize (2018).	2018/01/02 to 2018/01/13	Research meeting Participation in Workshop
31	Kenneth H. Nealson		University of Southern California	Ph.D.	Wrigley Chair in Geobiology Fellow, American Academy of Microbiology	2018/01/03 to 2018/01/07	Research meeting
32	Ivo Hofacker		University of Vienna	Ph.D. Physics	Editorial board member Algorithms in Molecular Biology	2018/01/03 to 2018/01/13	Participation in ELSI Symposium, Research meeting
33	Joseph A. Nuth		Senior Scientist, NASA, Goddard Space Flight Center	Ph.D. Chemistry	NASA Group Achievement Award-Astrobiology Roadmap Team (2009) Elected a Fellow of the Meteoritical Society (2004)	2018/01/03 to 2018/01/13	Participation in ELSI Symposium, Research meeting
34	Nigel Goldenfeld		University of Illinois	Ph.D. Theoretical Physics- degree	* Nordsieck Award for Excellence in Teaching (May 2002) * Elected Fellow, Institute of Physics (May 2011) * Elected Member, National Academy of Sciences (May 2010) * Elected Member, American Academy of Arts and Sciences (May 2010)	2018/01/03 to 2018/01/13	Participation in ELSI Symposium, Research meeting
35	Yuk Yung		California Institute of Technology	Ph.D. Physics	Fellow, American Geophysical Union, elected 2003 NASA Exceptional Scientific Achievement Medal, 2004 Fellow, American Association for the Advancement of Science, elected 2005 Academician, Academia Sinica, elected 2010 Fellow, American Academy of Arts and Sciences, elected 2011	2018/01/03 to 2018/01/13	Participation in ELSI Symposium, Research meeting
36	Costantino Vetriani		Professor, Institute of Marine and Coastal Sciences, Rutgers University	Ph.D. Molecular Biology		2018/01/03 to 2018/01/18	Participation in ELSI Symposium, Research meeting
37	Michael Russell		California Institute of Technology	Ph.D. Mineral Deposit Geochemistry	William Smith Medal, 2009, Geological Society of London Nature 2009, feature in 459, 316-319 (Whitfield: Nascence Man)	2018/01/04 to 2018/01/12	Participation in ELSI Symposium, Research meeting
38	Everett Shock		Arizona State University	Ph.D. Geology	Designation of a hyperthermophilic archaeon as <i>Thermogadus shockii</i> , 2011 Fellow, Geochemical Society and European Association for Geochemistry, 2009 Distinguished Geoscience Lecturer, Sandia National Laboratory, 2008 Steinbach Scholar, Woods Hole Oceanographic Institute, 2007 Fellow, American Geophysical Union, 2005 Hooker Distinguished Visiting Professor, McMaster University, 2004 Visiting Scholar, Western Michigan University, 2003	2018/01/07 to 2018/01/12	Participation in ELSI Symposium
39	George Cody		Carnegie Institution of Washington	Ph.D. Geosciences	Distinguished Visiting Scholar, California Institute of Technology, 2010 Japanese Society for the Promotion of Science Fellowship, GL 1996 Enrico Fermi Scholar, ANL 1994 Phi Kappa Phi-Graduate Honors Society, PSU 1991 Mining and Mineral Resources Fellowship, PSU 1991 Texaco Fellowship, PSU 1990	2018/01/07 to 2018/01/12	Participation in ELSI Symposium
40	George Whitesides		Harvard University	Ph.D.	Kyoto Prize for Advanced Technology (Inamori Foundation, Japan) (2003) Benjamin Franklin Medal in Chemistry (Franklin Foundation) (2009) Popular Mechanics Breakthrough Award (2009) Dreyfus Prize in the Chemical Sciences (2009) IKCOC Prize (International Kyoto Conference on Organic Chemistry) (2009) Othmer Gold Medal (Chemical Heritage Foundation) (2010) King Faisal International Prize for Science (2011) F.A. Cotton Award (Texas ACS Section) (2011) Gold Medal (Industrial Research Institute) (2013) Jan Czochralski Award (European Materials Research Society) (2014)	2018/01/07 to 2018/01/12	Research meeting
41	Sang-Mook Lee		Seoul National University	Ph.D.	2008 Commendation (Certificate of Honor), The Board of Supervisors of the City and County of San Francisco 2009 Medal of Merit, Republic of Korea 2010 2010 DO-IT Trailblazer Award, DO-IT Center, University of Washington 2011 Grand Prize, Seoul City Welfare Award	2018/01/07 to 2018/01/13	Participation in ELSI Symposium, Research meeting
42	Marc Koper		University of Leiden	Ph.D.	2016 Brian Conway Prize for Physical Electrochemistry of the International Society of Electrochemistry	2018/01/07 to 2018/01/14	Participation in ELSI Symposium, Research meeting
43	Dan McKenzie		University of Cambridge	Ph.D.	Fellow of the Royal Society (FRS), 1976 Wollaston Medal, Geological Society of London, 1983 Rutherford Memorial Lecture, 1988 Japan Prize, with Dr W. Jason Morgan and Dr Xavier Le Pichon, 1990 Awarded a Royal Society Research Professorship, 1996 Awarded an Honorary DSc from the University of Bristol, 2000 William Bowie Medal, 2001 Crafoord Prize Royal Swedish Academy of Sciences, 2002 Order of the Companions of Honour by Queen Elizabeth II, 2003 Copley Medal, 2011	2018/01/17 to 2018/01/20	Participation in Workshop Research meeting
44	Steven Desch		Arizona State University	Ph.D.	Meteoritical Society's Alfred O. Nier Prize (2003)	2018/01/18 to 2018/02/23	Participation in Workshop Research meeting
45	Anders Johansen		Lund University	Ph.D.	Sten von Friesen prize (Royal Physiographic Society of Lund, 2015) Harold C. Urey Prize in Planetary Science (Division for Planetary Sciences of The American Astronomical Society, 2013) Otto Hahn Medal (Max Planck Society, 2007) The Patzer Prize (Max Planck Institute for Astronomy, 2007)	2018/03/01 to 2018/03/30	Research meeting

Appendix 6 FY2017 State of Outreach Activities

* Using the table below, show the achievements of the Center's outreach activities in FY2017(number of activities, times held).

* Describe those activities that have yielded novel results or that warrant special mention in the "Special Achievements" space below.

* In appendix 7, list and describe media coverage (e.g., articles published, programs aired) in FY2017 resulting from press releases and reporting.

Activities	FY2017 (number of activities, times held)
PR brochure, pamphlet	2
Lectures, seminars for general public	20
Teaching, experiments, training for elementary, secondary and high school students	8
Science café	4
Open houses	1
Participating, exhibiting in events	4
Press releases	8

<Special Achievements>

■ Art and Science Workshop

The collaboration project called the "ELSI 'Creators Meet Scientists (CMS)' Project" has started. This project aims to create new values and innovations for research society in natural sciences in general.

This workshop was attended by Kosuke Fujishima, who is active in the field of astrobiology and has attracted much attention from various media, Mayuko Nakagawa, who is verifying a hypothesis on the origin of life using a powerful tool of "isotopes," and Shigeru Ida, who is a leading expert in the field of planet formation theory; they introduced their research activities in the workshop. On the other hand, nine creators active in various fields such as music, art, stage expression, video, product design, architecture, and games participated in the workshop.

In addition to the kick off workshop in March 2017, we held two more workshops; several collaborative projects are going

■ Contents Development

• New format of scientific articles with multi-layered contents -dealing with accuracy-readability trade-offs by using multi-level writing criteria-

How can we deal with dilemma between accuracy and readability of scientific information in the area of education, PR, and other communication?

We provided readers with five different articles with multi-level writing criteria, where they can see different accuracy-readability trade-offs. The trade-off is named "AR(Accuracy-Readability) Index", which is a measure with priority on readability rather than accuracy (from 5 to 1). This index enables us to deliver contents with multiple trade-offs simultaneously as a package to readers for a single scientific topic.

• Structured Interviews with ELSI researchers to reveal its interdisciplinarity

The same set of questions is asked to all the researchers. You can see the answers to these questions to compare their similarities and diversities. You can also find "connectivity" among different researchers and research topics. Of course, you can enjoy a series of answers by the same researcher. All the questions are designed to facilitate viewers to find these things effectively. By doing so we have tried to convey an interdisciplinary aspect of ELSI's research activities.

<https://www.youtube.com/channel/UC4Hhems5U-nf6neDKauDai2w/>

■ Events for Elementary, Middle, and High School Students

• Workshop "Let's make a planet using dough clay!"

We carried out a workshop "Let's make a planet using dough clay!" at JGU (Sep. 16, 2017) for elementary school pupils. Participants chose one from the Earth, Mercury and Mars, and made the three layers (nucleus, mantle and crust) with flour clay. The workshop enabled them to learn practically and happily common points and differences in the internal structure of the planets.

■ Public Lectures

• School Nalanda Special (communication between religion and science), "Origin of Life and Artificial Cell" (Yutetsu Kuruma) / Dec. 9, 2017

• The 6th ELSI International Symposium Public Lecture / January 9, 2018

• Kavli IPMU-ELSI Joint Public Lecture "Quest for "Origins"" (Shigeru Ida) / January 21, 2018

■ Books for general public

Ida, S., *Extraterrestrials -the exploration technology that has come so far-*, Mynavi Press, 2017

Appendix 7 FY 2017 List of Project's Media Coverage

* List and describe media coverage (e.g., articles published, programs aired) in FY2017 resulting from press releases and reporting.

	Date	Types of Media (e.g., newspaper, television)	Description
1	2017/4/6	Magazine	Nikkei Science reported a new hypothesis by Dr, Hidenori Genda and his colleagues regarding how the marks observed on the Pluto were created.
2	2017/4/6	Newspaper	The research of the Center Director, Professor Kei Hirose was introduced on the Mainichi Newspapers 'Kagaku-no- Mori (Forest of the Science)' section. The article dealt with his experiment to re-create the environment of the Earth interior to understand the magnetic field of the earth .
3	2017/4/9	Newspaper	The new hypothesis by Dr, Hidenori Genda and his colleagues regarding how the marks observed on the Pluto were created was introduced in the Yomiuri Shimbun (morning edition).
4	2017/4/27	Newspaper	Professor Shigeru Ida's comment regarding the life in the Universe in relation with NASA' finding of new planets in the habitable zone was cited in the Mainichi Newspapers (Tokyo Morning edition).
5	2017/5/21	TV	Dr. Kosuke Fujishima was featured in the BS Japan's TV program 'Mirai Eyes (Future Eyes)'. The secondary title of this broadcast was 'Astrobiology': Origins of Life - Where the human beings came from?'
6	2017/5/26	Newspaper	Dr. Kosuke Fujishima was introduced in 'Kagaku Agora (Science Agora)' section of 'News na Kagaku' (Science in the News) page in the Nihon Keizai Shimbun (morning edition).
7	2017/6/7	Magazine	Dr. Joseph Kirschvink's Snow Ball Earth theory was introduced in the featured article titled 'The Earth Complete Freezing' in the Newton June edition.
8	2017/10/27	Web article	Newsweek Japan edition reported that Dr. Yuka Fujii and her colleagues developed a new method of knowing the possibility of a planet reserving water.
9	2017/12/6	Web article	A collaboration project between scientists and creators called 'Creators Meet Scientists' organized by ELSI was reported on the Web Magazine Axis
10	2018/3/31	Web article	Dr. Ramses Ramnirez's research on planets' potential habitable zones was introduced on the Forbes website. Forbes: Extrasolar Ocean Worlds In The 'Ice Cap Zone' Could Harbor Life, Say Planetary Scientists