# Application for Academy Center Certification
# World Premier International Research Center Initiative (WPI)

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|---|---|
| Host Institution | Tokyo Institute of Technology |
| Research Center | Earth-Life Science Institute |
| Host Institution Head | Kazuya Masu |
| Center Director | Yasuhito Sekine |
| Administrative Director | Kei Kurita |

Please prepare this application based on the content of your Center's progress report and the progress plan you submitted for the Center's final evaluation. Summarize the Center's future plans with regard to the following 8 items **within five A-4 pages**. (Also fill out the appendices at the end of this form.)

## 1. Overall Image of Your Center

* Describe the Center's overall image including its identity.

"How did our planet, Earth, form in the Solar System? How did we, Earth's life, emerge on this planet?" – These are fundamental and universal questions that people all over the world might raise once and that ELSI has been tackling since its establishment. ELSI was originally established to promote interdisciplinary researches among astronomy, Earth and planetary sciences, chemistry, complexity science, and life science, and to play an international leading role in solving these fundamental questions. With the high interdisciplinarity and internationality, ELSI has also been promoting administrative innovation and organizational excellence among universities in Japan. Implementing and promoting "science", "fusion", "globalization", and "reform" will continue to be ELSI's (and WPI's) missions in the WPI Academy framework. ELSI's outstanding characteristics are that it covers a truly wide range of disciplines, including all pure natural sciences of physics, chemistry, Earth science, and life science, by scientists gathering under one roof.

## 2. Mid- to Long-term Research Objectives and Strategies

* Describe new challenges in the Center's research objectives and plans after FY2022.

In the first 10 years, ELSI provided the view of the sequence of diversifications and filter selections toward the current Earth-Life system (called "ELSI model"; Fig. 1). However, at the same time, this raises new fundamental questions. Are there alternative planet-life systems in the universe? Are there any other paths to reach to emergences of lives? If we find lifeless planets, how can we characterize them and what can we learn from them? Earth is the only one planet that we know the existence of life. Revealing of the origin of life on Earth may be more like the study of one specific history. The origin-of-life science can be ***Universal Biology*** only after understanding the possibilities of emergence of alternative lives and lifeless planets in the ELSI model.

The sequence shown in Fig. 1 is irreversible, and factual evidence for large parts of key transitions that occurred on primitive Earth has been lost. On the other hand, we are now starting to know that there are multiple planetary bodies that experienced similar sequential evolution, but the evolution has stopped or dramatically slowed down. These bodies include Mars, C-type asteroids, and icy ocean worlds in the Solar System. Thus, future space explorations to these bodies could provide factual evidence for the key transitions in the diversifications and filter selections.

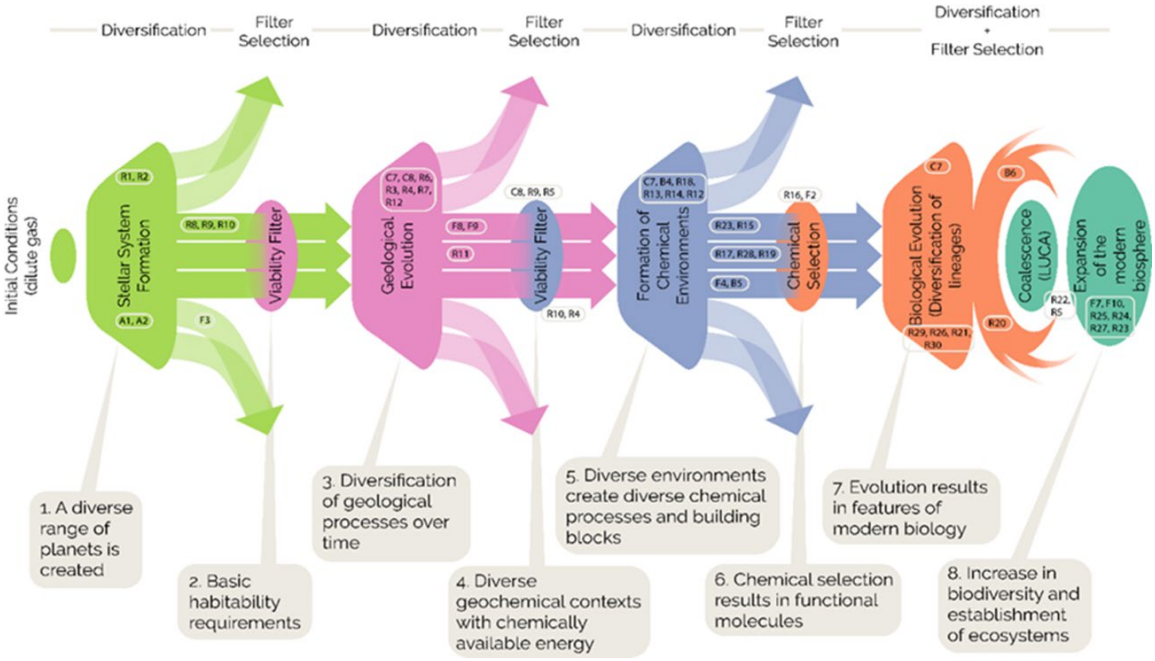


**Fig. 1.** ELSI's new framework developed in the first 10 years. The origin of the Earth-Life system can be understood as a sequence of diversifications and filter selections from formation of a star and planets to modern biosphere.

After the first 10 years, we will tackle the new fundamental questions. While keeping existing approaches in ELSI to understand the emergence of our Earth-Life system, we will newly try to understand the possibilities of alternative planet-life systems to exist anywhere in the universe. The latter approach requires institutional collaborations inside and outside Japan (e.g., JAXA, NASA, NAOJ, and JAMSTEC). ELSI will try to be an incubator for space missions and ground-based observatories through providing conceptual foundations. In other words, ELSI will provide a program of hypothesis-driven missions and observations with Japanese and international mission-design agencies. Through the existing and new approaches, we attempt to construct a concept of ***universal biology***, in which we can characterize life on Earth, or ourselves, in a wide range of parameters of planet-life systems.

In our next decade, we would focus on tackling the following research themes. In one, we try to predict organic and geochemical networks in planetary environments (**1. Organic and geochemical networks on planets**). By combining knowledges on geodynamic circulation and hydrogeochemical cycles, we will construct general models of chemical cycling of bioessential elements and nutrients on planets. Plus, through collaborations with organic chemistry, systems chemistry, and catalytic chemistry, we will investigate possibilities of networks of proto-metabolism and chemical evolution on planetary bodies with different geological settings. These would be a bottom-up approach to predict a diversity and selectivity of functional polymers and molecules.

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

These researches will be done by in-house/institutional collaborations among astronomy, geoscience, chemistry, and life science, and will maximize science values of space missions and telescope observations planned by mission-operation agencies.

## 3. Management System of the Research Organization

* Describe the system of organizational management via which the center will execute the above-described research strategy and plan.
* In Appendix 1-3, list the Principal Investigators, enter the number of center personnel (researchers, research-support staff, and administrative staff), and provide a diagram of the Center's organizational management system.

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

In addition to these existing categories, a new category of **Science Coordinator** will be created to achieve effectiveness and efficiency in research and institutional development. The Science Coordinator will make one research network in a compact ELSI. This Science Coordinator will be the person who oversees all the research taking place at ELSI and uses all available information to promote fusions among PIs and A-PIs. to acquire large grant and support from industries, and to develop institutional collaborations inside and outside Japan. In addition to the Science Coordinator, the Director and Administrative Director will actively participate in such development roles.

## 4. Plan for Promoting the International Circulation of World's Best Brains

* Describe your policy and concrete plan for promoting the international circulation of the world's best brains, which is an important function of the WPI Academy.

**Policy**: Director and Science Coordinators will take initiative to lead the international collaborative researches (Fig. 2). For instance, as the Science Coordinator, Mary Voytek (former Executive Director of ELSI and headquarters of NASA), with abundant knowledge of astrobiology, strong connections with astrobiology space missions, and know-how to promote interdisciplinary researches, will play a central role of Science Coordinator, especially focusing to connect ELSI and top-level astrobiology and space mission teams in both USA and Europe.

The Director and Science Coordinator will promote the international circulation of world's best brains in three ways. First, ELSI will promote mid-term (~two years) exchanges of early-career scientists (researchers and Ph.D graduate students of ELSI course (see Section 5 below)) with key research partners in USA and Europe. Second, ELSI will promote to hire promising, mid-to-early career researchers as fixed-term A-PIs or researchers in ELSI. As the host institute, ELSI has provided world-class facilities and equipment as well as living support to foreign researchers, including their families. Through these two, ELSI can continue to be "**Agora (gathering place)**" for ambitious interdisciplinary scientists, connecting space, Earth, and life sciences, and to create real new fields of science, such as astrobiology and universal biology.

In addition to these two, we will hold international symposia and conferences in order for ELSI to keep as one of the top leading institutes of astrobiology and the origin of life science. ELSI has worked hard to be a globally accessible and appealing center for research that serves as a hub for outstanding science. ELSI will keep being a leader for the global origins community by holding international symposia and conferences.

**Concrete plan**: In the next decade, ELSI will set the following research themes (see Section 2

above): **1. Organic and geochemical networks on planets** and **2. Synthetic and theoretical biology in space**. As for theme 1, ELSI will strengthen connections with space mission teams (space-planetary partners; Fig. 2), with aims to predict and interpret the observational data of organic matter and geochemical materials on planetary environments, Mars, icy ocean worlds, and exoplanets, by using the models constructed by in-house/interinstitutional collaborations. The counterpart research teams of theme 1 include NASA JPL & GSFC, ESA, Colombia Univ., Georgia Inst. of Tech, Penn State Univ., and Univ Colorado, Boulder, with all which ELSI has been conducting collaborative researches. Collaborative research topics include reconstruction of aqueous environments and geochemical cycles on early Mars, habitability and life detection in icy ocean worlds, and possible discovery of atmospheric biosignatures on exoplanets.

Concerning theme 2, ELSI will make collaborative researches through exchanging researchers with major centrals in synthetic biology (biology-chemistry partners; Fig. 2), with aims to understand selectivity and evolution of molecular systems with functions in changing environments (e.g., pH, redox, temperature, pressure, etc.). The counterpart research teams of theme 2 include Harvard Univ., Cambridge Univ., and LMU Munich. Collaborative research topics include formation of proto-cell with materials different from those used by the modern life, artificial evolution of biomolecular systems in planetary environments, and RNA synthesis in geochemical cycles.

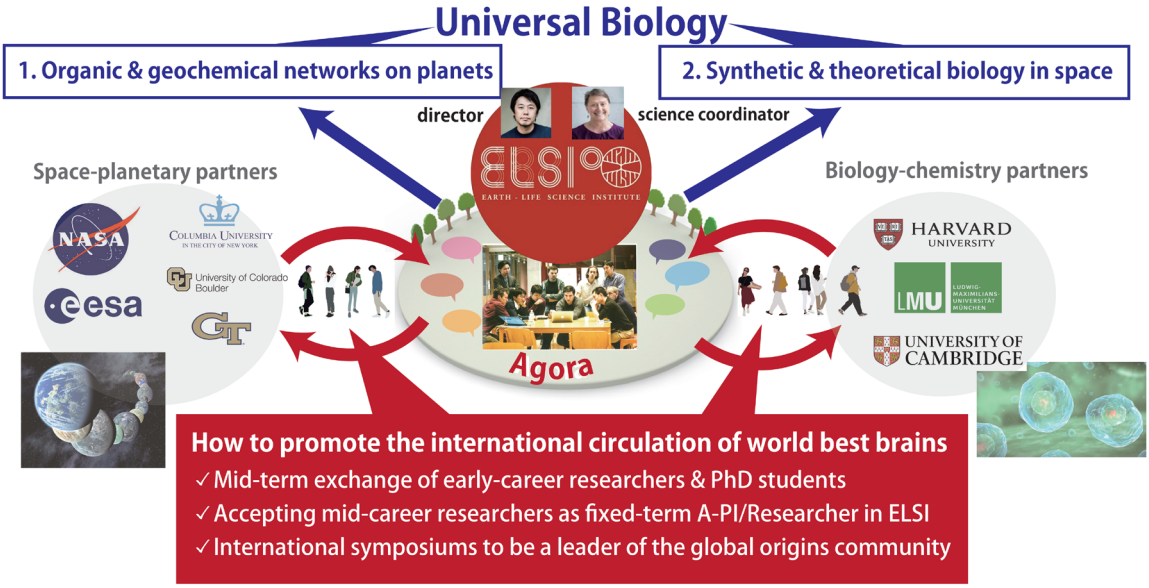


**Fig. 2.** Concepts and plans of the international circulation of world's best brains led by ELSI.

## 5. Plan for Disseminating the WPI Program Achievements

* Describe your policy and concrete plan for disseminating WPI center achievements both within the host institution and to other universities, especially their experience and know-how accumulated on establishing top world research institutes and advancing system reforms.

In the next decade, ELSI will return acquired knowledge and developed systems to Tokyo Tech and public. These returns include education, public outreach, and collaborations with industries. Return to education by ELSI will be a reform of the existing education system. In Japanese education system, academic subdivisions occur as the grade progresses. However, many fundamental issues in science, industries, and society are more complex and cannot be solved by a single subdivided discipline, calling for integration of academics. ELSI will provide an integrated education course of Earth-Life sciences. This will be a benchmark for establishment of other integrated education programs in Japan. Through return to public and industries, ELSI will seek new

ways to acquire fund from society to be a self-propelled, pure-science institute. This would be a reform of way of being a national pure-science institute in Japan.

Given the unique international and interdisciplinary expertise, ELSI will be able to be a premier research and education institution on campus of Tokyo Tech. From 2022, ELSI faculty will have a major role in training the next generation of researchers and engineers in interdisciplinary research by teaching graduate course and supervising students. ELSI will start new integrated graduate course, called the ELSI course, in Tokyo Tech. In the ELSI course, we will provide systematic lecture series of astrobiology, lab/industry/overseas internships, and practical project exercises in collaboration with industries. This course is a 5-year (Master-PhD) program and will financially support students. This is a unique education program in universities of Japan.

## 6. Plan for Sustaining the WPI Brand

* Describe your plan for sustaining and enhancing the WPI brand.

ELSI will continue its annual ELSI International Symposium, which had been very effective in increasing the visibility of ELSI worldwide. For scientific outreach activities, ELSI PR office has been organizing a public lecture series and joint Kavli-IPMU/ELSI/IRCN lecture series "Quest for Origins". The science theme of ELSI or astrobiology – How did life emerge? Is there life beyond Earth in space? – is fundamental and universal to people all over the world. We will make an appeal to public through sharing science achievements and will acquire ELSI funs to financially support ELSI's science activities. ELSI's PR Office is already working along with Tokyo Tech PR in English-language based science outreach and communication. We have hosted the Japan Science Communication Forum twice (2018, 2019), attended by PR and outreach staff from universities and institutions from all over Japan. ELSI will continue hosting this event and providing regular science communication trainings.

## 7. Support by Host institution

* Describe measures that the host institution will take to support and sustain your Center.

To maintain ELSI's position as one of the world's leading research centers after the completion of the WPI program, Tokyo Tech has guaranteed that it will provide 10 full-time PIs and supporting staff necessary for the operation of the institute. In addition, Tokyo Tech will continue to support ELSI with the presidential discretionary budget and provide space for laboratories, meeting rooms, and offices. ELSI has already been assigned eight tenure positions for full-time PIs. These are the results of Tokyo Tech positioning ELSI as a key institute in its mid- and long-term strategic plans for strengthening education and research. In the newly-established ELSI course, Tokyo Tech has already prepared a scheme to financially support the graduate students enrolled in this course.

## 8. Resource Allocation Plan

* Describe your plans over a 5-year period for allocating resources acquired from both the host institution (e.g., financial resources and positions) and from external research funding to execute the Center's functions and activities described above.
* In Appendix 4, enter concrete numbers in the Resource Allocation Plan.

In addition to the financial support offered from Tokyo Tech, ELSI is trying to obtain large grants. Also ELSI will make collaborations to promote research projects with industries. For instance, ELSI's science, such as cycles of nutrients on planets, is applicable to space agricultures on the Moon and Mars. Many of ELSI's researches can be applicable to space development and business. Since an artificial cell is a compact and functional system, social implementation of synthetic biology is another potential to collaborate with industries. Under leaderships of the Director and Science Coordinators, ELSI will organize collaborative development projects as a project exercise of the ELSI course. This would provide an opportunity of recurrent education for young company employees.

# Appendix 1 List of Principal Investigators (Application for Academy Center Certification)

* If the number of principal investigators exceeds 10, add rows as appropriate.
* Give age as of 1 April 2022
* For investigators who cannot participate in the center project from FY 2022, indicate the time that their participation will start in the "Notes" column.
* Enter the host institution name and the center name in the footer.

| | Name | Age | Current affiliation<br>(position title, organization, department) | Academic degree and current specialties | Effort(%)* | Notes<br>(Enter "new" or "ongoing") |
|---|---|---|---|---|---|---|
| 1 | Yasuhito SEKINE | 43 | Director,<br>Tokyo Institute of Technology, Earth-Life Science Institute | Ph.D.,<br>Planetary Science, Astrobioloby, Evolution of Earth and planets | 80 | ongoing |
| 2 | Kei HIROSE | 54 | Professor, The University of Tokyo, Department of Earth and Planetary Science | Ph.D., High-pressure Geoscience | 30 | ongoing |
| 3 | Mary VOYTEK | 63 | Professor, Tokyo Institute of Technology, Earth-Life Science Institute<br>Professor, Columbia University<br>Senior Scientist, NASA | Ph.D.,<br>Biology and Ocean Sciences, Astrobiology | 25 | ongoing |
| 4 | Shigeru IDA | 61 | Professor, Tokyo Institute of Technology, Earth-Life Science Institute | Ph.D.,<br>Planetary Sciences, Planetary Physics | 80 | ongoing |
| 5 | John HERNLUND | 49 | Professor, Tokyo Institute of Technology, Earth-Life Science Institute | Ph.D.,<br>Geophysical Modeling, Fluid and Solid Dynamics | 80 | ongoing |
| 6 | Eric SMITH | 56 | Professor, Tokyo Institute of Technology, Earth-Life Science Institute<br>External Professor, Santa Fe Institute<br>Senior Research Scientist, Georgia Institute of Technology | Ph.D., High-energy/particle Physics | 80 | ongoing |
| 7 | Yuichiro UENO | 47 | Professor, Tokyo Institute of Technology, Department of Earth and Planetary Sciences | Ph.D.,<br>Geochemistry | 30 | ongoing |
| 8 | Shawn McGLYNN | 38 | Associate Professor, Tokyo Institute of Technology, Earth-Life Science Institute | Ph.D.,<br>Evolutionary Biology, Microbial Biochemistry | 80 | ongoing |
| 9 | Ryuhei NAKAMURA | 45 | Professor, Tokyo Institute of Technology, Earth-Life Science | Ph.D., Electrochemistry | 80 | ongoing |
| 10 | Hidenori GENDA | 47 | Associate Professor, Tokyo Institute of Technology, Earth-Life Science Institute | Ph.D., Planet Formation | 80 | ongoing |
| 11 | Tomoaki Matsuura | 50 | Professor, Tokyo Institute of Technology, Earth-Life Science | Ph.D., Biotechnology | 80 | ongoing |
| 12 | Kosuke Fujishima | 39 | Associate Professor, Tokyo Institute of Technology, Earth-Life Science Institute | Ph.D., Astrobiology | 80 | ongoing |

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

# World Premier International Research Center Initiative (WPI)
# Number of Center Personnel

| | | | FY2022 | |
|---|---|---|---|---|
| | | | Number of persons | % |
| Researchers | | | 28 | |
| | Overseas researchers | | 15 | 54 |
| | Female researchers | | 8 | 29 |
| | Principal investigators (PIs) | | 12 | |
| | | Overseas PIs | 4 | 33 |
| | | Female PIs | 1 | 8 |
| | Other researchers | | 7 | |
| | | Overseas researchers | 5 | 71 |
| | | Female researchers | 3 | 43 |
| | Postdocs | | 9 | |
| | | Overseas Postdocs | 6 | 67 |
| | | Female Postdocs | 4 | 44 |
| Research support staffs | | | 35 | |
| Administrative staffs | | | 15 | |
| TOTAL | | | 78 | |

# World Premier International Research Center Initiative (WPI)
# Diagram of Organizational Management System

- Diagram the Center's organizational management system and its position within the host institution in an easily understood manner.