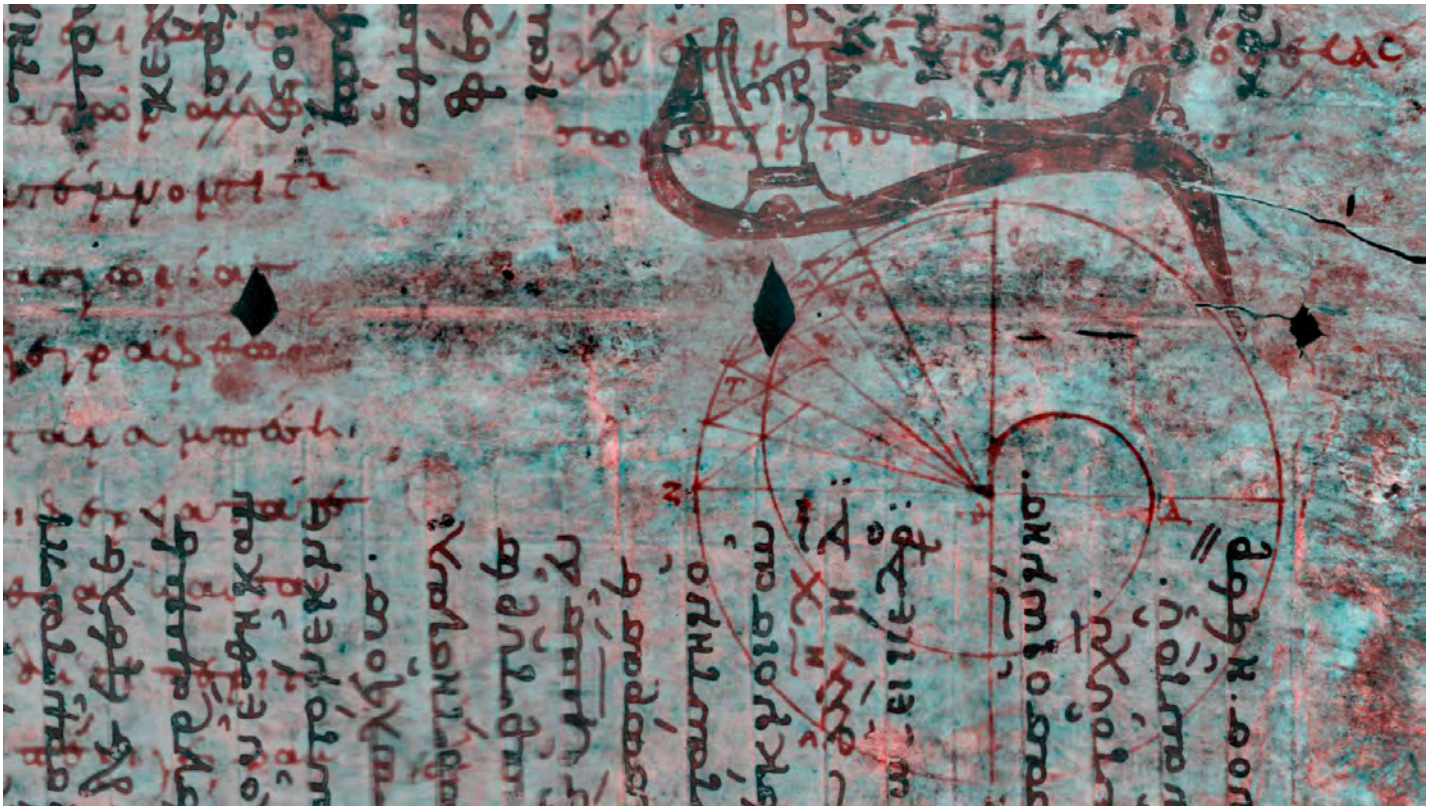


The Archimedes palimpsest is a Byzantine copy of a previously unknown work by the ancient Greek mathematician Archimedes of Syracuse. It was overwritten with religious texts in the 13th century, but the original was rediscovered and the underlying writing and math was uncovered ten years ago using advanced imaging technology.

1. Signatures

It's an everyday technique for scientists in the origins-of-life field, but it remains something of a marvel.

The presence of early microbial life forms will not be preserved in fossils – no bones, no telltale organics left behind – but they can be preserved in isotopic signatures. A less-than-normal amount carbon-12 in a rock can mean that life was once present because that's the isotope of carbon that life prefers and then leaves the carbon-13 isotope behind.

Using the same kind of logic and measurements, geochemists can tell what elements and compounds were present in an ancient atmosphere by analyzing what was left behind. A skewed ratio of sulfur isotopes in a sample, for instance, would tell scientists that there was very little – or later a lot – of oxygen in the atmosphere at one time.

While we can directly measure and analyze biology and chemistry and geology on the Earth now, origins-of-life and early-Earth science is driven by creative indirection.

And not just from the faint isotopic remains of long-ago interactions. Sometimes the issue is working out what must have happened to produce a particular reality today. An iconic example: RNA exists everywhere, yet the long-chained molecules needed to form the backbone of RNA break apart in water. So how did the earliest RNA molecules form, since almost everything else involved with the origin of life needed water?

Might the same logic of indirection work when it comes to understanding the present and the promise of a social construct? Might it, for example, be useful in understanding

Andre´-P. Drapeau P.

Stromatolites are round, multilayered mineral structures built by layers upon layers of cyanobacteria mats. They are the oldest clear evidence of life on Earth, with some having been dated to more than 3.5 billion years ago.

a unique social construct like the Earth-Life Science Institute, on the campus of the Tokyo Institute of Technology?

Some of what we see is self-evident: a thoughtfully conceived new building; a series of public and private seminars, workshops, and presentations; a population of scientists from varied disciplines who make up an unusual mixture of Japanese and non-Japanese researchers from around the world.

We can see that in a surprisingly short time ELSI has science and scientists. This achievement is noteworthy but was not at all preordained. Things could have turned out quite differently, as they did in many stages of the origin of life story itself.

So how did this happen and why?

I suggest we look to those often-faint, left-behind signatures of decisions made and unaddressed, of people and their science and values that have been woven into the fabric of the endeavor. Isotopic social and scientific remains, if you will.

Perhaps they, if teased out, can tell us even more than what our eyes can now see and our ears can now hear about not only the past, the present, and the likely future of a place but also about its strengths and its fault lines. They might even provide insights and lessons for similar social constructs in the future.

Origins stories are always cloaked in a complex system of actions and reactions. That's why they're so interesting.

Kei Hirose - Director ELSI

2.The Idea of ELSI

ELSI was born out of a formal government consensus that Japanese science, however strong it might be in some areas, was nonetheless as a whole falling behind. The word "crisis" was frequently heard.

That something needed to be done was a decision formally taken in 2007, when the Japanese economy was in the doldrums and had been for some time. While still prosperous by global standards, the nation was judged by its leaders to be under-performing in some essential way, while at the same time doing an insufficient job of highlighting the scientific advances that were being made.

One way out designed by the government was to set up and generously fund a number of scientific institutes that would be run in novel ways and would have as their goal future recognition as world-class destinations – thus the World Premier International Research Center Initiative (WPI).

As explained to me by one of the men at the center of the initiative, Toshio Kuroki of the Japan Society for the Promotion of Science, those groups competing for the $100 million over ten years would have to clear a bar that was both high and quite unusual:

- They would have to outline plans to attract and keep significant numbers of quality scientists from abroad.
- They would have to design policies to make the institutes more freewheeling and open to innovation than many institutions in Japan.
- And they would have to provide models for transforming some of the traditional ways that Japanese science and education have operated.

"For Japanese science, change was and is essential," says Toshio Kuroki, who was the longtime program manager for the WPI program. "We need new ways to encourage as opposed to discourage innovation, and we need to make it more desirable for talented young Japanese scientists to stay and work in Japan."

The selection of what would ultimately be nine new $100 million institutes took place over five years and resulted in a rather eclectic mix. Some institutes have a decidedly practical mission – in materials science, in nanotechnology, in sleep research, in green energy – but two are embedded in

Shigeru Ida - Vice Director ELSI

basic science. First in 2007 came a center at the University of Tokyo for research into the origin and evolution of the universe, and then, in 2012, came ELSI at the Tokyo Institute of Technology.

Under the leadership of Kei Hirose, a renowned researcher of deep-Earth dynamics, ELSI set out to wrestle with the very big question of how life began and evolved on Earth.

The effort would be unique in several crucial ways: ELSI would focus as much on the Earth science question of how our planet became a place conducive to life as it would on how that life might have started. And it would be a stand-alone institute with the goal of tackling the many intractable questions surrounding the origin of life, rather than a looser affiliation of scientists with similar projects and goals but many home bases.

Mary Voytek, director of the astrobiology program at NASA, knows as much as anyone about where and how the origins question is being studied. Her conclusion: There is no place in the world like ELSI. It is unique in bringing together a significant number of scientists into one building to work separately and together on these questions.

So ELSI started with the highest of aspirations, with generous funding, and with a research approach that encouraged scientists from different disciplines (and different countries) to focus on problems they together identified as related.

In an effort to internationalize the feel and workings of the institute, meetings and lab consultations were to be held in English even though the original ELSI staff was made up largely of Japanese researchers and administrators.

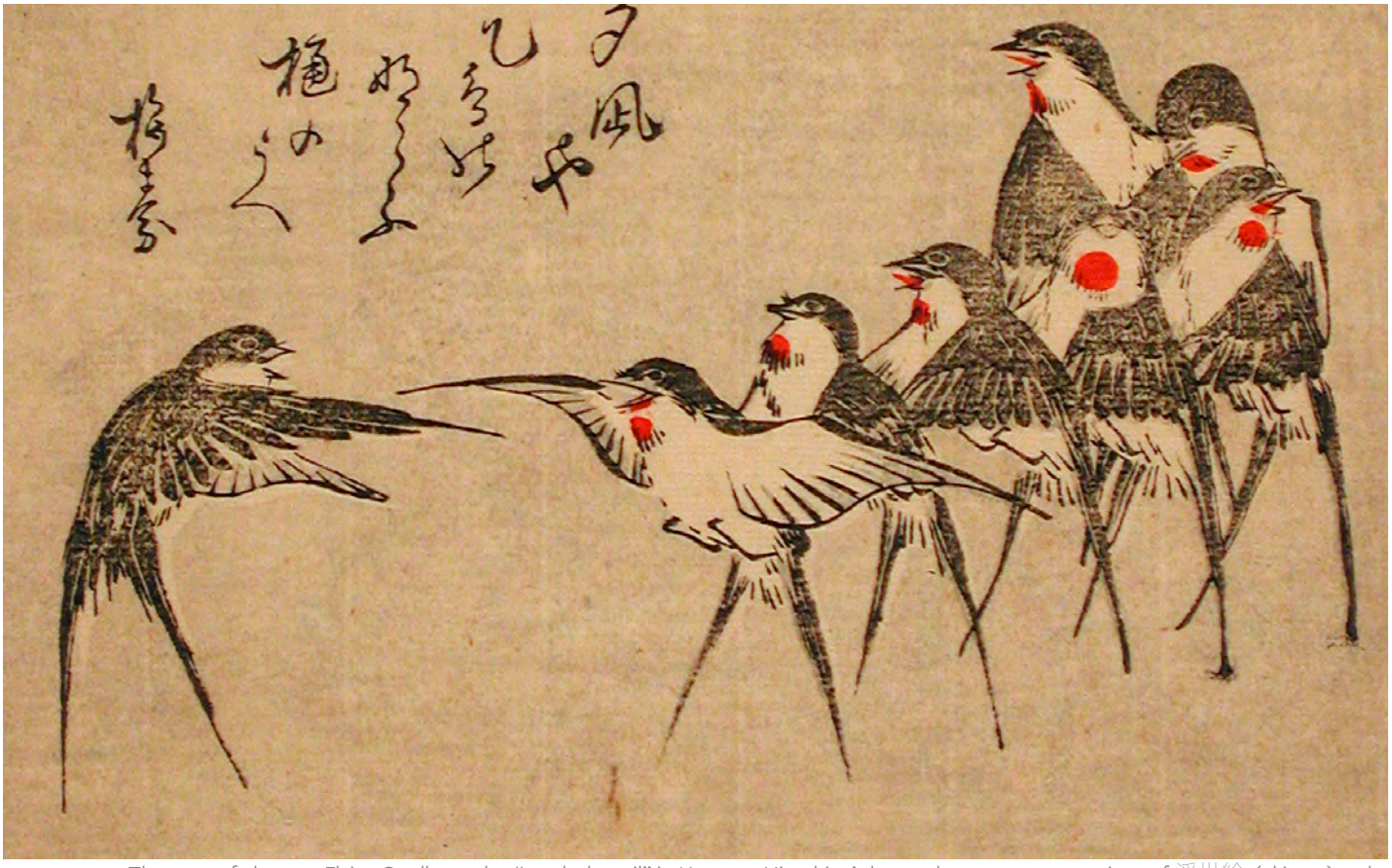
A difficult undertaking under any conditions, the birthing of ELSI would take place in a wider campus environment that remains often hierarchical, as many Japanese scientists and educators describe it. Scientists tend to primarily be loyal to their disciplines, and ways of approaching science remain – very broadly speaking – distinctively Japanese.

As ELSI Vice Director Shigeru Ida describes it, a great and longtime strength of Japanese science has been its ability to bring together individuals to form cohesive teams that work with great focus on a subject. Whereas many of the international newcomers are inclined to think about their subjects as broadly as possible, many Japanese scientists are inclined instead to dig deep into the specific areas of their expertise. The traditional Japanese approach is both a great strength, Ida said, and also at times a source of scientific conservatism.

Isaiah Berlin's hedgehog and the fox come to mind: A fox knows many things, but a hedgehog knows one important thing well.

At ELSI the signatures of this dichotomy, and the results of its creative tension, are not hard to find.

Mary Voytek is the leader of NASA's extensive astrobiology program, and is a frequent visitor to ELSI. As a Global Science Coordinator for the ELSI Origins Network program, she has shared her expertise in science and management as well as given guidance to early-career researchers at ELSI. She has also helped connect NASA scientists with the institute.



The cusp of change. Flying Swallows play "catch the tail" in Utagawa Hiroshige's late 19th-century masterpiece of 浮世絵 (ukiyo-e) style.

3.Fertile Ground

Why Tokyo? Or, viewed from another angle, why origins of life? Why would the Japanese government select that subject for one of its premier institutes?

While deep-Earth science and the dynamics of the early, pre-biotic Earth are historically important in Japan – for reasons having everything to do with its location on the Ring of Fire – origins of life have not been a major focus, and especially not at the Tokyo Institute of Technology.

But there are good reasons why origins-of-life science would resonate in Japan. Some had to do with particular individuals and their passions and others had to do with the culture, says former Tokyo Tech biology professor and former ELSI administrator Motonori Hoshi.

His explanation of the origin of ELSI begins, however, on an unexpected note: The long-ago arrival in Japan of one Edward Sylvester Morse, a student of the renowned Harvard University professor and innovator Louis Agassiz.

The footloose young Morse landed in Tokyo after Japan had been opened up to the world by the Meiji Restoration and the gunboats of Commodore Matthew Perry. That period of opening and the American role in it is usually described in terms of opening Japan for trade, and the ensuing understanding by Japanese leaders that the country had to modernize or risk domination by others.

But on a less-martial and less-commercial note, quite a few Europeans and Americans such as Morse began coming to Japan as well and their contribution was rather different. A life scientist and specialist in mollusks, Morse introduced zoology to Japan and established the first marine laboratory in the country. And on a regular basis, he lectured on Darwinian evolution.

E.S. Morse first came to Japan in 1871 at his own expense to collect marine animals (brachiopods) for his scientific work. He researched extensively and lectured on evolution and other topics, and became the first professor of zoology in Japan.

ELSI Science Steering Committee chair Eric Smith and former ELSI Administrative Director Motonori Hoshi walking on Mt. Fuji.

He fell in love with the country and its culture, returned numerous times, and became an avid collector of Japanese ceramics. Such was the sophistication of his ceramics collection that Count Ōkhuma Shigenobu, an influential man of the day, donated his own fine collection to Morse. These priceless ceramics now form part of the "Morse Collection" of Museum of Fine Arts in Boston. Morse later became the president of the American Association for the Advancement of Science.

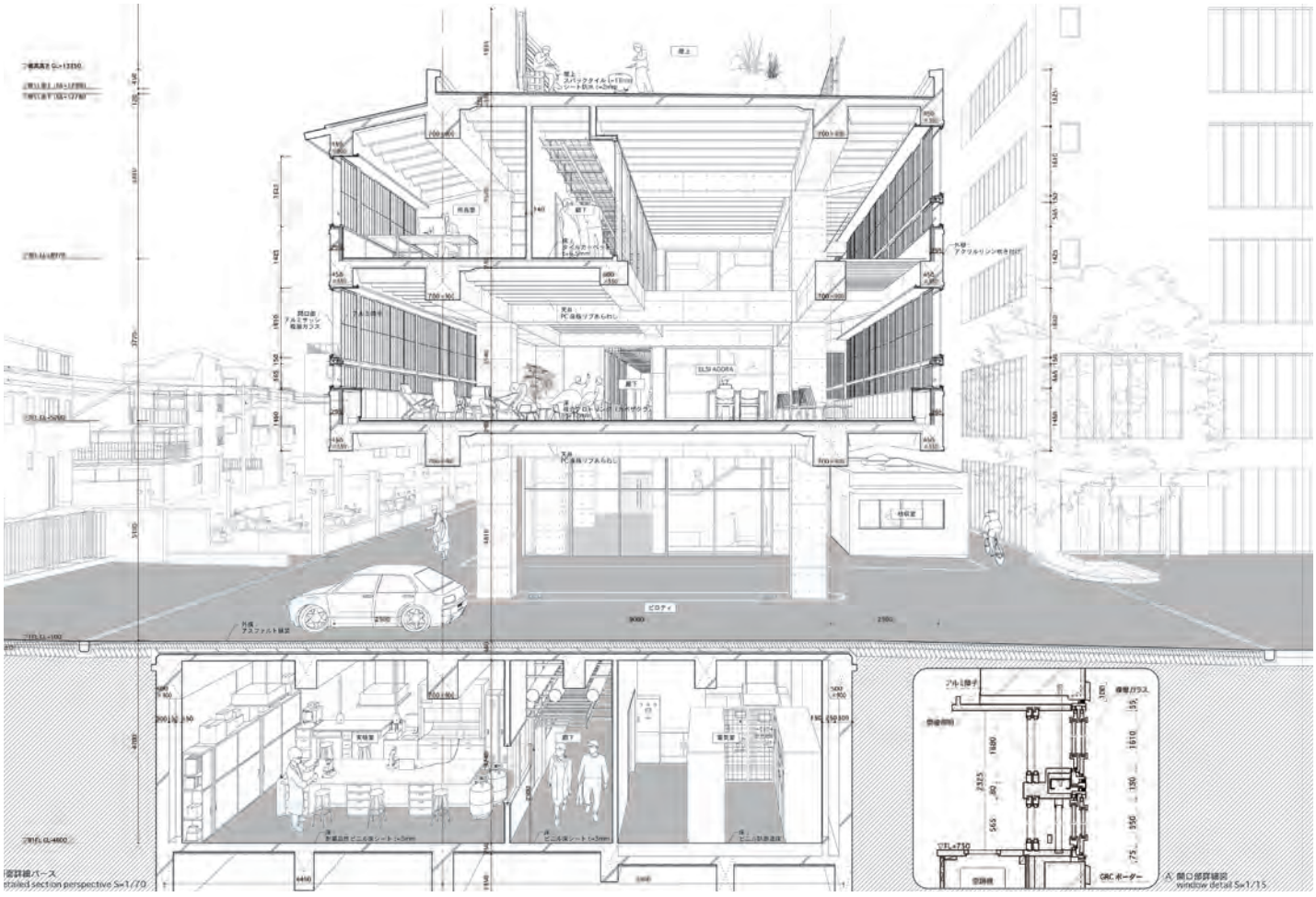
As Hoshi explains, Morse and other American and European scientists were welcomed and appreciated in Japan, and their message on evolution and the changing Earth fell on receptive ears.

And why not? The Buddhism that pervades the culture and has as a central theme that change is inherent in all things.

This iconic message, as expressed long ago by the Buddha, is a key aspect of his teaching. The embrace of inevitable change, Hoshi says, made evolution an entirely comfortable explanation of the world in Japan, and there has never been much (or possibly any) opposition to it. Evolution might be expressed, in fact, as a scientific elaboration on that central Buddhist teaching.

So ELSI was generously funded by the Japanese government (specifically the Ministry of Education, Culture, Sports, Science and Technology, or MEXT) in part because it dealt with issues that are of interest to the society and that fit quite well into its general comfort zone. This preference was not a promoted factor in the specific decision making; rather, it was a silent but definitely supportive part of the background.

The broad origins-of-life subject also fit into the WPI vision of starting up institutes that it expected to have some global importance. And that often means setting up shop in areas of inquiry that have, to some extent, not been similarly embraced elsewhere. While there are origin-of-Earth and origin-of-life programs at numerous campuses around the world, there is no other large institute dedicated solely to those two subjects.



©Jumpei Suzuki

4.The Originators

The men who conceived of ELSI and put together the winning proposal were the deep-Earth, high-pressure specialist Hirose; the long-respected planet formation expert Shigeru Ida; the biogeochemist Yuichiro Ueno; veteran geologist Shigenori Maruyama; and, later, Jun Makino, now a prominent pioneer in space-related, high-performance computing and then an at-large researcher, like the others, at the Tokyo Institute of Technology.

The ELSI building was designed by Yoshiharu Tsukamoto and team. Tsukamoto is an architecture professor at Tokyo Tech's School of Environment and Society. His designs follow his theory of "architectural behavior," which takes into account how a building evolves, how it touches and affects people, and how it fits into its setting.

Another person present at the beginning was astrophysicist Piet Hut of the Institute for Advanced Study at Princeton. Hut specializes in computer simulations of dense stellar systems and, in the broadest of ways, interdisciplinary studies.

Hut had spent enough years in Japan to speak the language well and was brought into the ELSI effort primarily by Makino, for whom Hut had been something of a mentor. As an insight into how important relationships are formed in this premier science world, the story of the Makino-Hut connection is illustrative.

Hut, at that time 35 and the youngest person ever hired onto the IAS staff, had invited a prominent astrophysicist from Tokyo to a 1993 conference on "Dense Stellar Systems" at the Institute for Theoretical Physics at Santa Barbara. At the last minute, the man became ill and called Hut to ask if his student could take his place. Hut asked about the replacement and learned that he was only a beginning masters student, 20 years old, not terribly proficient in English, and had never spoken before an audience before. He didn't sound promising.

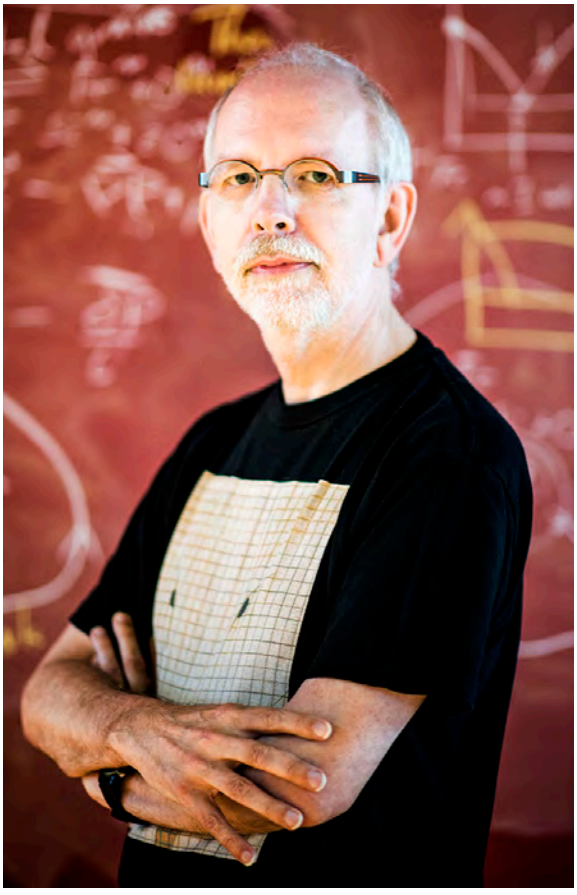
And when Makino got up to speak, he was soft-spoken, accented, and, not surprisingly, uneasy. Few people understood what he said. But Hut and at least one other specialist in their field realized that young Makino had just solved an important problem in the simulation of stellar dynamics. Years later, Hut still describes the day with delight.

A decades-long collaboration began between Hut

and the precocious student. And so, when Makino considered in 2012 who might be an attractive, international addition to the ELSI-proposal team at Tokyo Tech, he had no doubt that it was Piet Hut.

"He is a famous scientist and has very wide connections in many fields," Makino says. "He started in physics and astronomy but had shifted more to philosophical subjects and math. He brought to us what nobody else could bring."

Hut's philosophical side would be particularly important both because it would help broaden the proposal and also, Makino said, because the origin-of-life question still didn't really have a hard science approach that scientists could agree on.



Piet Hut

It should come as no surprise that the then-existing proposal to WPI played to the hard-science strengths of Tokyo Tech in the earth and planetary sciences, where staffing is generous and expertise deep. Planet formation, geochemistry, and especially research into the Earth's deep mantle and core were fields where the school had an impressive research track record.

But the proposal was less robust on the bioscience side of the equation, as were two previous Tokyo Tech proposals that had failed to be selected several years before. That weakness was worrisome to Hut in particular.

Something of a wizard at connecting people and organizing scientific efforts, Hut reached out to someone he had never met but who seemed like a perfect addition to the ELSI proposal – Harvard Nobel Laureate Jack Szostak. While Szostak had won his Nobel for work in medicine, he had changed fields soon after and embraced origins-of-life research, where he quickly became a star.

Hut says it must have been his IAS pedigree that moved Szostak to get back to him right away. They met and dined with Harvard early-Earth expert Andrew Knoll (who knew some of Hut's interdisciplinary work on palaeontology), and Szostak became part of the ELSI team and its proposal. Nobel Prize winners are often described as demigods in Japan, and it seems reasonable to assume that Szostak's participation helped put ELSI over the top to win the $100 million grant.

But even Szostak's presence might not have been enough without the strong support of Tokyo Tech's President, Yoshinao Mishima. A material-sciences expert, he had just been named to a five-year term as president, and he was clearly proud to tell me later that his first formal responsibility as president was to go before the WPI selection board and make the case for ELSI.

Presidents of universities vying for WPI funding are naturally supporters of those programs. But for Mishima it was something more. The changes that the WPI had set as priorities – internationalizing, innovating, and breaking out of some of the more hidebound ways of Japanese academic science – were among the primary and most deeply felt goals that he brought to his new job at Tokyo Tech.

Mishima had spent some years as a doctoral student at the University of California, Berkeley, and he knew about and very much appreciated the more freewheeling, interdisciplinary American and European way of conducting science. So it was both auspicious and fitting that his first formal task was to argue ELSI's case.

Jun Makino

"My address to the (WPI) program committee was literally the first thing I did formally as president," Mishima said recently. "And I was very glad to do it because I was 100 percent behind the idea."

The selection was made in October, 2012.

Getting approval and substantial funding to set up an institute is difficult but straightforward. Actually setting one up – collecting the scientists, creating a culture, and building a community -- is quite another thing.

ELSI began in the bottom floors

of a distant building on the Tokyo Tech campus, with no labs, no meeting place other than a small lunchroom, and no clear path forward to implement their vision.

Vice Director John Hernlund - a deep-Earth modeler who had worked with Hirose before and was, with his wife, Christine Houser, among the first international hires at ELSI - remembers his cramped office in a room shared with mainframe computers. To get any work done, he brought large earphones to keep the noise out. He also remembers sneaking in some chairs from the lobby of the Earth & Planetary Sciences department building so that visitors and colleagues could sit down.

Almost all the principal investigators were earth scientists (as opposed to life scientists) and almost all were Japanese. The same was true of the younger research scientists.

Complicating the situation was that the world's habit of always changing also operated in Japanese politics and government. The WPI was started under the long-ruling Liberal Democratic Party, but it lost control of the government to the Democratic Party in 2009. After an unstable three years in government, the Democratic Party of Japan was defeated in December, 2012 and the Liberal Democratic Party of Japan took power again.

December 2012 also happened to be when ELSI was selected as a WPI winner, so it started out in a time of some government disarray. It wasn't until late 2013 that the government's funding really began to flow, in effect cutting ELSI's ten years of support to just a bit over nine years. It was, by all accounts, a rocky beginning.

Origins stories generally start with chaotic conditions, and order is achieved, necessary structures are created, and a positive complexity grows later. In a manner that ELSI computer simulators now explore, advantage can flow in surprising ways from the destabilized situation.

The construction of the ELSI building is a prime example of that unpredicted and unpredictable turnaround from disadvantage to advantage.

As Tokyo Tech President Mishima was well aware, the traditional governing party that swept back into power in late 2012 had a general policy of distributing government stimulus funds to a vast array of building projects. And one category of building the new government was focused on was university expansion.

Mishima could have pushed for any number of new buildings on the Tokyo Tech campus, but he selected the fledgling (and unhoused) ELSI effort as where he wanted to put what turned out to be some $25 million. ELSI's WPI money was supposed to pay for the construction of its new quarters, but the ELSI building was financed instead by the government's university-expansion funding. The result was that ELSI could spend all its money hiring scientists, inviting guests, and setting up seminars, workshops, and symposia.

What a building it turned out to be! At the request of institute leaders, their new home featured a spacious and central two-story agora, a traditional Greek gathering place for learning and discussion. Several of the agora walls feature red chalkboards at which scientists commonly meet and chalk dust flies. Comfortable chairs abound.

The building includes a tatami room and meeting rooms large and small are also everywhere. And beneath the agora and now in a second ELSI building are labs for the scientists to do their work, although a growing cohort of researchers rely instead on their computers, often because they work with computer simulations.

Though the distinctive agora has an iconic western pedigree and feel, the idea for it came initially from Shigeru Ida, the planetary formation specialist and one of the original scientists to propose the idea of ELSI. Ida is a theorist, and he says he wanted to have a place for other theorists to meet and discuss ideas, a place somewhat parallel to what the lab scientists have two flights below.

As explained by Vice-Director Ida, the ELSI building was designed with an ancient Japanese palace or grand house in mind.

Ida had seen similar spaces at the University of Cambridge and the University of California, Santa Barbara, so visualizing the kind of central gathering place that would help bring ELSI scientists and staff together came easily to him. And as the amiable Ida says with visible satisfaction, it has clearly served that purpose.

ELSI won its WPI grant in late 2012, but it wasn't until late 2015 that the scientists could come out of their far-flung offices and inhabit the clean lines of the elegant home built specifically for them. The institute's new building had laboratories to offer scientists and so could begin to draw more researchers on the biological and chemical sides of the origin of life question.

Many who have been at ELSI since the early years speak of the time lost putting the institute on its feet. Given that the WPI ten-year-deadline clock is always ticking, that concern is hardly surprising.

It is undoubtedly true, however, that five years after that rocky beginning, ELSI is on the path to becoming the world-class institute that the WPI banked on. It has a wide range of researchers from Japan and around the world – 60 full time and hundreds more with a variety of formal and informal connections who produce often pioneering and provocative work.

Nobody expects quick answers to the questions surrounding how the Earth became ready to support life and then how life began. But now scores of scientists at ELSI are focused on these difficult questions.

But perhaps we are getting ahead of this story.

Photo courtesy of Tokyo Institute of Technology

President Mishima and ELSI

Tokyo Institute of Technology President Yoshinao Mishima is not someone for whom an international origins of Earth and origins of life institute would, at first glance, appear to be a high priority.

His background is in materials science, perhaps the most applied of sciences. His last published article before becoming president was titled "Electron Diffraction Study on the Crystal Structure of a Ternary Intermetallic Compound Co_3AIC_x." What is studied at ELSI may someday have some practical use, but that is hardly the point of the enterprise.

Tokyo Institute of Technology President Yoshinao Mishima has been a strong advocate for the Earth-Life Science Institute throughout his six-year tenure term.

But Mishima does have a strong background in interdisciplinary science – running two non-traditional institutes at Toyko Tech before becoming president. He was also dean of the Interdisciplinary Graduate School of Science and Engineering.

What's more, he received his PhD at the University of California, Berkeley, and so was exposed early to less traditional approaches to education.

"The level of science in Japan is very high, especially in areas like material science, physics, mathematics, robotics and information science," he recently said.

"Since 100 years ago, the Japanese education system has been pretty good and has made space for researchers to concentrate in their own field. The idea was always to go deeper and deeper into things; narrow but deep."

"However, once we start talking about scientific fusion or interdisciplinary work, Japanese scientists have not done so well. They try to live in their own fields. The idea, for instance, of combining earth sciences, chemistry and biology to make astrobiology is very hard for Japanese to get comfortable with."

"But that is a very important direction that world-class science is going – becoming more interdisciplinary. In the 21st century, this is the kind of scientific foundation we need."

This thinking was central to his drive to secure additional funds for the ELSI building, and to prepare the ground for continued Tokyo Tech support for ELSI after the WPI funds run out in 2022.

ELSI vice director John Hernlund, who has worked a great deal with Mishima, said that the president was essential to the survival and growth of ELSI.

"The fact is that he shepherded us through the rough times, the starting phase. He was amazing to us. There were so many times when things could have fallen fully apart and he saved us."

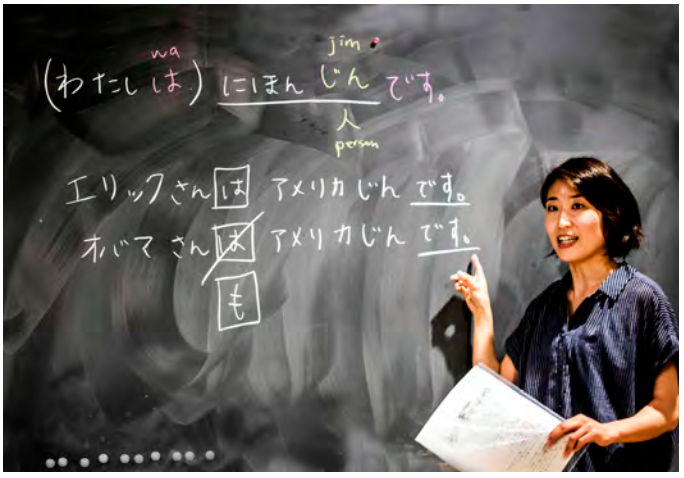
And ELSI director Kei Hirose has been in on scores of meetings with Mishima and agrees that the president has been a constant and forceful ally.

"Mishima-san had a very good experience when he was a doctoral student at (the University of California,) Berkeley, and he has been trying to make Tokyo Tech similar to Berkeley," Hirose said. "He believes that globalization must occur at Tokyo Tech otherwise our presence in the world becomes less and less."

Of the many signs of Mishima's support for ELSI, none is perhaps as striking as his (kept) promise to hire ELSI investigators as full-time Tokyo Tech tenured staff, and to similarly support a small cadre of less senior researchers.

As the population shrinks in Japan as a whole and on Japanese campuses, tenured positions are especially precious and usually controlled by the deans of various departments. But Mishima was willing and able to wrest away those four slots (with more to come) and to award them to ELSI scientists.

"This is extraordinary," said McGlynn, who is one of those ELSI researchers now tenured at Tokyo Tech. "This was the work of Mishima and it is a very, very strong indication of how much he wants ELSI to succeed and last."

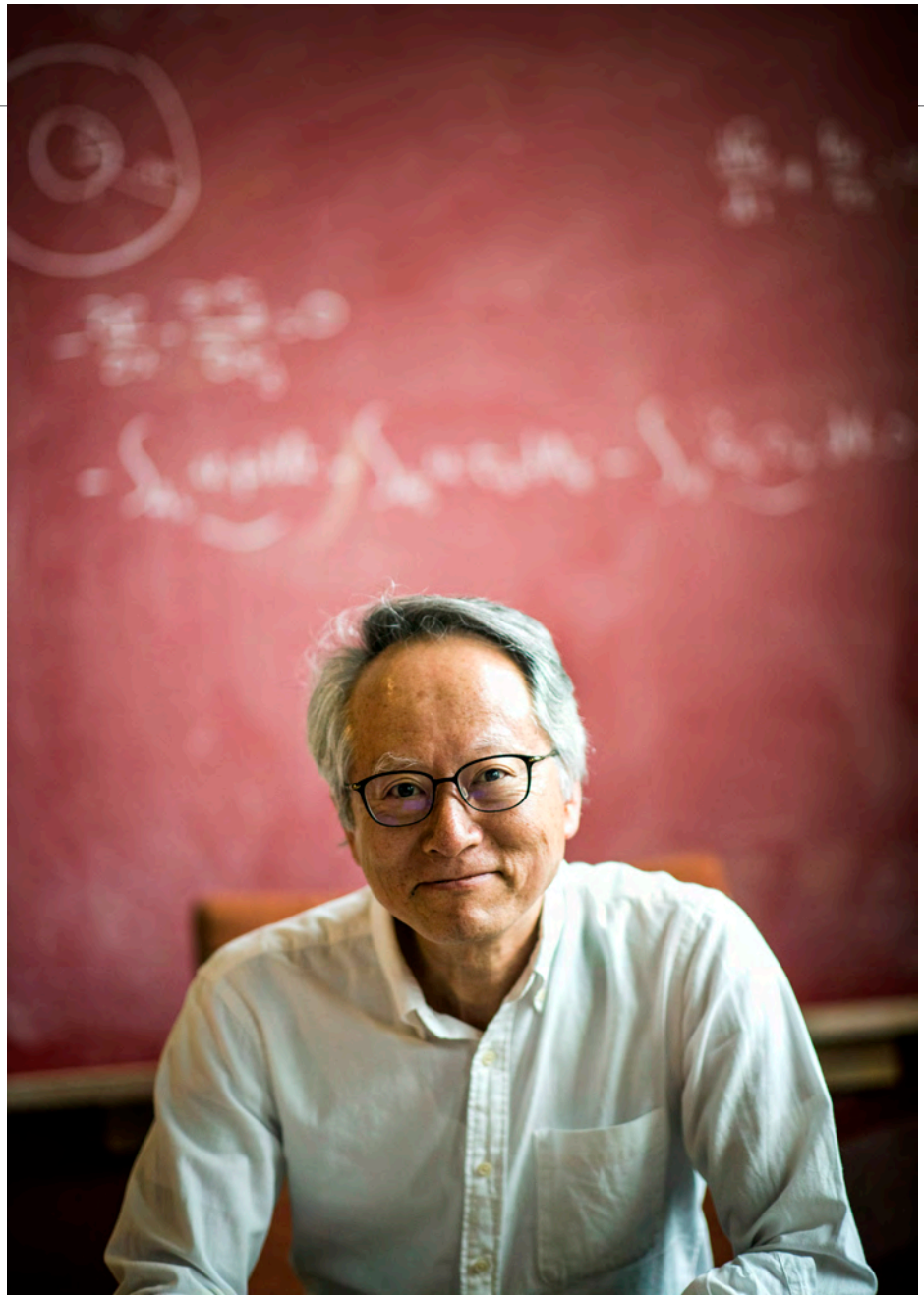


An essential component of the WPI program is to make administration of the institutes less hierarchical and less bureaucratic than what is the norm at other Japanese institutes and schools. A related WPI goal is to expose the host universities to different ways of running their administrations, and as a result hopefully become more agile and international as well. So some of the administrative staff members are hired by ELSI and some are from Tokyo Tech, cycling through for several years.

Those responsible for the daily working of these policies at ELSI are, from top left, Reika Sakai, Taneaki Matsumoto, Tadashi Sakurai and Rie Malvicino; from bottom left are Sachiko Ishiwata, Kenichi Nishimura, and Saeko Endo (who has rotated back to Tokyo Tech and was replaced by Yoko Kadono, (left).

Reika Sakai is ELSI's current "Life Officer," with the innovative job of working with foreign scientists to unravel snags large and small, to navigate Japan's notoriously complex bureaucracies, and to help ELSI members find housing, financial services and medical care. She also teaches introductory classes in Japanese, along with sharing insights on navigating social and cultural waters. Her (and ELSI's) goal: to allow scientists from abroad to settle in and start their work as soon as possible.

Akiyoshi Nouda, computer & network manager, singlehandedly runs the day-to-day information technology infrastructure at ELSI. For those in the know, Nouda is admired as much for his culinary skills as for his technical ones.



Naohiro Yoshida . Biochemist

Naohiro Yoshida has been involved with ELSI since before there was an ELSI, helping to formulate the proposal to the WPI. A biogeochemist at the Tokyo Institute of Technology who specializes in global environmental analyses using isotopic substituted molecules, he said that the other ELSI founders "encouraged me a lot to start collaborations with biologists related to the early Earth's environment and the origin of life."

An avid collaborator, he has worked with many ELSI scientists and has brought several of his former students to the institute – including biogeochemist Mayuko Nakagawa and analytic chemist Alexis Gilbert. Many consider him a statesman for ELSI, connecting the institute with other organizations such as the Geochemical Society of Japan, the European Association of Geochemistry and the Geochemical Society. He also oversees a major Japan Society for the Promotion of Science grant that will run for the next five years.

A transnational research community: Joseph Moran from the University of Strasbourg, a long-term visitor through the ELSI Origins Network program, describes recent advances in understanding the roles of metals in near-surface organic geochemistry.

5.An Institute Needs Scientists

The earliest days of ELSI made a strong impression on planetary scientist Hidenori Genda, as they had on John Hernlund. How could they not?

Hired early on as a research scientist with a specialty in planet formation, he spent his first two weeks sharing an office with director Hirose. And, as with Hernlund's, that office was also in a computer room that was quite cold and always noisy. Hirose moved out when another office was located for him, but Genda stayed put for some time.

Having been encouraged by Ida, Genda had left a teaching job at the prestigious University of Tokyo to join ELSI. He was attracted, he says, by ELSI's emphasis on research and, he has to admit, the freedom from teaching students.

But doing research in such a cold and noisy room was hardly ideal.

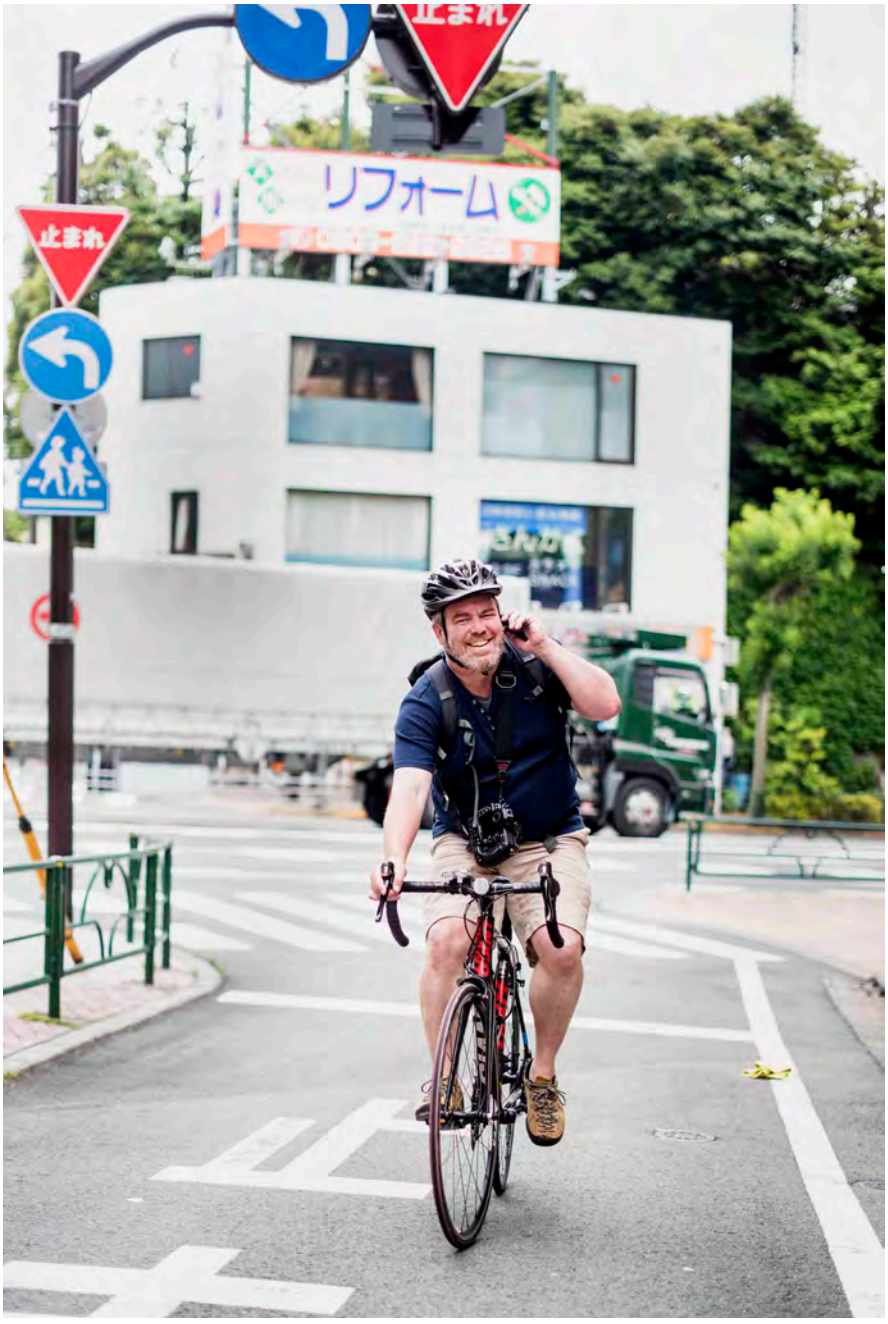
What's more, the fledgling ELSI team had no real meeting room, only rudimentary labs and clearly limited office space.

Still, the team did have a substantial budget, and the funds came in the second half of the Japanese budget year. That meant the money had to be spent expeditiously or it would be lost. Soon the all-important process of putting together a scientific community from scratch was in a higher gear.

Recruitment depends on many potential attractions, but the presence of researchers who have produced important results perhaps looms largest. ELSI started out with several scientists in that category.

Hirose, for instance, is a prominent high-pressure scientist, someone who has made significant contributions to the field of deep earth and, especially, core science. In his lab, he and his students and colleagues simulate conditions deep inside the Earth's mantle and core – up to 2,000 miles below the surface – to see how minerals and rocks known to be present there behave under different pressures, temperatures, and with different chemical compositions.

He made a lasting mark in the field by discovering what material was responsible for a mysterious layer at



Jon Hernlund - Vice Director ELSI

the base of the mantle, just outside the core, known only from seismological signatures. He called it post-perovskite, a unique and previously unsuspected phase of $MgSiO_3$. The discovery, made using specially designed diamond anvil cells, opened the door to explain other anomalies in measurements of the core and lower mantle.

So, when Hirose recruits you, it is an outreach that scientists – especially young scientists – are inclined to take seriously. One of his successes was bringing aboard Tomohiro Usui, who had worked for NASA in the United States and was involved with several major Japanese Space Agency (JAXA) missions. Hirose felt that it was important to make that ELSI-to-JAXA connection, just as connections were being made through staffing and appointments with NASA and with other Japanese organizations such as the scientifically influential Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

Another attractor was Ida, a longtime and respected Tokyo Tech planet formation theorist and professor. For five years he had been a Tokyo Tech leader of another Japanese government initiative that was a precursor of sorts to the WPI. Called the Global Centers Of Excellence (COE), the program encouraged interdisciplinary study but was designed to prepare Japanese student scientists for work on the global stage rather than to bring them together with international scientists.

As Ida explains it, the focus of the COE group he led was on the evolution of life on Earth but with a heavy emphasis on planet formation, earth science, geology, and, in the end, planetary evolution. The program was funded for five years, and at the end of it he, Hirose, and Tokyo Tech geologist Shigenori Maruyama wanted to continue its multidisciplinary, international approach. Thus the ELSI proposal to study the origins of Earth and of life on Earth together, a relatively novel approach.

But they soon hit the inevitable obstacle.

"We had many people working on the surface of the early Earth, the primordial atmosphere, and the deep interior, and we made clear that we saw the formation of the early Earth as central to the origin of life question," Ida recalls. "But after we were selected by the WPI, we looked around and it was obvious to see that we had nobody working actually on the origins of life. And really, we didn't know how to access them because that wasn't our field."

The primary biology and chemistry recruiting abroad fell then to Hut, who actually was not an origin of life scientist but quickly became knowledgeable; geochemist Henderson "Jim" Cleaves, who has a deep background in prebiotic Earth science and with the origins-of-life community; and geodynamicist Hernlund, who had developed a professional and personal friendship with Hirose over the years. Indeed, Hirose had tried to recruit Hernlund and his deep-Earth seismologist wife, Christine Houser, to Tokyo Tech even before there was an ELSI.

Formally, though, it was Hernlund who had the job of recruiting the international side of the science staff, especially young scientists eager for an opportunity and an adventure.

Hernlund has traveled the globe for more than three

years now talking to potential recruits at conferences such as the Astrobiology Science Conference and the yearly meeting of the American Geophysical Union. He was manning an ELSI table at the 2017 Ab-Sci-Con meeting in Mesa, Arizona.

Especially in the early years, the recruiting of international scientists was not an easy task. ELSI was hardly well known, it was in a country with a limited history of origin-of-life science, and initially it had little to show in terms of a campus. There was also then – and still is now – the lingering issue of the future of ELSI after the WPI funds stop flowing.

For Hernlund, who is a frequent collaborator with Hirose, the last issue was the most important. He couldn't help but feel responsible to the recruits he asked to pack up and move halfway around the world to work at an institute that was an early work in progress. As vice-director of ELSI, he has fought long and hard to ensure that the institute will be a permanent presence at Tokyo Tech. That permanence is more assured now, but it wasn't when he began his recruiting.

"I knew that we could not ask people to make the kinds of sacrifices that would be necessary to make ELSI a success if it were only a temporary project," he said. "Why would anyone make such a monumental effort for something that would be closed down after only a few years? When I explained this situation to President Mishima, he completely understood and responded by committing to make ELSI a permanent institute after the WPI."

To make a big splash, Hernlund and others decided to put out an advertisement for 20 research scientist positions. "To get the word out, we needed to also advertise the offering broadly, in high-profile publications and job-listing services, many of which publicize listings for a fee.

"We soon ran into trouble paying for these fees from our WPI budget since the administrative staff could not find any precedent to justify the expenditure. In fact, they said that no recruitment in the history of Tokyo Tech had ever paid to place an advertisement for a position opening in an international listing service."

On a tight schedule to get the ads out and with no available funds to pay for them, Piet Hut offered to put all of the charges, totaling around $50,000 USD, on his credit card. He would wait to be reimbursed because reimbursements could not be made until the ads went up and the numerous documentations were submitted. That process took many months.

The recruiting ads did their job, letting a particular kind of scientist know what ELSI was trying to do.

For instance, Matthieu Laneuville, who was about to be awarded his PhD from the Institute de Physique du Globe de Paris (the Paris Institute of Earth Physics), saw an ELSI job notice for a research scientist in an online list. His background was in physics and geodynamics.

"It looked quite unique, so I contacted John (Hernlund) and Ida-san to ask if my profile would be interesting to them. Even if I didn't know them, they encouraged me to apply, which I did.

"I hadn't heard of any other postdoc opportunity at the time that sounded really exciting to me both on the professional and personal level. That one caught my attention because I knew that, even if something went wrong from the research side, it would be an incredible human adventure."

He was flown out to Tokyo for a week of interviews and of getting to know the boisterous city and its overwhelmingly gracious people. He got to know ELSI and the city a bit, while he experienced the Hernlund family's warm hospitality.

"I was 26 when I moved to Japan in April 2014 and actually turned 27 a couple of weeks later. They brought a cake for the coffee break, which was a nice touch.

"Scientifically speaking, the bridge building aspect of ELSI really resonated with me. I was not trained as a geo person, so I did not have some of the deeply rooted feeling that some people have about what question belongs to what field.

"I actually seek this kind of experience because it allows me to not take anything for granted -- by that I mean that each culture has its own rules and living abroad helps me recognize them as such. I had no particular ties with Japan

Matthieu Laneuville and Julien Foriel

before. But I did want to spend time living in a country with a different cultural heritage than western."

Laneuville's contract was extended after two years in Tokyo, and he will be at ELSI for at least another two years as a project assistant professor. He has been productive in his field of the formation and evolution of planets and moons as well as in his longer-term goal – as he described it – of integrating "the geophysical consequences of life in the geodynamic evolution of the Earth, considering both aspects as part of the same system."

In all, there are more than 70 scientists and lab technicians now at ELSI, and slightly under half are internationals.

Hidenori Genda, last seen shivering in an early ELSI "office," remains at ELSI and has come into his own as a researcher and modeler. His field is giant impacts and the role they play in planet formation, but his focus has long been on the much-debated question of how Earth came to have water. He has published extensively on that and other subjects and recently won the prestigious 2017 Goldschmidt Geochemical Journal award and gave a talk in Paris on his paper, "Origin of Earth's Oceans: An Assessment of the Total Amount, History and Supply of Water."

ELSI has been a good fit for him – allowing him to dig deep into his chosen fields and to write prolifically. "I would gladly stay at ELSI for as long as there is ELSI," he says.

He also has returned to working with young scientists but as their postdoc adviser and mentor rather than as a teacher.

One of his postdocs is Keiko Hamano, who came to ELSI on a Japan Society for the Promotion of Science fellowship to work with him on how and why planets have very different atmospheres. This effort led her into fields such as simulating the aftershocks of planetary giant impacts, a Genda specialty; the magma oceans that result from those impacts, on which she has published in the journal Nature; and the formation of new atmospheres after the impacts is a primary focus now.

Her work is not origins-of-life work per se, but it is origins-of-Earth work that leads to a better understanding of the processes that made Earth ready for the emergence of life. Given that the search for habitable planets beyond Earth often deals with similar issues of planet and atmosphere formation, her work is cutting edge and inherently multidisciplinary.

It's also very demanding. But what she focuses on is "the free atmosphere of ELSI," which allows her to pursue her challenging scientific interests in myriad ways.

A major theme of origins-of-life work is the cycling of elements and compounds around and through the planet's interior, surface, and atmosphere. The cycling of carbon, nitrogen, water, and much more supports a wide variety of states of environmental balancing needed for successful life.

In a different kind of virtuous cycle, veteran Ida attracting established but less-than-satisfied Genda and Genda some years later attracting talented young scientists like Hamano, an institute can similarly build an increasingly complex and self-sustaining vitality.

Hidenori Genda (*left*) and Ryuki Hyodo (*right*)

Marine Lasbleis . Planetary Scientist

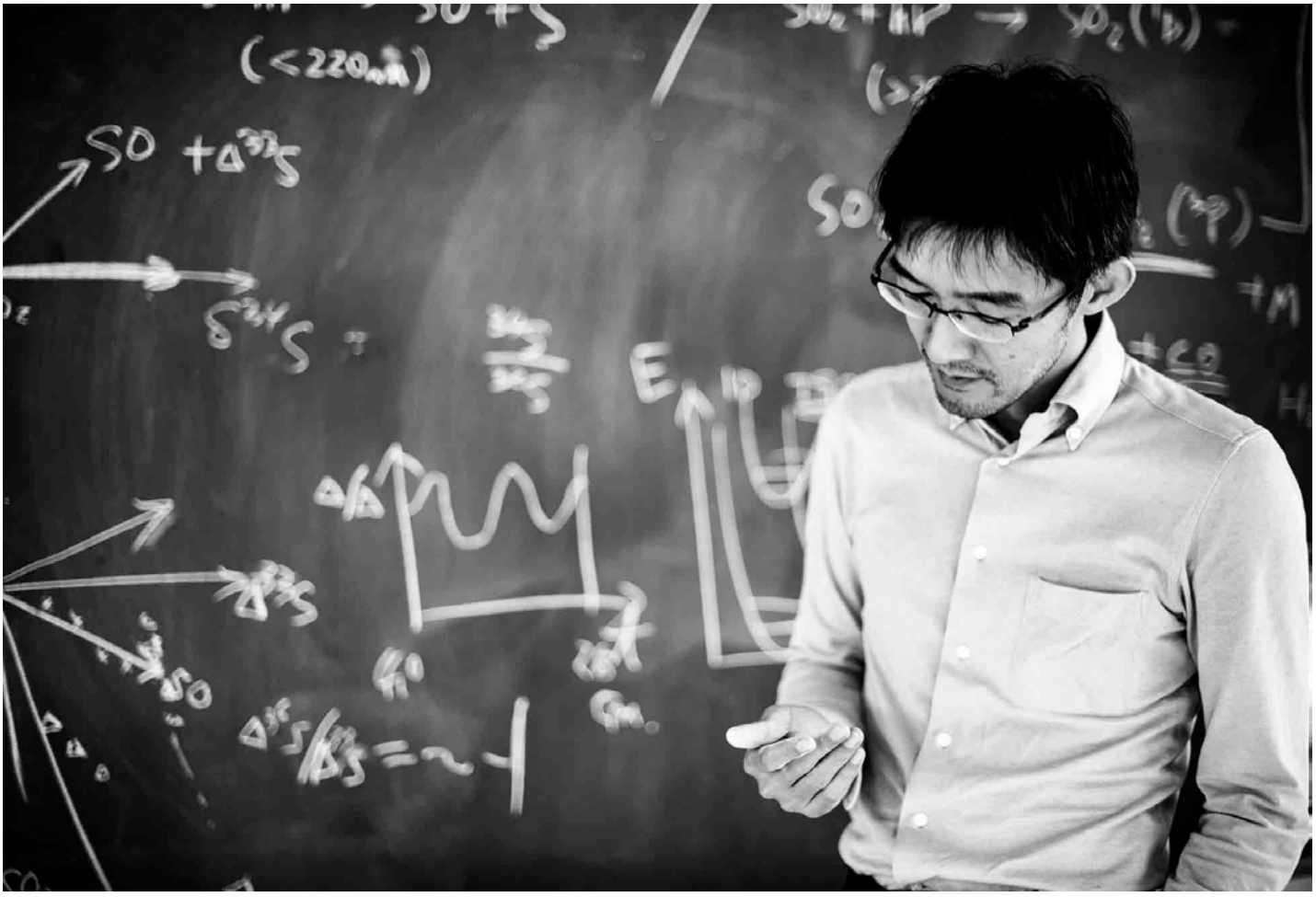
Part of the contingent from France at ELSI, Lasbleis specializes in deep-Earth, high-pressure science and the effort to better understand the formation and behavior of the Earth's inner mantle and core. She is currently collaborating on a paper with director Hirose and vice-director Hernlund on "Growth of the inner core by snow fall," but this is not H_2O snow falling.

She earned her doctorate at the Laboratoire de Géologie de Lyon, France in 2014 and was a Japan Society for the Promotion of Science fellow for two years after that, working with Hirose at ELSI. She currently studying the effect of melts and solids on the dynamics of deep Earth, with an emphasis on ramifications for Earth's inner core formation and for the evolution of the early magma ocean.

Albert Fahrenbach. Organic Chemist

Fahrenbach is an organic chemist and was awarded his doctorate from Northwestern University in 2013. He subsequently applied for a position at Nobel Laureate Jack Szostak's origin-of-life lab at Harvard University. Szostak is a principal investigator at ELSI and a regular visitor, and periodically encourages his post docs to spend time and do research at ELSI. Fahrenbach was interested in the opportunity and arrived at ELSI in 2013.

Fahrenbach has now been off and on at ELSI for four years and recently became an associate principal investigator. His research involves prebiotic and non-enzymatic replication, and he has become interested in the role of radiolysis – the molecular decomposition of a substance via radiation – as the chemical building blocks of life were forming before there was life on Earth.



Yuichiro Ueno

6.ELSI Needs Focus and Scientific Leaders

Once the institute was fully up and running, the question of how precisely to proceed scientifically at ELSI became more pressing. While individual scientists were doing important work and getting it published, the topics were often separate from what other colleagues might be working on. ELSI needed a master plan for its science.

Basically the central question for ELSI is how Earth transitioned from geochemistry to biochemistry. But that is such a broad question and it takes in scores of fields. The challenge was: how could ELSI become unique in this sprawling field?

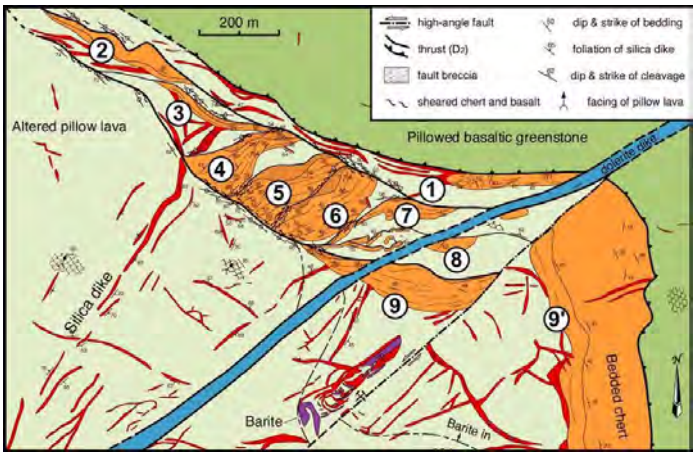
After a series of guided meetings and lots of debate – the unavoidable question of going deep versus going broad – a number of core areas were identified: planetary formation and deep-Earth dynamics, the emerging field of "messy" chemistry, the magma ocean of early Earth and its influences on the atmosphere, evolution on a molecular level, and geometabolism and artificial life. Some researchers worked in different but related fields, and they would continue doing that.

All the core areas have seen progress over the years, some more and some less. But tracing their arcs would only give a somewhat bureaucratic view of what the institute is accomplishing. Better that we focus on one particular scientist who, by many accounts, reflects much of what ELSI is trying to do.

That scientist is Yuichiro Ueno, and his evolution has been from geologist to geochemist to biogeochemist. He says ELSI encouraged and in some ways made possible his ever-broadening reach.

Ueno was trained as a geologist and has been on many, many field trips to important geological – and often ancient-Earth – sites. An early and major success came from his time in the Pilbara section of northwest Australia, where some of the oldest microbial life signatures on Earth have been found.

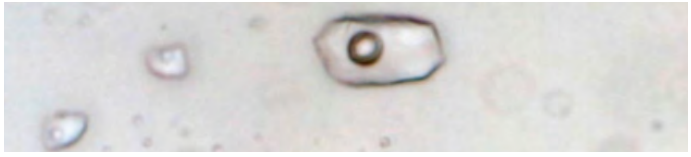
Ueno went as part of a Tokyo Tech-based team once a year for seven years, often spending several months at the site, some 70 miles from the nearest town. In time Ueno and others discovered the fossil remains of a hydrothermal vent in the rock, and they took many samples.



A geological map drawn by Yuichiro Ueno of the North Pole area of the Pilbara craton in western Australia. Some of the oldest rocks in the world have been found in the region, as was the specimen (*below*) that Ueno determined to be a 3.5 billion year old inclusion holding fluid and methane gas.

One of the samples led to his breakthrough discovery: a gas bubble inclusion in a rock that was found to contain the gas methane. And using pioneering techniques, he was able to determine that the methane was the product of life, a methane-eating and methane-producing microbe. The inclusion was dated to 3.5 billion years ago, and in 2006 his discovery made quite a splash in the journal Nature.

He was hired as a teacher by his alma mater, Tokyo Tech, and he continued his research in both geology and



increasingly in geochemistry. That research focused on analyzing and uncovering isotopic signatures largely of sulfur in rocks, and the research would help him understand the makeup of the atmosphere at the time the rocks were formed.

As an up-and-coming researcher and teacher, he was asked to help write the WPI proposal that ultimately was accepted. And so he has been a force at ELSI since 2012.

During that time, he says, he has entered as many as 10 collaborations with international ELSI researchers, has been a frequent participant at informal agora discussions and in more formal workshops, and has gradually moved more into the origin of life field.

As he explained, "After those discussion at ELSI, I wanted to find a way to extend my views, to study more important and fundamental questions.

"I came to understand with them that early Earth was like another planet than ours today, a variation on different kinds of habitable or inhabited planets. That kind of thinking – that Earth was only one example of a bioplanet – came from my time at ELSI. That allowed me to think differently about my research."

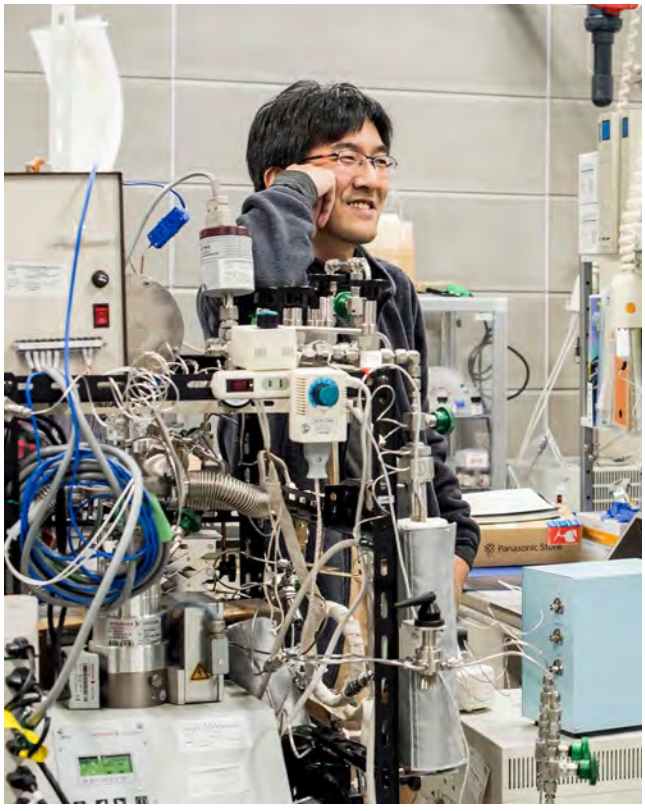
Now Ueno focuses on early-Earth interactions between the surface and the atmosphere. While he still spends much of his time experimenting in the lab (and teaching), he has moved additionally into the realm of theory.

This is most evident in his hypothesis that the early Earth contained large amounts of carbon monoxide (CO.) Known best as a gas that will asphyxiate many living creatures, its presence in the early atmosphere before the advent of life has not been well studied. But Ueno now thinks that it is key to understanding the atmosphere that made life possible.

It was during his discussions with other scientists at ELSI that Ueno more fully grasped that carbon monoxide is a very useful molecule to synthesize organic compounds and that early microbes would thrive on a carbon monoxide diet. That new understanding got him interested in pursuing the logic of the compound further in part because a CO atmosphere would help explain some of the anomalies he found in his earlier work on sulfur isotope ratios.

Now he presents regularly around the world about a possible carbon monoxide early atmosphere on Earth and possibly on Mars. He even has some NASA scientists re-examining data from the Curiosity rover on Mars to see if isotopic signatures might be present that would suggest an ancient carbon monoxide atmosphere.

Did his time and interactions at ELSI make possible this potentially pioneering turn in his research? Ueno's reply is "Yes, of course."



Ueno became a full professor at Tokyo Tech this year as well as a principal investigator at ELSI.

A Gathering of Scientists in Images

The enduring figure of a solitary Galileo or Einstein or Hubble hard at work to solve a scientific problem lives on in the public imagination, but most of science has long since changed course. The goal at ELSI, and many other research centers, is to pro-actively bring together researchers from many fields to see what sparks might fly, what surprises may jump out.

Still, scientists grow up in particular disciplines and often need to dig deep in their specialized fields before they can also be effective and useful on a multi-disciplinary team. For instance, Ryuhei Nakamura is a specialist in electrochemistry and he came to ELSI as a principal investigator to work with microbial ecologist, and also principal investigator, Shawn McGlynn. Each has a unique knowledge that the other needs to more effectively push forward their now shared scientific enterprise.

Some ELSI collaborations are formal – such as the CYCLOP (Cycles and Life on Planets) group, which is working on ways to better categorize types of exoplanets. Others are formal but more limited, as when scientists from different fields collaborate on a project and paper. And then there are the collaborations waiting to gel.

So here, then, are some of the scientists of ELSI and their fields of research – their take-off points for the deep dives, the collaborations and possibly the breakthroughs to come.

1. Masafumi Kameya
Microbial Metabolism

2. Alexis Gilbert
Analytical chemistry

1.

2.

3. Ramon Brasser
Planetary Science

4. Junko Kominami
Planetary Formation

3.

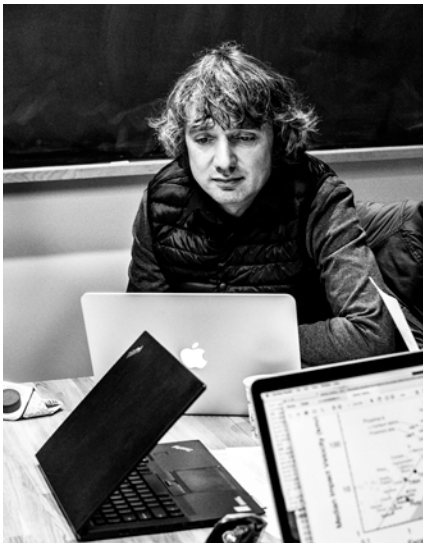
4.

5. Tomohiko Sato
Geology

6. Ryuhei Nakamura
Electrochemistry

5.

6.



1.

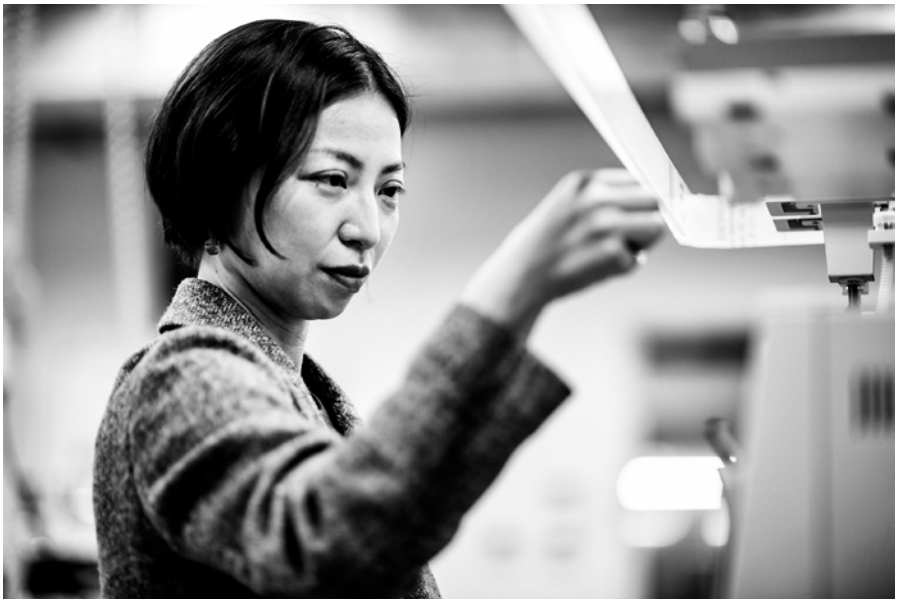
2.

1. Julien Foriel
   Isotope Geochemistry
2. Takayuki Saitoh
   Galaxy Formation
3. Hiroyuki Kurokawa
   Planetary Science
4. Christine Houser
   Solid Earth Geophysics
5. Joe Kirschvink
   Geobiology

3.

4.

5.



10.

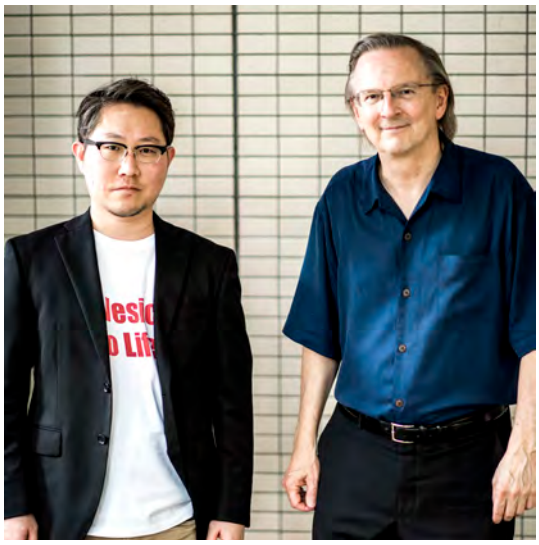
11.

6. Yutetsu Kuruma / Jack Szostak
Synthetic Biology / Biophysics & Chemical Biology

7. Kyoko Akiyama
EON Project Manager

8. Chihiro Furumizu
University Research Administrator - URA

9. Chisato Saito
University Research Administrator - URA


6.


7.


8.


9.

10. Yayoi Hongo
Analytical Chemistry

11. Olaf Witkowski
Artificial Life & Complex Systems

12. George Helffrich
Solid Earth Geophysics


12.

7.The Culture of ELSI

It was 3 o'clock and one of the members of the administrative staff at ELSI was walking the halls ringing a bell. As everyone knew, that meant it was teatime.

From the start, the organizers of ELSI set out to create an environment where scientists young and old could get together informally every day. The idea was that bringing together an often-changing cohort of scientists from different though related fields could and should cause creative sparks to fly and scientific collaborations to be born.

So at one end of the agora is a long wooden bar with stools around it, and at mid-afternoon it is often filled with the talk and laughter of scientists. (A similar setup exists in the second ELSI building as well.)

Collaborations among scientists in the same or related fields are hardly unusual. Rather, they are the norm.

But collaborations between scientists from quite diverse fields are not common because the issues to research and the ways to study them are often too far a reach, or so it might seem.

However, those conversations around the agora tea bar, which often continued around the ELSI compound and into the surrounding Ookayama neighborhood of Tokyo, had a way of bringing together scientists, particularly younger ones, who suddenly found an unexpected commonality with a colleague.

Research scientist Jennifer Hoyal Cuthill, for instance, got into a conversation with Nicholas Guttenberg, a gifted and passionate specialist in computer simulations and what is generally called "machine learning." From their conversations came the rather unexpected conclusion that Hoyal Cuthill's palaeobiology data could seemingly benefit from some machine learning.

"Collaborations don't just happen by accident," she says. "There's a real effort to encourage these discussions, to highlight their importance. I think most of us have found great benefit from that effort."

While ELSI has taken some definite steps into the unknown as it has gelled, there is a pedigree of sorts to its culture and style. Hardly surprising, they come from the experiences of some of ELSI's leaders.

An emphasis on interdisciplinary work, a focus on forming an institutional community that might achieve

what separate individuals might not, daily teatimes to gather and exchange ideas and laughs – that is the Institute for Advanced Study model and, particularly, Hut's model.

The idea of a stand-alone institute where scientists do only research – and mostly basic (as opposed to applied) research at that – was made real more than a century ago at

Hanako Ricciardi is ELSI's Coordinator of International Initiatives. At ease in a variety of cultures, she plays many linking roles within ELSI and with other institutions. In addition, she is a practiced problem spotter and solver.

the Carnegie Institution for Science in Washington, D.C., and Pasadena, California. Many key people at ELSI, both Japanese and internationals, have spent time at the Carnegie hilltop campus in Washington.

And Ida and Hirose had both been active leaders in Tokyo Tech's branch of the government's earlier Global Centers of Excellence initiative, and both had felt nourished by the multidisciplinary and international possibilities it encouraged.

All these institutional cultures have brought both strengths and pitfalls to ELSI, and all are indelibly stamped into its DNA.

There is also a distinctly Japanese way of doing things that has indisputably played a role in creating the cooperative, respectful feel of the place. That culture begins with the ELSI building.

It's nothing glaring, but there are many subtle touches. The shoji window coverings and the concrete struts on the ceilings of offices and most meetings rooms reflect traditional Japanese interiors. You hardly notice these things until they're pointed out; they are physical manifestations of the Japanese origin of the institute.

But while many Japanese-international collaborations and friendships have blossomed at ELSI, it would be naive to think that five years into the experiment the melding of Japanese and international researchers has been or could be wholly successful. Even though most of the internationals are Japanophiles and most of their Japanese colleagues are welcoming.

The obstacles are many, and members of each group tend to clump together, especially in their nonscientific lives. This habit continues not because of any animosity but rather because of cultural differences, because of personal comfort, because of degrees of being embedded in the culture, and because of language.

Hanako Nakano Ricciardi is the Coordinator of International Initiatives at ELSI. Her job is broadly to implement policies that help internationalize daily life at the institute while acting as a watchdog for problems that might emerge. That coordination often means working to explain Japanese ways to confused and sometimes irritated internationals and international, mostly western, ways to confused and sometimes irritated Japanese.

Born in Taiwan to Japanese parents and educated in part in the United States, she feels comfortable in all of her three cultures. Moreover, her husband is American, they live with their son in the international port city of Yokohama, and her parents remain part time in Taiwan. So, living in a multicultural world comes naturally to her.

What she sees at ELSI is a lot of people trying to do right by each other but also persistent breakdowns in communication. And a lot of that, she says, is cultural and kept under wraps.

"As a rule, Japanese don't really like to spell things out. And that makes things harder for the non-Japanese," she says. "But when you have an island culture of homogeneity, a lot of things are intuited. You grew up with certain understandings and so you don't have to say things to communicate.

"In the U.S., for example, its multicultural character requires people to be verbal; they have to be to be clear. But here someone might subtly lift an eyebrow or inhale or 'hmmm' in a particular way or not say anything, and other Japanese will know it means a particular thing, or maybe a number of particular things depending on the context.

"But the truth is that you can raise your eyebrow or suck air as much as you want and foreigners might not get what is implied. They won't get that you don't want to do something, let alone the why behind it, unless you explain it. The training for cultural awareness has to come from both

sides and we are learning."

In her experience, she says, Japanese culture tends to be more detail oriented than western culture, and that can lead to misunderstanding as well. There is also a heightened Japanese respect for detailed social awareness of others and for adjusting one's behavior accordingly for group harmony.

"When Japanese scientists or administrators come to a meeting, they come prepared for a particular task. But if it then becomes a lot more open-ended, they can get frustrated. They wonder 'Why am I here? What is my role here? What can I deliver?' The Japanese probably would appreciate some direction.

"And meanwhile, the international folks are saying 'hey, let's see where this goes' because that's their training and style, to look for unexpected possibilities."

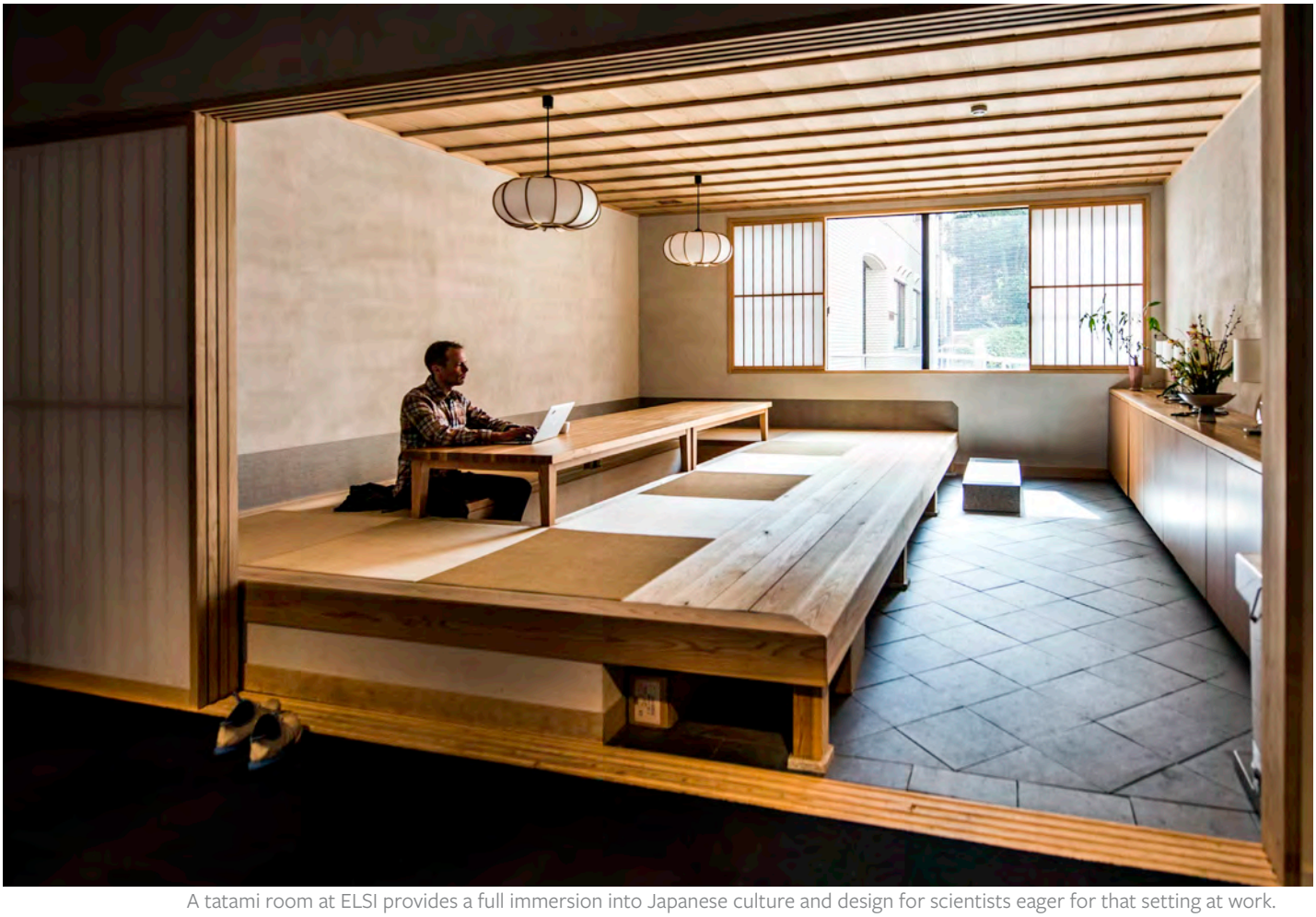
She says that breakdowns in communication have had some consequences. The ELSI schedule is filled with meetings, some for the staff as a whole, some for smaller groups, and others for ELSI scientists and visiting scientists. Especially at the institutional and multidisciplinary meetings, a substantial majority of attendees are international because Japanese colleagues often stay away.

"This can be a language issue; this can be a feeling that they have more-productive things to do," Ricciardi said of the Japanese researchers. "This is a real problem for the institute because their input would be so valuable."

But while bringing together the cultures may be difficult, she says her door is always open, progress is evident, and the effort is definitely worthwhile for all involved. What's more, it is a formal part of the WPI mission.

"We tend to think of reform and internationalization as top down, like mandates that get carried into successful action," she concludes.

"Yes, that is the initial impetus. But to me, what makes internationalization and reform work, really produce results, really stick, is the incremental trust building and communication…Successful internationalization, to me, isn't about Japan being like another model outside of Japan but rather finding and recognizing Japan's strengths and working with that to improve its weaknesses with the inspiration of outside examples."



A tatami room at ELSI provides a full immersion into Japanese culture and design for scientists eager for that setting at work.