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FEATURE NICT Way of Space Research

DIALOG

Sci-fi author , Winner of NIKKEI "HOSHI Shin-ichi Award"

NICT Research Executive Director

SEKIMOTO Satoshi × KASAI Yasuko

Sci-Fi author and Researcher talk on Space

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Cover Photo:
Launch of the European Space Agency (ESA) Ariane 5 rocket, carrying the JUpiter ICy moons Explorer (JUICE)
April 14, 2023
(Photo: ©ESA-M. Pédoussaut)

FEATURE

NICT Way of Space Research

Searching for Signs of Life around Jupiter

What will the terahertz wave spectrometer installed on the JUICE probe show us?

On April 14, 2023, the JUpiter ICy moons Explorer (JUICE) was launched into space by the European Space Agency (ESA). One of JUICE's objectives is to search for signs of life on the icy moons that orbit Jupiter. A total of 11 measurement instruments are installed on JUICE, one of which is a terahertz wave spectrometer developed by NICT and other partners. This instrument will analyze the atmosphere and surface of Jupiter's icy moons. If it is successful in discovering biomarkers that suggest signs of life, this would mark a major discovery.

This special issue features a dialogue between KASAI Yasuko, NICT Research Executive Director and one of the foremost experts in terahertz wave remote sensing, and sci-fi writer SEKIMOTO Satoshi, winner of two consecutive Hoshi Awards Grands Prix, which are presented by Nikkei, one of NICT's collaborators. Where will this interaction between a scientist and sci-fi writer lead?

KASAI Hello! I've been looking forward to speaking with you today.

SEKIMOTO Nice to meet you. Last night I couldn't sleep for thinking about our talk today.

KASAI Shall we start with self-introductions? My specialty is terahertz wave remote sensing. Electromagnetic remote sensing is a way of remotely estimating the physical properties and volumes of substances based on the interactions between those substances and electromagnetic waves. NICT is currently engaged in research on terahertz wave remote sensing. The terahertz spectrometer installed on the JUpiter ICy moons Explorer (JUICE) is part of an international mission, and NICT is one of the international team members involved in its development. This sensor will also search for biomarker molecules on Jupiter's icy moons.

SEKIMOTO I'm a sci-fi fiction writer and I received the Grands Prix in the 9th and 10th (2022 and 2023) Hoshi Awards, presented by Nikkei, Inc. Linnaeus, my prize-winning work at the 9th awards, is about biodiversity, while Elliptical Orbit Spirits, my prize-winning work at the 10th awards, deals with global warming and virtual reality. In particular, Linnaeus touches briefly on life in the Jovian system, which is your specialty, so I am really looking forward to our conversation today.

SEKIMOTO Satoshi
Sci-fi author (member of Science Fiction and Fantasy Writers of Japan (SFWJ)) and environmental consultant
Sekimoto won the Outstanding Work Prize at Nikkei's 7th Hoshi Awards for his work Black Plants. He has also won two consecutive Grands Prix, once at the 9th awards for Linnaeus and again at the 10th awards for Elliptical Orbit Spirits, as well as the Special Judges' Prize in the SFWJ First Short Novel Contest. Sekimoto has been captivated by space and the stars since childhood, and is actually the person who gave the name Ryugu to the asteroid in the Japan Aerospace Exploration Agency's (JAXA's) Hayabusa2 Project. He currently works as both an environmental consultant and a writer.

KASAI Yasuko
Research Executive Director, Terahertz Technology Research Center, Beyond 5G Research and Development Promotion Unit
Professor, School of Environment and Society, Tokyo Institute of Technology
Fellow, Bureau of Science, Technology and Innovation, Cabinet Office, Government of Japan
After receiving her doctorate in 1995, Kasai joined the Communications Research Laboratory (CRL; present-day NICT) in 1999 and has been engaged in Earth and planetary observation using terahertz wave remote sensing. She is the lead representative from Japan on the Submillimetre Wave Instrument (SWI) Development Team in the JUpiter ICy moons Explorer (JUICE) program.
Dr. (Doctor of Science)

KASAI I believe another work of yours, Black Plants, also won a prize (7th Hoshi Awards Outstanding Work). That one's my favorite, and it's full of inspirational ideas, such as artificial plants that start to evolve independently. You majored in botany at university, didn't you?

DIALOG

Searching for Signs of Life around Jupiter

What will the terahertz wave spectrometer installed on the JUICE probe show us?

SEKIMOTO I'm honored that you've read my books! I majored in tree ecology at university, researching the role that trees play in the natural environment. Even now, I work as an environmental consultant at a company that conducts nature surveys, and Black Plants and Linnaeus are works that were inspired by my knowledge and experience in ecology.

KASAI What first inspired you to write science fiction?

SEKIMOTO One day, on my commute into work, I saw an ad on the train for applications for the Hoshi Awards and I thought I would apply. I've loved sci-fi since childhood and before I reached elementary school, it was all that I would read. After getting a job, I was too busy to do anything sci-fi-related but as I gradually found more time on my hands, I became determined to try and write my own fiction.

KASAI The Hoshi Awards honor "scientific literature," which is really wonderful. I love sci-fi myself and have read almost all of the books that have won Hoshi Awards.
JUICE is a comprehensive exploration mission that will study the appearance of Jupiter, as an archetype for giant gas planets in space, as well as the potential for life in the subsurface oceans of Jupiter's icy moons. It was decided in 2012 that JUICE would include a terahertz spectrometer and, after more than 10 years of development, JUICE was finally launched into space in 2023. Terahertz waves are electromagnetic waves that exist in the boundary region between light and radio waves and, because of newly pioneered technology they open up many possibilities. Besides sensing, they could, for example, also be a target for next-generation mobile communication systems such as Beyond 5G and 6G because they enable large-volume communications.

Terahertz waves, the best tool to seek out new life

SEKIMOTO What can we learn from looking at celestial bodies using terahertz waves?

KASAI The terahertz wave spectrometer makes it possible to observe the atmospheric composition and wind speeds in Jupiter's stratosphere and on its icy moons, which is something that has not been technologically possible until now. It is also possible to observe the surfaces of the icy moons. Through such observations, we hope to understand Jupiter's stratosphere, which characterizes the planet's atmosphere, and also assess the potential for life on the icy moons of Jupiter. Using this new and unprecedented "terahertz eye," we hope to conduct observations that were previously not possible, which will hopefully lead to new discoveries.

SEKIMOTO So, is it fair to say that your motivation in engaging in terahertz wave research was to find signs of life in outer space?

KASAI Yes, very much so. During my doctoral studies, I would use the telescope at the Nobeyama Radio Observatory to search outer space for the existence of amino acids that form the basis for life. I changed my doctoral thesis after being unable to find any though (*laughs*).

Possibility of systems that differ from life on Earth

SEKIMOTO I hear that the JUICE exploration will focus particularly on the moon Ganymede, which has a subsurface ocean. I am really excited at the prospect that, within my lifetime, we might find signs of life somewhere other than on Earth.

KASAI JUICE stands for JUpiter ICy moons Explorer, and one of its missions is to explore the possibility of the potential for life. Jupiter's diameter is 11 times larger than Earth and its mass is 318 times greater, but it is also a gas giant with a density only 0.24 times that of Earth and has multiple moons in orbit. Although these moons appear to be blocks of ice, it has been hypothesized that their interiors may have been heated up from, for example, deformation caused by Jupiter's gravitational pull, and that there could be liquid water in the form of subsurface oceans, which may harbor extraterrestrial life.

SEKIMOTO Even here on Earth, in the vicinity of hydrothermal vents in the deep oceans, there are organisms called tube worms that have a life system completely different to our own and use hydrogen sulfide as an energy source. It's possible organisms like that may also be present on the moons of Jupiter, right?

KASAI Yes, on moons such as Europa, it is thought that so-called "plumes" of heated water may erupt out from under the surface. Using the terahertz spectrometer, we will investigate the composition of the atmosphere and what components exist at what altitude. In this process, we will explore whether there are any substances, or biomarkers, that indicate the possible existence of life and, if so, what kinds of biomarkers and in what concentrations. At NICT, we are also developing our own unique algorithm capable of analyzing the data we collect.

SEKIMOTO Will you find out whether there are any organic substances there?

KASAI Besides water, the terahertz spectrometer is adept at measuring simple molecules, such as hydrogen sulfide, methane, hydrogen cyanide, and ammonia. From the volumes and proportions of these chemicals, it may be possible to make the case for the possible existence of life. We're having a lot of fun speculating about the various lifeforms that might exist (*laughs*).

SEKIMOTO Arthur C. Clarke, one of the giants of the science fiction world, wrote a novella called A Meeting with Medusa (1971). It's about lifeforms in the jet streams of Jupiter. I was particularly influenced by this work, and in Linnaeus, I had there be lifeforms on Jupiter. I imagined them not as carbon-based lifeforms, but rather highly heat-resistant silicon-based ones. What do you think about the possible existence of silicon-based lifeforms?

KASAI Generally speaking, that's hard to imagine, but the extent of human beings' scientific knowledge is tremendously small in the grand scheme of things, so we can't dismiss such a possibility completely. We simply can't say that there is zero chance of finding completely different lifeforms.

SEKIMOTO It would be fun if there were different types of life in our own solar system, wouldn't it?

KASAI It would make things exciting, yes. The terahertz wave spectrometer will enable us to study many different kinds of molecules in the atmosphere of Jupiter's moons, which should expand the possibilities.

SEKIMOTO That's something to look forward to. When do you expect to get results?

KASAI The mission will reach Jupiter in 2031 and we plan to start observing Ganymede in 2034.

SEKIMOTO That's eight years before JUICE reaches Jupiter, which will give me time to write a sci-fi work set on Jupiter before then! Once it's written, I'll be sure to mention you in the acknowledgements!

KASAI I look forward to reading it. But as you've already written about in your previous works, we must tackle the issue of "What is life?" How do we express the mind and consciousness scientifically? As a scientist, I find myself thinking about such things from my involvement in the search for life in outer space.

SEKIMOTO Generally speaking, living organisms are considered to have cell membranes, be capable of self-replication, and metabolize energy, but the mind and consciousness are separate things altogether. Plants, however, seem to exchange information using chemicals. So, if there is life on Ganymede or Europa, I wonder what kind of life it will be?

KASAI Here on Earth, life needs three things: liquid water, organic matter, and energy. If, using a terahertz wave spectrometer, we are able to confirm the presence of biomarkers in water and air, and also whether the environment is oxidative or reductive through estimates of chemical reactions, it would certainly generate much more discussion about the potential for the existence of life. It's difficult to imagine that there would be some kind of intelligent lifeform, but I really hope to be able to confirm some form of primitive life.

Exploring water resources on the moon using terahertz waves

KASAI We are also using terahertz waves to explore water resources on our own moon. If humankind is to succeed in living on the moon, the nearest celestial body to Earth, it will be important to secure water as an energy source. Water is essential for sustaining life and, when broken down into hydrogen and oxygen, can also be used as rocket fuel. It is therefore important to understand where water is on the moon and to use it efficiently. That is why we are currently planning to create a "Space Treasure Map" of the moon's resources.
However, there is hardly any water on the moon's surface. Even in the places where there is thought to be most water, it is still only one-hundredth of the water that is present in the soil in the Sahara Desert. That being said, there are scientific indications that water might lie under the surface. It's very difficult to dig down deep, so, ideally, we would want to extract water from a place where it is close to the surface and available in large volumes. A Japanese consortium is working together on the Lunar Terahertz SUrveyor for KIlometer-scale MappIng (TSUKIMI), a small-scale terahertz wave resource surveyor satellite, in order to conduct just such an exploration. We are aiming for a launch date in 2025.

SEKIMOTO That's amazing. I get a real sense that the effective utilization of lunar resources is nearing reality, and even on the fictional side of things, the concept of sci-fi prototyping has recently started to gain attention. It's a conceptualization method that combines sci-fi thinking with cutting-edge science and technology to stimulate creativity and generate new ideas. I think that sci-fi and entertainment will have a major role to play in helping us to "adapt" to the future that we are heading towards.

KASAI You're absolutely right. We need DORAEMON-like concepts and inspirations to drive disruptive innovation.
Thank you so much for joining me for this chat today.

NICT Research Activities for JUICE/SWI

YAMADA Takayoshi

Researcher , Collaborative Research Laboratory of Terahertz Technology, Terahertz Technology Research Center, Beyond 5G R&D promotion Unit

He received the Ph.D. degree in science in 2018.
He is currently a Researcher with the National Institute of Information and Communications Technology, Tokyo. His scientific research interests include terahertz radiative transfer modeling, remote sensing for Earth's and planetary atmosphere, and laboratory experiment for Terahertz spectroscopy for gas molecules and regolith simulants.

Wang Suyun

Researcher(Tenure-Track), Collaborative Research Laboratory of Terahertz Technology, Terahertz Technology Research Center, Beyond 5G R&D promotion Unit

She received the Ph.D. degree in 2020. From October 2020 to March 2021, she was a Research Fellow with the Center for Northeast Asian Studies, Tohoku University, Since April 2021, she has been with the National Institute of Information and Communications Technology (NICT), Tokyo, Japan. Her research include forward modeling, system design, inversion algorithm development and measurement of microwave and terahertz remote sensing for planetary exploration.

On April 14, 2023, the JUpiter ICy moons Explorer (JUICE), a large-scale European Space Agency (ESA) mission, was launched successfully. One of the 11 scientific instruments on board JUICE is the Submillimeter Wave Instrument (SWI), a terahertz wave spectrometer. SWI was developed by an international team including NICT, with NICT working on the primary and secondary mirrors, and the actuator. Another unique global challenge we are working on is the development of algorithms capable of extracting key information from observational data about the possibility of the existence of life.

Background

JUICE is a mission to comprehensively explore the appearance of Jupiter, as a typical gas giant planet in space, and also search for any signs of life or the possibility of life existing in the subterranean seas of Jupiter's icy moons. This mission is to be implemented by observing the gas giant Jupiter and orbiting icy moons such as Ganymede, Europa, and Callisto (Figure 1). JUICE was launched on April 14, 2023, and is now on its way to Jupiter, with an expected arrival date in 2031. One of the instruments on board JUICE is a terahertz wave spectrometer, named Submillimeter Wave Instrument

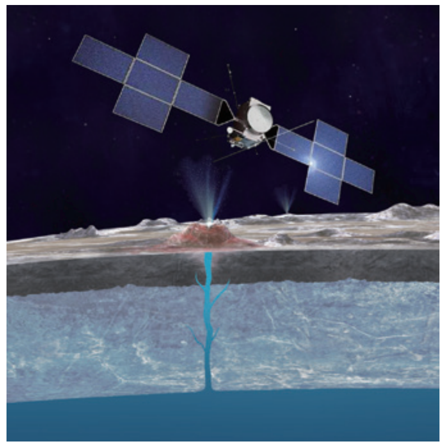
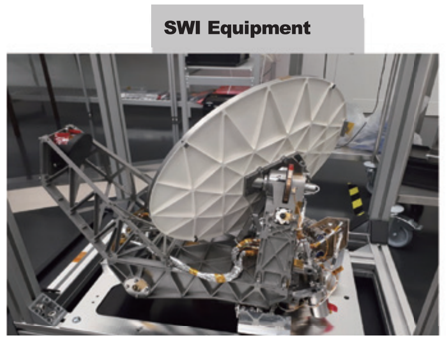


Figure 1 Image of JUICE and plumes erupting from the surface of Europa
(image: NASA and Airbus, source：https://www.mynewsdesk.com/se/irf/images/juice-europa-plumes-nasa-airbus-cropped-1506712)

(SWI). This instrument will measure Jupiter's atmospheric material and wind speeds, which until now have been difficult to measure, with the aim of understanding the planet's stratospheric structures, and also explore the possibility of the existence of life on Jupiter's icy moons, by observing their atmospheric materials and surfaces. These world-first observations are anticipated to open up great possibilities. SWI was developed by an international team including NICT, with NICT working on a part of the primary and secondary mirrors, and the actuator. Another challenge we are working on is the development of algorithms capable of extracting key information about the possibility of the existence of life, based on data collected in unique conditions, such as those of the Jovian system.

SWI's instrument capabilities and molecules to be observed are shown in Figure 2. The primary mirror is an offset Cassegrain antenna with an aperture diameter of 30 cm, with two observation frequency bands, 0.6 THz and 1.2 THz. The terahertz electromagnetic waves received are ultimately converted into an optical spectrum of vertical intensity and horizontal frequency using a high-resolution Chirp Transform Spectrometer (CTS) and Autocorrelation Spectrometers (ACS). Using SWI for terahertz wave remote sensing, it is possible to estimate the wind speed, air temperature, and abundance distribution of various trace molecules in the atmosphere, as well as surface conditions. Another feature is that observations are possible day or night as SWI does not rely on sunlight.

It is thought that the surfaces of Ganymede and Europa are mostly covered in ice, but that below this icy crust lie vast subterranean seas. Understanding the composition of these seas, such as whether they are oxidative or contain reductive substances, is important for discussing the possibility of the existence of life. In particular, on Europa there are already known to be plumes, where water and other substances from the subterranean seas or icy crust erupt from the surface into space, and it may be possible to estimate sea composition from observations of Europa's atmospheric composition.



SWI Specification

Observation capabilities		
	Observation frequency	600 GHz band (～530-600Khz) 1200 GHz band (1075-1275Khz) (optional)
	System noise temperature	1500 K (DSB[1], 600GHz band) 3000 K (DSB, 1200GHz band) (optional)
	Spatial resolution	1000-2000 km @15jupitar-radius (0.5-1.0 km@500km)
Antenna system		
	Beam width	Approx. 0.11°@600 GHz
	Observation accuracy	< 6 μm r.m.s.
	Range of motion	internal direction of orbit: -73-+73° orthogonal direction of orbit:-4.3-+4.3°
	Pointing accuracy	< 5sec angle (knowledge), (< 30 sec for setting)
Receiver system		
	detector	Shotkey-barrier-diode
Spectrometer		
	Type	Wide-bandwidth spectrometer(ACS[2]), High-resolution spectrometer (CTS[3])
	bandwidth	ACS: 5GHz, CTS:1GHz
	Frequency resolution	ACS:19.5-4.9 MHz (256-1024 ch), CTS: 0.1 MHz (10000ch)

[1]SW1 is a doubleside band receiver.
[2]Autocorrelation Spectrometer
[3]Chirp Transform Spectrometer

SWI Observing Physical Values and their accuracy

Icy moons			Jupiter
Surface	Atmosphere 3D profile of temperature, wind speed and composition		
Understanding Ganymede's regolith: Measuring High spatial resolution by 600, 1200 GHz band Calculating ampliitude and phase of heat wave between regolith surface to 1 cm beneath. Measuring heat and physical properties of regolith Observing correlation between atmospheric and surface properties	3D structural monitoring of tracer molecules	Ganymede, Callisto: Alt/Para Ratio of H_2O, O_2, CO	H_2O,CS, HCN, CO, OCS(air monocular from SL9 collision or outer space of Jupiter)
	Exploring for new molecular species	NH_3, C_3H_2, CH_3OH, H_2CO, CN, C_2N, CS, C_3S, NO, SiO, OH,HO_2,HC_3N, CH_3CCH,halides(HCl)…, ^{17}O, ^{18}O, D, ^{13}C, ^{15}N,^{34}S (from HCN,Co,CS), C+	
	Vertical resolution	1 km	～ Scale height
	Horizontal resolution	2-10km	<5 degrees
	Temperature observation accuracy	<2 K in collisional range	<5 K
	Doppler wind observation accuracy	10m/s	10 m/s (CH_4, H_2O)

Figure 2 left)SWI Equipment(Credit: MPS(Max Planck Institute for Solar System Research))middle)SWI Specification*1, right)SWI Observing Physical Values and their accuracy*1

With terahertz wave observation using SWI it is anticipated that in addition to atmospheric water, oxygen, carbon monoxide and its isotopes, exploration for other key molecular species will be possible, including H_2S, CH_4, NH_3, C_3H_2, CH_3OH, and H_2CO.

NICT's Globally Unique Terahertz Radiative Transfer Model

In order to accurately estimate atmospheric and ground surface information, a terahertz radiative transfer model capable of properly expressing new physical processes needs to be developed. A terahertz radiative transfer model is one that understands the physical mechanisms that govern interactions between electromagnetic waves and media, and developing such an algorithm and obtaining basic physical parameters will play a significant role. NICT is concentrating its efforts mainly on the development of two unique algorithms and is conducting lab-based measurements to obtain basic physical parameters (Figure 3). Here we will introduce each of the algorithms.

Jupiter's icy moons have extremely thin atmospheres (e.g. 10-11 times thinner than earth or less for Ganymede). Understanding the behavior of molecules in this atmosphere will lead to understanding of the magnetospheric interactions between Jupiter and its icy moons. Moreover, the search for new molecular species, as well as the abundance ratio of water molecules (H_2O) to isotopic molecules HDO and $H_2{}^{18}O$, will be key to discussions about planetary material cycles and physical evolution. Quantification of such molecular abundance requires the development of a non-local thermodynamic equilibrium (Non-LTE) model, in order to determine the molecules' equilibrium state of level distribution, which is different from that on earth. To understand these physical processes, NICT is independently developing a terahertz radiative transfer model*2 incorporating a non-LTE model, which compared to other models around the world has been confirmed as being the most accurate and standardized model available. We anticipate that observation data collected by JUICE/SWI will be used to characterize the Jovian system through dynamic studies of the interactions between gas giant Jupiter and its icy moons.

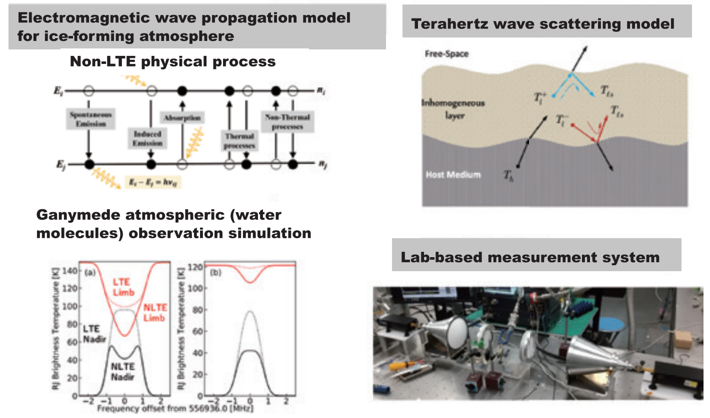


Figure 3 NICT development of unique algorithm and lab-based measurements for obtaining fundamental physical parameters

On the surface of the moon, planets, asteroids, and other terrestrial bodies, there is a sedimentary layer of dust and other particles called regolith, that covers the solid rock surface. Regolith is composed of particles and other materials with a rough surface. The regolith surface is rough and uneven, and its roughness corresponds to the wavelength of the electromagnetic waves observed. In electromagnetic wave propagation, surface roughness and heterogenous distribution cause scattering (rough surface scattering). In addition, non-uniform distribution due to factors such as the structure, density, dielectric constant, temperature, water-ice content, and composition of the medium through which electromagnetic waves propagate may cause volume scattering, which further complicates propagation of terahertz electromagnetic waves. NICT has successfully developed the world's only terahertz radiative transfer model that can take into account a planet's surface roughness and volume scattering, including boundary interactions. It is anticipated that future JUICE/SWI observation data will make it possible to estimate surface properties such as surface ice distribution on the surface of icy moons.

Future Pprospects

As of June 2023, we were able to confirm that JUICE/SWI is functioning normally in outer space, albeit with a few minor issues that require attention. From now, using deep space observations from JUICE/SWI, we will continue to explore the mysteries of the universe, utilizing the above-mentioned terahertz wave characteristics as well as the algorithms we have developed. NICT is also developing terahertz wave remote sensing for use in wide-area exploration of water energy resources on our own moon. We are currently constructing a database of terahertz wave properties and a lunar electromagnetic wave propagation model, while also developing a terahertz wave radiometer that can be used for observations on actual lunar missions.

Planetary exploration through terahertz waves is a new and exciting field that has only just begun. It holds great promise for the future, and we will continue challenging ourselves to bring dreams and discoveries to many people.

[Reference]

＊1 KASAI et al., " All to Jupiter and icy moons part 2 ～Challenge of Submillimeter Wave Instrument JUICE-SWI～ ," J. of Japanese Society for PlanetaryScience, vol.23, no.2, pp.140–148, 2014. (in Japanese)

＊2 T. Yamada et al., "Solving non-LTE problems in rotational transitions using the Gauss–Seidel method and its implementation in the Atmospheric Radiative Transfer Simulator", Astronomy and Astrophysics, vol. 619, A181, 2018.

Advancement of Space Weather Forecasting for Safe and Secure Use of Space

TSUGAWA Takuya

Director of Space Environment Laboratory, Radio Propagation Research Center, Radio Research Institute

After completing graduate school, he joined NICT in 2007 after working as a JSPS Research Fellow (Nagoya University, and Massachusetts Institute of Technology). He is engaged in research, development, and operations related to space weather forecasting. Ph.D.(Science).

Disturbances in the near-earth space environment due to solar activity can impact a variety of social systems such as communications, broadcasting, satellite positioning, power grids, and satellite operations, and may even cause disruption to stable use of such systems. To prepare for disasters caused by such disturbances in the space environment, or "space weather," we are monitoring space weather events and delivering forecasts 24 hours a day and seven days a week. We are also conducting research and development to improve monitoring and forecasting technologies and making efforts to provide information that meets user needs.

Background

Solar activity, which varies on a roughly 11-year cycle, entered a new cycle known as Solar Cycle 25 in December 2019. It is expected to reach its maximum in around 2025-2026 (Figure 1). In fact, solar activity is gradually increasing, with the largest X-class solar flares occurring twice in 2021, seven times in 2022, and eight times as of June 2023. On the other hand, the use of space in business has recently seen rapid expansion, including satellite communications with small commercial satellite constellations, as well as the use of high-precision satellite positioning for automatic driving, drones, and other applications.

Under these circumstances, the U.S., the U.K. and other countries and international organizations have considered the potential impact of space weather phenomena on social infrastructure and their countermeasures. For example, the United Nations Office for Disaster Risk Reduction (UNDRR) and the International Science Council (ISC) have classified space weather phenomena as a hazard requiring countermeasures[*1]. In Japan too, in January 2022 the Study Group on the Advancement of Space Weather Forecasting (the "Study Group") was established at the Ministry of Internal Affairs and Communications (MIC), and has engaged in discussions on strengthening observation, analysis, forecasting, and warning of space weather phenomena, impact on social infrastructure and how to deal with them, and also policy implications. In June 2022 the Study Group compiled a report setting out recommendations, including a worst-case scenario for an extreme space weather event, the first of its kind for Japan, and also the results of a world-first study on new forecasting and warning standards that take into account the social impact of such space weather phenomena[*2].

In order to prepare for severe space weather disasters, NICT is working to further improve monitoring for current status and forecasting technologies that form the basis for space weather forecasting, and provide information that meets user needs.

Advancement of Space Weather Monitoring and Forecasting Technologies

To improve our capability to observe and understand the current status of space weather, we are working to expand our routine observations from space using satellites, and from ground-based observations through international cooperation. In order to be able to predict the impact of space weather phenomena on satellite operations it is necessary to accurately understand the space environment for satellite orbits, but we are faced with an observational blind spot, as there are no satellites over Japan to monitor the space environment on a routine basis. In order to solve this problem, NICT is working with the Japan Meteorological Agency (JMA) and MIC on the development of space environment sensors that are planned to be installed on Himawari-10, which is scheduled to start operation in 2029 (Figure 2).

In this development project we aim to extend the observed energy range of the high-energy electron and proton sensors installed on the current Himawari and improve their accuracy to enhance our space environment monitoring capabilities over Japan.

The ionosphere affects communications, broadcasting, and positioning, and is strongly influenced not only by the sun and the magnetosphere, but also by the lower atmosphere, resulting in localized disturbances. Due to this, a multi-point observation network covering a wide area is needed to accurately monitor and understand the current status of the ionosphere. NICT has monitored the ionosphere for more than 70 years in Japan. Also, in order to monitor and predict the "plasma bubble" ionospheric phenomenon that can severely affect positioning, we have established one of the world's largest ionospheric observation networks in Southeast Asia through international cooperation. In addition, in collaboration with other countries including the U.S., we are receiving solar wind observation satellite data 24 hours a day, which is necessary to forecast magnetospheric and ionospheric storms.

To improve forecasting capabilities, we are working to improve forecasting technologies using high-speed computer simulations, data assimilation, and AI. To improve ionospheric forecasting precision, we are developing a data assimilation model for the coupled atmospheric and ionospheric model, GAIA. For the magnetosphere above the ionosphere, we are working on building a model that can reproduce extreme storm events and a forecast model for electrons in the radiation belt, which are a causative factor in deep charging in satellites. In addition, hoping to improve the accuracy and extend the lead time for forecasting disturbances in the magnetosphere and ionosphere, we are developing a solar wind forecast model, SUSANOO, and a solar flare prediction model using deep learning methods, DeepFlareNet.

Providing Information that Meets User Needs

In order to provide information about the current status and forecasts for space weather in an easily accessible and understandable manner for users, we are working to develop and release web-based services and applications, including Warning System for Aviation Exposure to Solar energetic particle (WASAVIES: Figure 3), Space Environment Customized Risk Estimation for Satellite (SECURES), and High Frequency Simulator Targeting for All-users' Regional Telecommunications (HF-START). To develop and improve such services and applications requires interaction with users and needs and seeds matching, and we will continue to hold the Space Weather User's Forum and Space Weather User's Council for such purposes. Also, based on the recommendations in the report of the Study Group, we will be working to promote efforts to provide the necessary information to users as and when they need it, including the actual operation of forecasts and warnings based on new standards that take into account the social impacts of space weather phenomena.

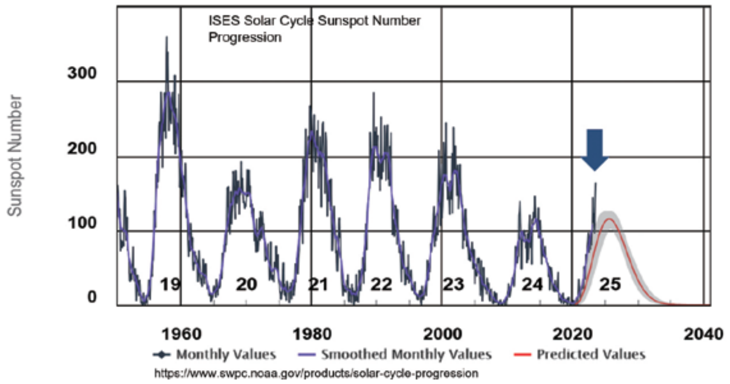


Figure 1 Changes in solar activity from 1950 to 2023
(Red line indicates predicted values)

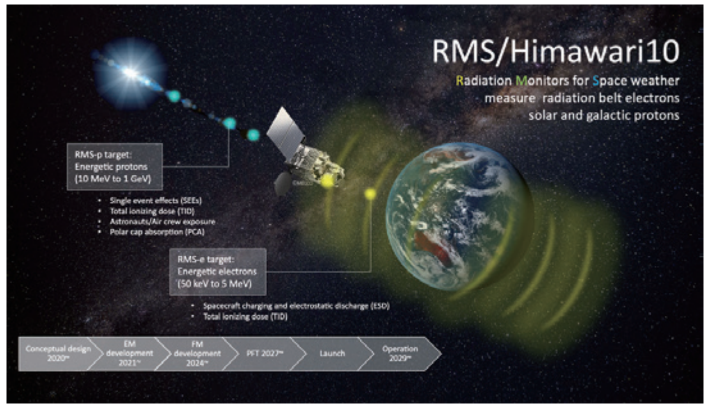


Figure 2 Space environment sensors development for installation on Himawari-10

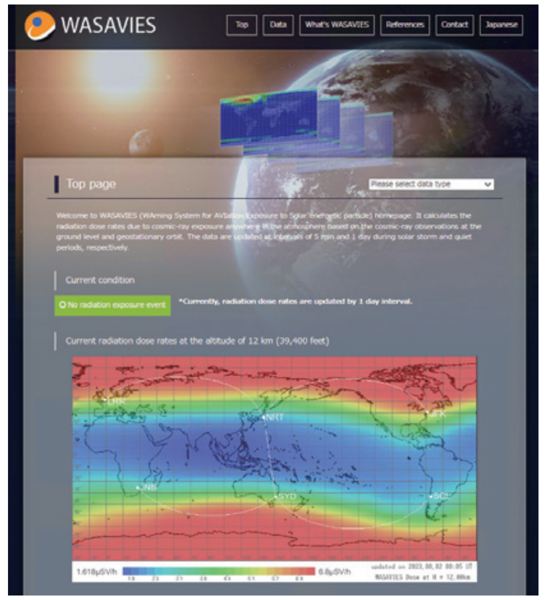


Figure 3 Warning System for Aviation Exposure to Solar energetic particle (WASAVIES) Web site
(https://wasavies.nict.go.jp/index_e.html)

references

*1 Hazard Definition & Classification Review: Technical Report, International Science Council
https://council.science/publications/hazards/

*2 Study Group on the Advancement of Space Weather Forecasting
https://www.soumu.go.jp/main_sosiki/kenkyu/space_weather/ (in Japanese)

Optical Ground Station Technology Supporting Optical Space Communications

Technology supporting optical satellite communications from earth

TSUJI Hiroyuki

Director of Space Communication Systems Laboratory, Wireless Networks Research Center, Network Research Institute

After completing a doctoral course, he joined the Ministry of Posts and Telecommunications Communications Research Laboratory (currently NICT) in 1992. He has engaged in research and development related to aircraft and satellite communication systems.
Doctor of Engineering.


SAITO Yoshihiko (left)

Senior Researcher, Space Communication Systems Laboratory, Wireless Networks Research Center, Network Research Institute

After working in National Astronomical Observatory of Japan (Subaru Telescope) and Tokyo Institute of Technology, he joined NICT in 2017. He is working on the research and development of free-space optical communication systems and adaptive optics systems. Ph. D. (Science).

SUZUKI Kenji (right)

Research Engineer, Space Communications Systems Laboratory, Wireless Networks Research Center, Network Research Institute

He joined the Radio Research Laboratory (RRL; currently NICT) in 1983. Since then, he has engaged in research on satellite control technology, mobile satellite communication, the Multimedia Virtual Laboratory, development of JEM/ICS(in NASDA-JAXA), research using small satellites and research on optical and RF signal multi-feeder links. And site diversity research for optical satellite communications. Currently engaged in the development of the ETS-9 ground systems.

Looking Beyond the 5G and 6G era, Non-Terrestrial Networks (NTN) are attracting a great deal of attention as a means of expanding communications networks across the sea, air, and outer space, with various R&D initiatives being advanced in Japan and overseas towards commercialization. In particular, to respond to hopes for greater diversity and enhanced capacity for satellite communications, such as satellite constellations, and also looking to solve spectrum resource constraints, satellite-to-satellite and satellite-to-earth optical communications technology will be critical. Although NTN generally focuses on the satellite side of a mission, in this article we introduce ground-based R&D activities being implemented with the view of realizing optical satellite communications.

Optical Ground Station Antenna

When communicating using radio waves between the ground and a satellite, a radio wave antenna (such as a parabolic antenna), is commonly utilized at the ground station. However, optical communications require technology capable of transmitting and receiving weak light (laser light) between a satellite and Earth using optical ground station (OGS) optical antennas (telescopes), and automatically capturing and tracking this light according to satellite position. NICT has accumulated over 30 years of R&D experience in satellite-to-earth optical communications and operates world-class, cutting-edge OGS facilities. The difference between an optical antenna and an astronomical telescope is that a telescope only needs to be able to track a targeted space body with respect to the Earth's rotation speed, whereas an optical antenna needs to be able to track a satellite in its orbital position. In addition, tracking precision of within 1/10th the width of a human hair is necessary to track light from a satellite 3,600 km away in geostationary orbit (GEO).

We currently have reflector telescopes with a diameter of over 1 m at three ground stations: one each at the NICT Headquarters (Koganei City), Kashima Space Technology Center (KSTC, Kashima City), and Okinawa Electromagnetic Technology Center (Onna Village) (Figure 1). In addition, to support satellite constellations comprised of LEO satellites and deep space communications such as from the Moon, a new OGS with a 2-m diameter reflector telescope, one of the largest in Japan, will be installed at KSTC, and OGS facilities equipped with 40-cm telescopes will be established at both the NICT Headquarters, Kashima, and Advanced ICT Research Institute (Kobe City) (Figure 2). These OGS will be linked to a 10-Gbps-class network, enabling integrated control and data transmission. Once this OGS network system is completed, it will be possible to achieve uninterruptible satellite-to-earth optical communications by switching to an alternative OGS even during cloud cover or rain, when optical communications are not possible.

Environmental Data Collection Device and Site Diversity Technology

One of the urgent challenges for Earth-to-satellite optical communications is to develop technologies that can avoid communications outages during rain or cloud cover. One solution is to develop site diversity technology capable of switching the connectivity to a cloud-free site while maintaining communication with satellites. To build and verify this technology, NICT is acquiring and accumulating environmental data for optical communications using environmental data collection devices (Figure 3) that collect information such as visible light whole-sky camera images and cloud height gauge data at dispersed locations throughout Japan. Parameters relating to optical communications are extracted from this data. For example, cloudage statistics for the evaluation of Earth-to-satellite optical communications (where clear blue skies are 0% and complete cloudage is 100%) can be calculated using a unique algorithm.

Figure 4 shows the results of the cloudage profile calculated from data collected from a

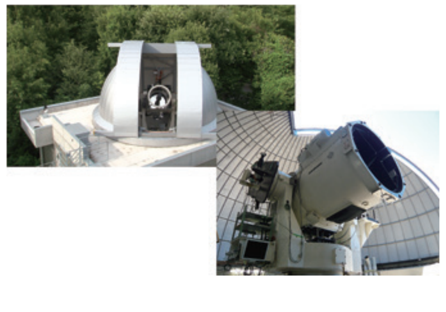


Figure 1 1 m (left) and 1.5 m (right) diameter optical antennas at NICT Headquarters (Koganei City)

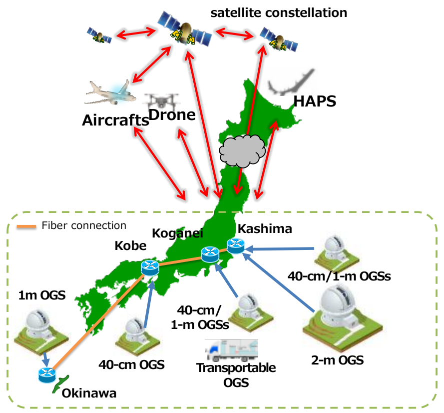


Figure 2 Optical ground station network system currently under development

Figure 3 Exterior of environmental data collection device (Okinawa)

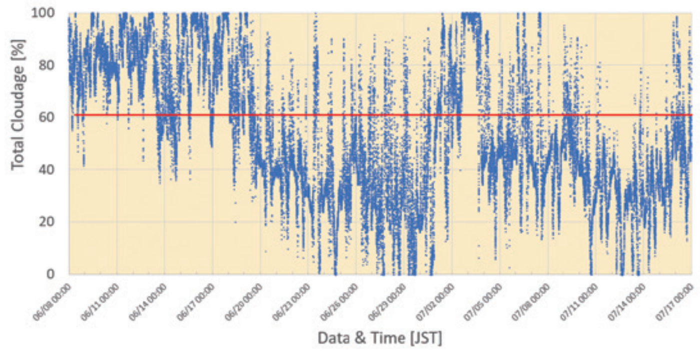


Figure 4 Example of changes in total cloud cover during rainy season (Okinawa observation point, 2020)

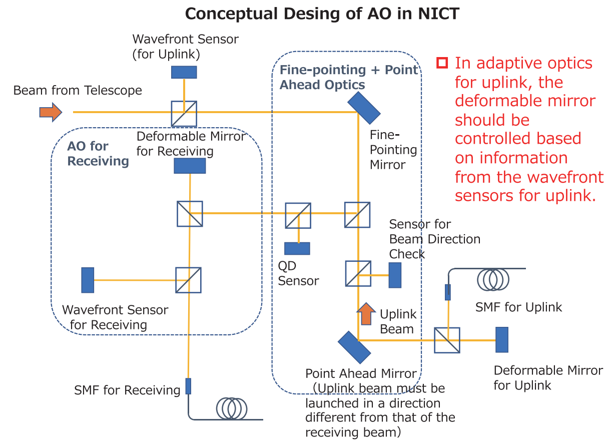


Figure 5 Wavefront correction using adaptive optics (AO)

device installed in Okinawa Prefecture in 2020 during the average rainy season period from June 8 to July 16. If we hypothesize that optical satellite communications are possible when total cloudage is less than 60%, then in Okinawa alone optical satellite communications would be possible 65% of the time. If it were then possible to combine Okinawa with other locations that have the same communications probability but bear no correlation with Okinawa or its weather conditions, then in the case of three locations the possibility of successful optical satellite communications rises to 94%, and further still to 99% when combining five locations.

Adaptive Optics (AO) Technology

Another challenge when implementing Earth-to-satellite communications is the degradation in the optical signal caused by the atmosphere in the optical path. For this degradation, wavefront turbulence caused by atmospheric refractive index fluctuations can be corrected on the receiving side, using corrective technology known as adaptive optics (AO). AO is a technology to adjust wavefronts by detecting the changing wavefront turbulence information from moment to moment in real time and controlling the deformable mirror or phase modulator, etc., based on this information (Figure 5).

AO technology was originally developed for the astronomy field, to enhance the performance of large aperture telescopes, and its effectiveness has already been well documented. At the same time, in optical communication applications, light collected by an optical antenna (telescope) ultimately needs to be kept coupled to a single-mode optical fiber (SMF) with an incident core diameter of approximately 10 μm (about 1/10th the width of a human hair). In such cases, as fluctuations in light received attributable to the satellite also impact the effect of AO, this heightens the role of the high-precision tracking optical system that conducts the tracking. In optical communications, as communication light is transmitted from the optical antenna to the satellite, AO is also required for transmission purposes. Bearing in mind that when transmitting, the satellite will have moved by the time the light reaches it, Point Ahead (PA) correction is also required.

For the 1-m optical antenna at NICT Headquarters, we have developed AO to receive light-based communication from the Engineering Test Satellite 9 (ETS-9), which is scheduled to be launched in the nearest future and have successfully improved the coupling efficiency of the SMF by more than 5 dB compared without AO system. The optical antenna is also fitted with the high-precision tracking optical system mentioned above. R&D is currently underway for AO for transmissions, with a plan to complete a system based on NICT's unique ideas.

Future Outlook

Japan is a country with considerable rain and cloud cover. Therefore, to realize a resilient ground-to-satellite and Earth-to-outer space (including the moon), optical communications speedily and accurately, ground-based site diversity technologies and AO technology will play a vital role. Furthermore, as demonstrated by environmental data collection devices, in order to realize robust and dependable optical communications, it will be necessary to look beyond Japan and consider international collaboration. This is why NICT has already started collaborating with research institutions in Europe and Canada and is engaged in R&D toward the realization of an international OGS network.

Secure Wireless Communication for Spacecraft

Research and development in the newspace era

YOSHIDA Maki

Senior Researcher,
Security Fundamentals Laboratory,
Cybersecurity Research Institute

After receiving Ph.D. in Engineering, she became assistant professor at Osaka University. Then she joined NICT in 2013, and has been engaging in research and development of information security.

NewSpace, the emergence of the private space industry, has been drawing attention worldwide. Low-cost yet highly secure wireless communications are desired for spacecraft such as small satellites and small launch vehicles, for protecting their critical commands and valuable data transmissions. We are engaged in R&D initiatives for secure wireless communication technologies that realize the highest level of security called information-theoretic security with low-cost consumer electronics device.

Background

In the recent NewSpace era, many small satellites including CubeSats have been launched on various academic or commercial missions. As of July 10, 2023, of the 9,943 satellites in orbit around the earth, 1,329 were launched in 2023*1, with an average of more than seven launches per day, mostly for small satellites for academic or commercial purposes. In Japan, a space activity law entitled "Act on Launching of Spacecraft, etc. and Control of Spacecraft (Act No. 76 of 2016)" entered into force on November 15, 2018. The guidelines of this law stipulate the following requirement: "As for transmission of signals related to safety-critical systems, etc., take measures including appropriate encryption so as to prevent interference and takeover." In fact, no impersonation attack or tampering attack against critical uplink commands to spacecrafts should be successful (Figure 1). Also, interception of downlink transmissions which involve highly variable mission data is undesirable.

R&D of secure communication technologies in the NewSpace era

At the Security Fundamentals Laboratory, Cybersecurity Research Institute, to establish high security and low implementation cost in wireless communication systems of small satellites and small launch vehicles in NewSpace era, we are working with Interstellar Technologies, Inc., and Hosei University (Figure 2).

At the initial stages of our research, we have identified and enumerated basic requirements in spacecraft uplink and downlink, proposed a new protocol that guarantees information-theoretic security, and investigated its implementability on low-cost consumer electronics devices. We also have presented some results of flight demonstration tests on sounding rocket MOMO.*2 The main objective of the tests is to confirm that all data is transmitted correctly over the proposed protocol and no significant hardware-device problem happens in the space flight environment. In the latest flight test conducted on July 31, 2021, the test objective was fully met, achieving successful downlink transmission of 558,313 packets (34Mbytes) at a practical effective bandwidth of 512kbps (Figure 3). In addition, the proposed protocol decreases the necessity for devices specifically made for use in space, which lead to a reduction of installation costs since such space-grade devices are extremely expensive. Such cost reduction makes it possible to implement the proposed protocol on a variety of small spacecraft.

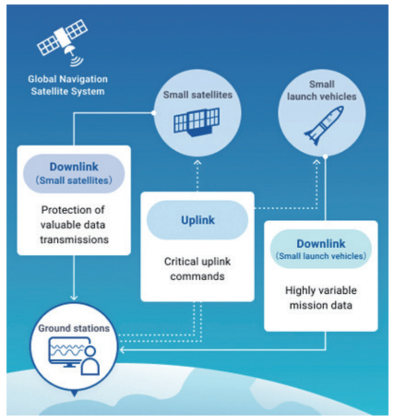


Figure1 Security requirements for wireless communications between spacecraft and ground stations

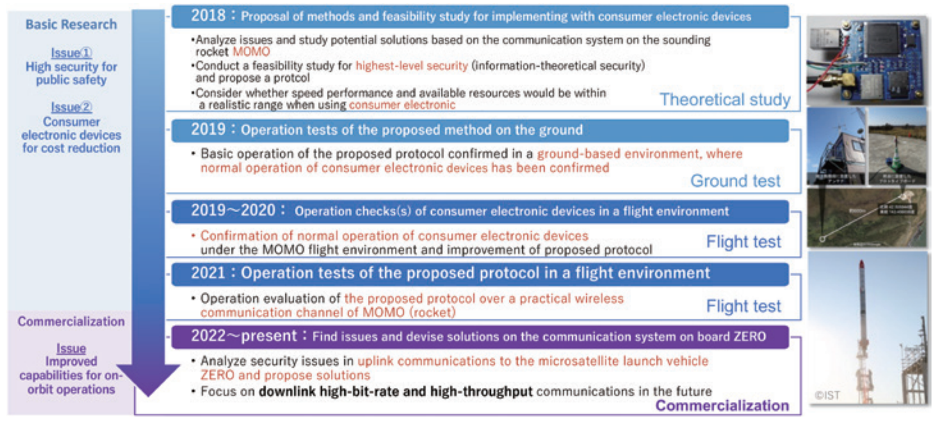


Figure 2 Progress in joint R&D

Towards commercialization

We are currently aiming to put this proposed communication method into practical use on the microsatellite launch vehicle ZERO*3. Although no problems were encountered during flight tests on the sounding rocket MOMO, care needs to be taken to ensure key synchronization capable of withstanding commercialization. A loss of key synchronization can lead to the permanent loss of communications with the spacecraft, or in other words mission failure. Accordingly, we are working towards the realization of a much more reliable communication protocol, which is mainly designed for robustness against the above malfunctions.

To this end, we have proposed a novel framework for secure wireless communication, where risk of key synchronization loss is minimized in order to improve resilience against temporal H/W failures. We have confirmed that key synchronization and data transmission are possible at a 10.2 Mbps rate, on our prototype transmitter and receiver implementations using FPGA boards. Our basic idea of key synchronization consists of the use of precise time information obtained from GNSS for control purposes, such as key reading, and does not keep control information permanently stored inside the device. As a result, the use of stored control information is minimized and the resilience against temporal H/W failures is improved. We have also proven that any spoofing or tampering is cryptographically impossible when combined with our proposed communication protocol. This means that it would be possible to avoid spacecraft loss caused by critical environmental factors (temporal H/W failures) as well as intentional attacks.

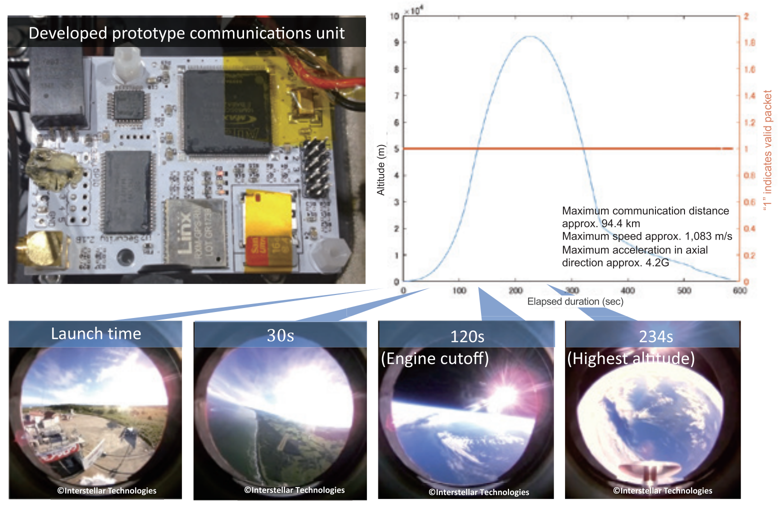


Figure 3 Flight test of proposed secure communication technology (July 31, 2021)

Future prospects

We have established the feasibility of highly reliable, highly secure, low-cost technologies capable of realizing high bit-rate and high throughput wireless communication between spacecraft and ground stations. Our next challenge is to develop cryptographic protocols resilient to variations of the communication environment and verify the performance of the proposed protocols towards commercialization. Through our R&D activities, we will contribute to space development in the NewSpace era.

＊1 UNOOSA, Online Index of Objects Launched into Outer Space, https://www.unoosa.org/oosa/osoindex/search-ng.jspx (Last accessed on 2023-09-26)

＊2 Common key cryptography and public key cryptography widely used on the internet, etc., are based on computational security logic that the computational power required for an attack is finite but enormous. However, information-theoretical secure ciphers have an advantage in that they are unbreakable even if the attacker has unlimited computational resources at their disposal.

＊3 Interstellar Technologies Inc. https://www.istellartech.com/en (Last accessed on 2023-09-26)

Establishing an Environment for Realizing Beyond 5G

Completion of a B5G electromagnetic wave anechoic chamber facility

Director of Planning Office / Senior Researcher, Terahertz Laboratory, Terahertz Technology Research Center, Beyond 5G Research and Development Promotion Unit **SAITO Shingo**

At the end of March 2023, a B5G electromagnetic wave anechoic chamber building was completed at NICT as part of initiatives to establish an environment for the development of B5G basic transmission technologies. This new facility is equipped with an anechoic chamber for intensive and efficient measurement and evaluation of antenna and transceiver transmission characteristics, which will be essential for engaging in timely R&D for realizing B5G. It is also capable of handling ultra-high frequency bands that are anticipated to be used in B5G, including the terahertz band.

To secure the position of Japanese companies in global markets in the Beyond 5G (B5G) era, it is imperative to quickly establish an open development environment, and to develop systems for domestic and international collaboration centered on NICT, which has the required technologies. In addition, at the World Radio Communication Conference (WRC 2019), a body that establishes common global wireless communication standards, the decision was made to utilize a portion of the terahertz band (275-450 GHz) as the frequency band for future mobile phone systems.

This decision has also spurred momentum in Japan to research transmission technologies capable of achieving further advancements that are anticipated in the B5G era, including ultra-high speed, ultra-low latency, and massive machine-type simultaneous communications. As R&D has progressed, high frequency and occupancy experiments have become essential, leading to increasing numbers of users both inside and outside NICT wanting to use an anechoic chamber and a greater need for facilities dedicated to B5G and ultra-high frequency bands.

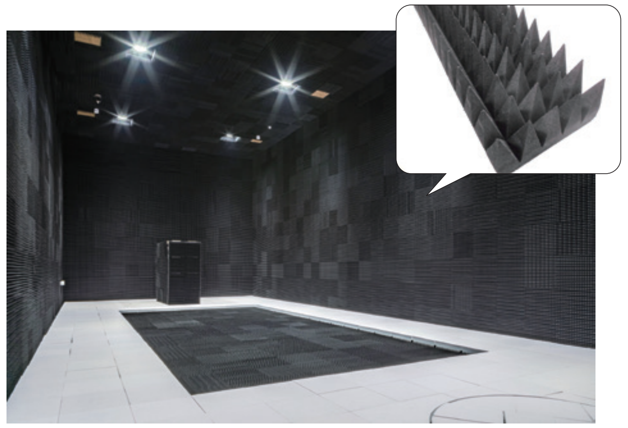
So, in order to accelerate R&D that can be directly translated into social outcomes and to promote collaboration with private sector companies, we have utilized NICT's research resources (people, technology, and know-how) to develop the B5G electromagnetic wave anechoic chamber facility.

By preventing the scattering of radio waves in the laboratory, the anechoic chamber makes it possible to evaluate aspects such as antenna characteristics, and also enables legally compliant experiments even in the stages prior to establishing a radio station. What is more, it strongly supports R&D in transmission technologies using terahertz and other radio waves in the ultra-high frequency band, which are expected to be utilized in B5G.

The B5G electromagnetic wave anechoic chamber facility provides a measurement environment into which private-sector companies are able to bring their own radio devices and is aimed at enabling efficient performance evaluations and confirmation of functions that can be swiftly fed back in to the development process.

The anechoic chamber has a length of 20 m, width of 8.5 m, and height of 7.5 m, and is equipped with a rotary table, antenna positioner and so on. Radio wave absorbers for radio waves above 10 GHz are fitted to the ceiling and walls, and the floor absorbers can be laid out or stored away, allowing experiments to also be implemented using metal floor conditions.

Exterior of B5G electromagnetic wave anechoic chamber facility



Inside anechoic chamber , photo top-right are radio wave absorbers (each 12 cm hight quadrangular pyramid)

The B5G anechoic chamber facility went into operation in June 2023, and NICT researchers are currently checking and evaluating its performance, with a view to opening it up for shared use in the near future.

This facility is being developed and operated not just by the many researchers in the Terahertz Laboratory, Terahertz Technology Research Center, Beyond 5G Research and Development Promotion Unit, but through cross-cutting collaboration among a range of NICT departments, including the Financial Affairs Department, Strategic Planning Department, and Operation Planning Department.

Journey to the Next Space Communications Network

ABE Yuma

Researcher, Space Communication Systems Laboratory, Wireless Networks Research Center, Network Research Institute Ph.D. in Engineering

Biography

1992 Born in Aomori Prefecture, raised in Tokyo
2015 Graduated from the Department of Applied Physics and Physico-Informatics, Faculty of Science and Technology, Keio University
2017 Completed master's degree at the Graduate School of Science and Technology, Keio University, and joined NICT
2020 Received Ph.D. from the Graduate School of Science and Technology, Keio University

AWARDS

2018 Received the Outstanding Paper Award and Takeda Award from the Society of Instrument and Control Engineers (SICE)
2021 Received the Telecom Systems Technology Student Award, 36th Telecommunications Advancement Foundation Award

Q&As

Q What is good things to be a researcher?

A Being able to spend a great deal of time thinking about only one thing. I have also had the opportunity to travel to various countries and meet different people and get to know various cultures.

Q What are you interested in other than research?

A Using maps and street view to go on virtual travels, and thinking about, studying, and imagining the origins of the cities I visit virtually. Why are people drawn to cities and how do they come to be?

Q How do you spend your time on holidays?

A I like to take walks to take photos of scenery and buildings. I have been using a FUJIFILM X-S10 for the last two years. I post my photos on social media and look forward to hearing from anyone who is interested in them!

What does outer space mean to you? For being something far removed from daily life, there are more and more services and products that utilize outer space and make it more relatable, including Wi-Fi on airplanes, or SpaceX's Starlink.

In terms of Beyond 5G, from the perspective of scalability, Non-Terrestrial Networks (NTN) are gaining attention as a means of interconnecting ocean, air, and outer space via various communication platforms such as satellites, high-altitude platform stations (HAPS), and drones. My research theme is optimization of networks, including NTN and terrestrial communication systems. With NTN, various factors change from moment to moment, like the number of users requiring communication, the content of their requests, the number of nodes available for communication, and the quality of communication links. In order to realize uninterrupted communications under these circumstances, it is essential to efficiently control communication resources such as frequency bands and power sources, and also routes of communication traffic. To this end, I am considering various system requirements and network structures, developing network control algorithms, and evaluating and analyzing these through simulations.

Utilizing the NICT international human resources dispatch program, I have been working as a visiting researcher at the University of Luxembourg since June 2023. Luxembourg is known as a multilingual nation, and the research group I am affiliated with is comprised of people from various countries, so in addition to English, I hear many languages every day at work, including Spanish, French and Hindi. After hearing about the details of the project being proceeded by the group, I was also reassured that the direction of my own research is on the right track, and I have also noticed areas where my own knowledge is lacking. I hope to further expand my potential as a researcher through this experience.

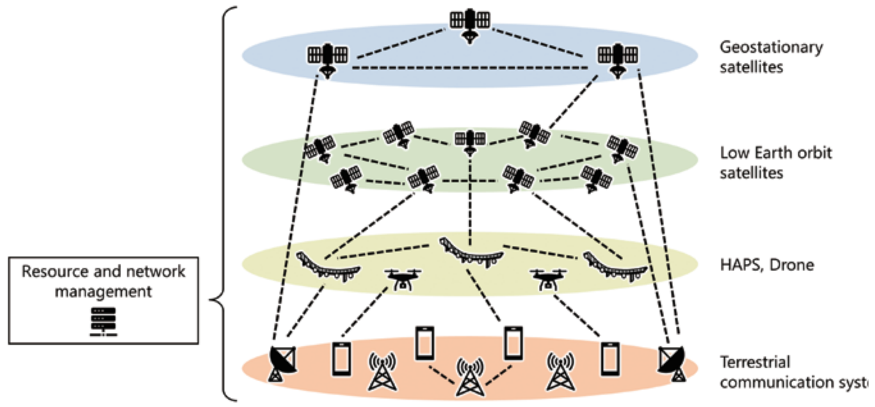


Figure Overview of Space Communications Network

The Radio Day and Info-communications Promotion Month Awards are given to individuals and entities who have contributed to the use of radio waves or the development of communication, and to persons who are expected to create outstanding digital content.

*Affiliations and positions are as of the time of the awards.

Photo: From left, SUMITA Eiichiro, MORIAI Shiho, KASAMATSU Akifumi

The Info-communications Promotion Month for FY 2023, Minister of Internal Affairs and Communication Award

SUMITA Eiichiro

NICT Fellow / Distinguished Researcher, Universal Communication Research Institute

●Date: June 1, 2023

●Awarded for: Making an outstanding contribution to the development of automatic translation technologies in Japan through wide-ranging activities that include not only developing high-precision automatic translation technology, but also social implementation through releasing such apps as VoiceTra and TexTra, building of a data collection ecosystem named Hon'yaku Bank (Translation Bank), and establishing foundational technologies for simultaneous interpretation using AI.

●Receiver's Comment: This award recognizes our various research and development initiatives, including national projects relating to voice translation using AI (the Global Communication Plan for serial interpretation, and the Global Communication Plan 2025 for simultaneous interpretation) and Hon'yaku Bank (Translation Bank), a data collection platform aimed at realizing high-precision machine translation, as well as the concrete outcomes of these various projects, such as VoiceTra and TexTra.

I am deeply grateful for this award, which has been made possible by help by the staff and directors at NICT including the Universal Communication Research Institute.

The Info-communications Promotion Month for FY 2023, SHIDA Rinzaburo Award

KASAMATSU Akifumi

Director General, Koganei Frontier Research Center, Advanced ICT Research Institute

●Date: June 1, 2023

●Awarded for: Making a significant contribution, as the long-serving representative of the Terahertz Wave research team, to the development of device and measurement technologies, the establishment of the Institute of Electrical and Electronics Engineers' first 300 GHz band wireless communication standard, and discussions on the allocation of the 300 GHz frequency band at the 2019 World Radiocommunication Conference.

●Receiver's Comment: It is a tremendous honor to receive this award named after Dr. SHIDA Rinzaburo, who made such a lasting impact on electrical engineering and communications technologies in Japan. Advances in terahertz wave research have been made possible by the guidance and cooperation of many people, and this award recognizes the contributions of all of them, not just myself. We have only completed part of our journey to commercialize terahertz wave technologies and I will continue to endeavor to engage in beneficial R&D.

The Info-communications Promotion Month for FY 2023, Distinguished Achievement and Contributions Award

MORIAI Shiho

Senior Executive Director / Director General, Cybersecurity Research Institute

●Date: June 1, 2023

●Awarded for: Making a significant contribution to the realization of a safe and secure digital society, through long-running efforts to research, develop, standardize and socially implement cryptographic technologies, as well as leading the formation of an R&D hub in the field of cybersecurity in Japan as the Director General of the Cybersecurity Research Institute.

●Receiver's Comment: I am deeply moved to receive this award in the year that marks the 30th anniversary of my involvement in R&D on cryptographic technologies. The boundaries of security technologies continue to expand, and their social impact and importance are becoming ever greater. With the aim of improving Japan's ability to counter cyberattacks and promoting safe and secure data utilization, I will continue to engage in R&D, social implementation and human resources development in the field of cybersecurity.

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