Space Terahertz Remote Sensing for Earth and Planets

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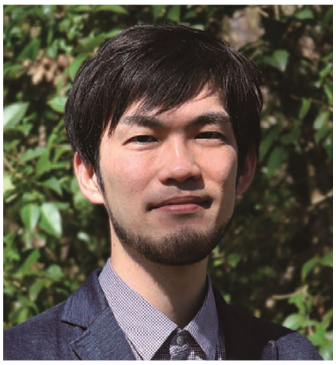
After receiving Ph. D in 1995, she joined CRL(currently, NICT) in 1999. Her interest is Terahertz remote sensing for Earth and Planets. Ph. D. (Science).



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After receiving Ph. D degree, he joined NICT in 2018. He is developing radiative transfer model and building a terahertz measurement system for small satellite. Ph. D. (Science).

Remote sensing is a technique which enables one to "see" an object or phenomenon without making physical contact with the object by detecting electromagnetic waves. It not only allows us to see almost as far as the edge of the universe, but also allows us to penetrate matter and see inside. Light and radio waves have been mainstream in sensing applications thus far, but progress is being made on the use of terahertz waves, which are located in a frequency band between light and radio waves. In this article, we will discuss new scientific discoveries, the evolution of new space businesses, and more made possible by the use of space terahertz remote sensing.

Background

Traditionally, satellites carrying out remote sensing of the Earth from space have primarily employed image-based or spectrometric observation using optics/infrared light or radio waves. Terahertz (THz) waves, located in the boundary region between radio waves and light, only started being used in 2002—relatively recent in terms of the history of satellite observation. THz technology is advancing rapidly in recent years, and new technologies such as high-gain antennas and high-power output devices are rapidly being developed for terahertz-based Earth/planet remote sensing observation from space. These technologies are being applied in space remote sensing techniques as well. THz waves have specific characteristics which are a mix of the advantages of both light and radio waves, for example, sensing with high spatial resolution (a characteristic of light), high matter transmissivity (a characteristic of radio waves), and ultra-compact and lightweight sensors with ranges of several kilograms (a property of high frequencies). These technical revolutions have enabled measurement of physical quantities in a variety of areas, which have been difficult in traditional environmental observations, such as: estimating the size distribution of ice clouds; exploring the habitability of Jupiter's icy moon, Ganymede, by observing atmospheric molecular isotopes and surface water content; and investigating water resources in near-Earth space, such as on the Moon and Mars.

Terahertz remote sensing research at NICT

Figure 1 illustrates the progress NICT has made in developing THz remote sensing observation from space. We have continued to

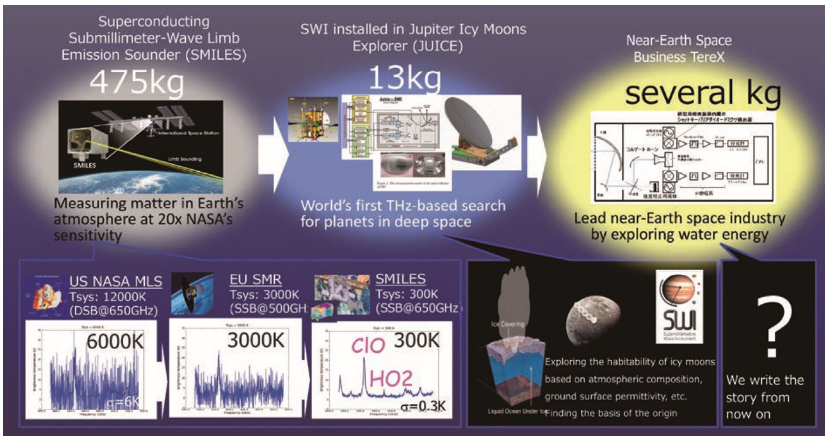


Figure 1 Progress of terahertz remote sensing at NICT

advance our research fields, from identifying actual environmental conditions on Earth, to searching for life in the Jupiter and its icy moons, to exploring water energy sources in near-Earth space (the Moon and Mars).

Development of the Superconducting Submillimeter-Wave Limb Emission Sounder (SMILES) began in 1998. The device was installed in the Japanese Experiment Module on an exposed part of the International Space Station, and used in observations for seven months, from October of 2009 to April of 2010. The project was a joint mission between NICT and JAXA for the purpose of exploring the use of THz electromagnetic waves for Earth environment diagnostics. SMILES features an ultra-sensitive and accurate calibration technique using a 4K superconducting mixer at 0.6 THz. The project presented many challenges for which we had neither precedents nor experience, including the launch of the first HTV, the development of a 0.6 THz superconducting mixer, HEMT low-noise amplifier, and THz optical system/calibration system (for which there were no terrestrial precedents), and the development of Japan's first THz space sensor. These challenges spurred some Western researchers to say "there's no way they will succeed." Ultimately, however, SMILES boasts the world's highest molecular detection sensitivity, which is about 20 times better than that of similar conventional satellites developed by NASA and in Europe, and even 10 years after its launch, SMILES' unique and highly-reliable data is still being reported by scholarly articles—even from letter journals which focus on prompt reporting.

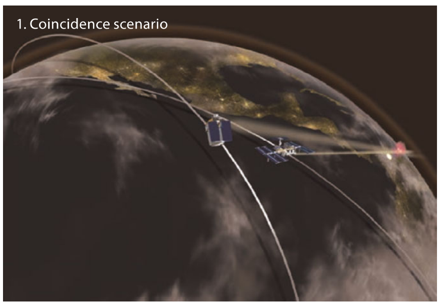
SMILES succeeded in capturing the spectrum of the short-lived and active "radical molecular HO_2," which is an ultra-trace species (around one part per hundred million at atmospheric pressure) in the Earth's atmosphere, by a single 0.5-second measurement. HO_2 radicals have an important role as strong oxidant which changes the atmospheric composition, such as H_2O, CO_2, and CH_4, which are the key species for radiative forcing and have indicated the possibility of an increase in the Earth's upper atmosphere by greenhouse gas emissions. We found spatial-temporal coincidence of SMILES HO_2 single scan observation with upper atmospheric transient discharge events called "sprite" by another imager satellite and ground-based lightning detections (Figure 2-1). Through this, we were able to prove that new HO_2 is being produced by lightning sprites and suggest that HO_2 concentration is increasing on a global scale (Figure 2-2). This research not only sounds a new alarm about climate change from a scientific point of view, but also paves the way for new types of science, which provide new knowledge by capturing "instantaneous phenomena" that do not appear in statistics, unlike the traditional data science, which primarily handles phenomena using statistical data.

Future prospects: exploring water energy in near-Earth space

The Fourth Industrial Revolution brings about a paradigm shift in industrial restructuring on a global scale. Industries involved with space business are undergoing drastic structural changes as well. "New Space" — an area where no main industry players are currently positioned— holds great promise as a stage for disruptive innovation which, through new ideas and technology, will dramatically alter society, the economy, and more as we know. The global space industry has started working on the basic infrastructure for economic activities aimed at "three-dimensional space" seamlessly linking the Earth with New Space (stratospheric platforms, low-orbit satellites, stationary satellites, the Moon, etc.).

While oil is the main energy source for industrial and human activity on Earth, water fills that role for New Space. Water is broken down into hydrogen and oxygen by chemical reaction. Hydrogen and oxygen are used for energy sources in rocket fuel, factory power sources, and more. A characteristic THz waves is the detection of water with the highest sensitivity among all electromagnetic wave regions. We are currently developing an 8 kg-class THz remote spectrometer, which is vastly smaller than the 475-kg SMILES. This requires us to meet many new challenges, such as reducing weight through the use of CFRP components for THz antennas and calibration systems; short development time for compiling the flight model in a mere three years, compared to the ten required for SMILES; and more. It is our hope to discover water on the Moon or Mars and lead New Space businesses in the future. A further dream of ours is to apply our experience with space THz sensors in THz communication for the Beyond 5G era to create an "AI-Driven Space THz Network" connecting all of New Space through THz communications. We welcome anyone who is interested in our research activities to join us.

＊The Ministry of Internal Affairs and Communications "Panel on Space x ICT" Report (in Japanese) https://www.soumu.go.jp/main_content/000502202.pdf



2. (a–c) Observation range of SMILES FOV at corresponding altitudes (yellow and blue lines), the estimated locations of sprites (red dots) and their ranges (red boxes), and lightning occurrence distribution between SMILES and ISUAL observations obtained from WWLLN data (grayscale mesh) for Events A, B, and C. Altitude ranges of the SMILES-FOV are 75–90, 77–90, and 80–90 km for Events A, B, and C, respectively. SMILES and ISUAL observed facing east (left to right in these figures).

(d–f) Images of sprites and their parent lightning emissions detected by the ISUAL for each event.

(g–i) Distributions of the mean intensity in the range of 649701.5 ± 0.8 MHz for the background atmosphere (white columns). Blue columns represent the mean line intensity near sprite events. Yellow columns represent the mean line intensity three scans before and after.

T. Yamada et al., JRL (2020)
doi.org/10.1029/2019GL085529

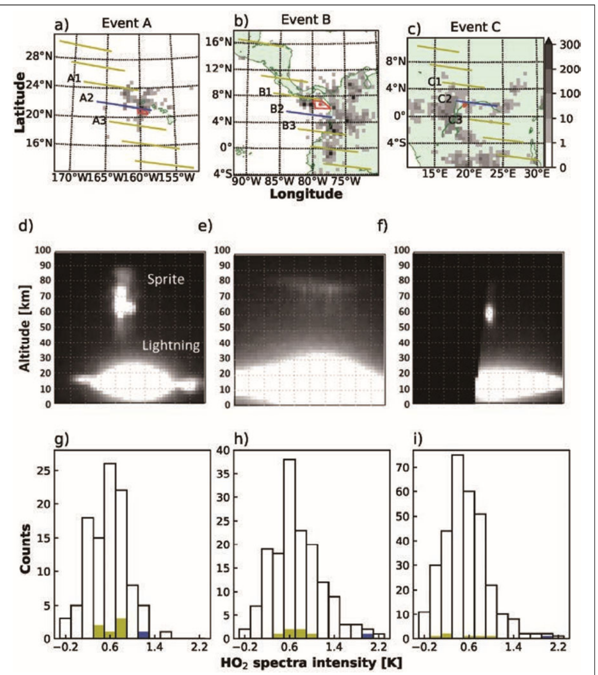


Figure 2 Schematic image and analysis of the coincident observation with SMILES-HO_2, sprite imaging satellite, and ground based lightning detection.