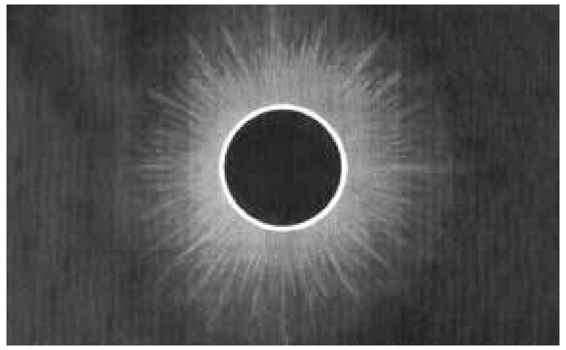
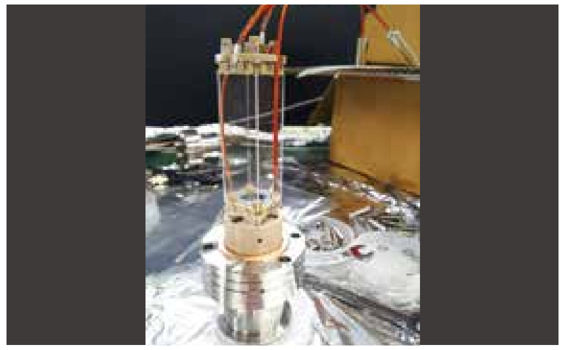
The 3rd ISEE Award Ceremony and Commemorative Lecture held online

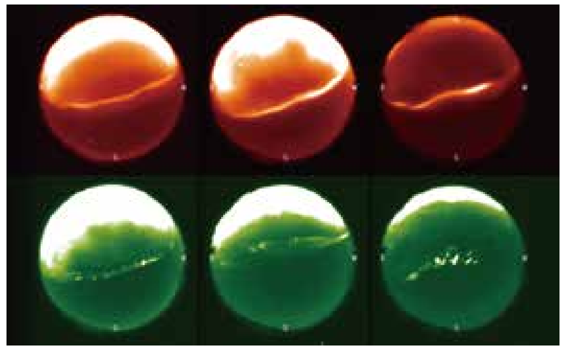


The solar coronal structure recorded in the 1806 total eclipse during the Dalton Minimum (Hayakawa et al., 2020, ApJ, 900, 114).

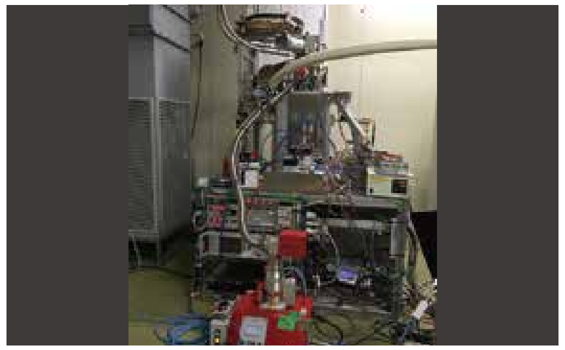


Technical verifier developed for a new TPC detector

IPrototype of a digital backend for the next generation IPS observation system

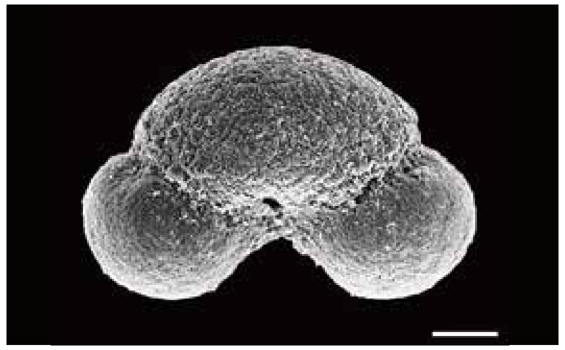


All-sky images of strong thermal emission velocity enhancement (STEVE) aurora taken at Athabasca, Canada



The upgraded multi-frequency millimeter-wave spectral radiometer at Syowa station, Antarctica

A scene in the oceanographic observation when the snow remains on the upper deck



Pine pollen in Lake Suigetsu, Central Japan (The scale bar indicates 10 microns)

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Published in September 2021

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Institute for Space–Earth Environmental Research, Nagoya University

Annual Report FY2020

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Annual Report

Institute for
Space–Earth Environmental Research

April 2019–March 2020

Foreword

2020 was a year during which the entire world faced historical challenges due to the COVID-19 pandemic. At the Institute for Space–Earth Environmental Research (ISEE), the impact of the pandemic was not small, and we had to postpone many of the international joint research and international workshops conducted by invited researchers from other countries. However, we maintained our research activities and produced critical scientific results by holding online research meetings.

For example, we developed the first-ever physics-based model that accurately predicts giant solar flares and published a paper (Kusano et al. 2020) in *Science*. This research will significantly contribute to the elucidation of the onset mechanism of solar flares and the improvement of space weather forecasting.

The Heliospheric Research Division led by Prof. Tokumaru succeeded in measuring the plasma density of solar wind in the vicinity of the Sun by observing the frequency dispersion of radio waves emitted from pulsars in the Crab Nebula. This new observation will play a major role in unraveling the mystery of how solar wind is accelerated.

The Center for Integrated Data Science (CIDAS) cooperated with the Japan Aerospace Exploration Agency (JAXA) to promote the data science of the geospace explorer “Arase (ERG).” This year, Dr. Imajo from CIDAS (currently an assistant professor at Kyoto University) and his coworkers found that active auroral arcs are powered by electrons accelerated at altitudes exceeding 30000 km, based on the high-angular resolution electron observations achieved by the Arase satellite in the magnetosphere and optical observations of the aurora from the THEMIS ground-based all-sky imager (Imajo et al. 2021).

Furthermore, Dr. Yadav from the Ionospheric and Magnetospheric Research Division succeeded in observing a peculiar aurora called STEVE for the first time using multi-wavelength spectroscopic imaging (Yadav et al. 2020). STEVE is a mysterious luminescence phenomenon that is different from that of a normal aurora. This observation brings new discoveries, such as confirming that the emission of STEVE is continuous, unlike normal auroras. These studies will make an important contribution to unraveling the mystery of the auroras that color the night sky.

At this institute, we conduct four interdisciplinary research projects (Solar–Terrestrial Climate Research, Space–Earth Environmental Prediction, the Interaction of Neutral and Plasma Atmospheres, and Aerosol and Cloud Formation). This year, we worked on various topics of interdisciplinary studies: Restoration of the paleo solar–terrestrial environment using historical literature and analog records, Observative research on atmospheric composition fluctuations due to high-energy particle deposition in the polar regions, Estimation of the origin of snowfall in the southeastern pole region using cosmogenic nuclides (tritium), and Research on food habits and residential areas explored by multi-Sr isotope analysis of burial bones. The advantageous characteristics of this institute will be used to develop new research areas, including space, the Earth, and humans.

In addition, we are promoting efforts to utilize basic science in a wide range of societies. For example, CIDAS and the Cosmic Ray Research Division collaborated to release a meta-database (RADARC311) for information retrieval of radiation measurement data related to the Fukushima Daiichi nuclear accident. For the measurements made immediately after the nuclear accident, metadata related to the measured data, measurement location, date and time, and the access point of the data have been stored in a database so that you can search where and what type of data can be found. This database will be widely used in accident verification and countermeasures in the future.

Every year, our institute awards excellent research activities based on ISEE joint usage and research to develop space–Earth environmental research, integrate related fields, and develop new fields. In 2020, Professor Ilya Usoskin and Dr. Stepan Poluianov of the University of Oulu (Finland) were awarded the third ISEE award. Through the ISEE International Workshop and ISEE International Joint Research, they undertook a study on extreme solar particle events and their environmental and social impacts, and established a new paradigm for space–Earth environmental change events. The awards ceremony and commemorative lectures were held online on March 11, 2021, with more than 100 scientists worldwide participating. This award will continue to be held in the future, and we will call for recommendations from international scientific communities.

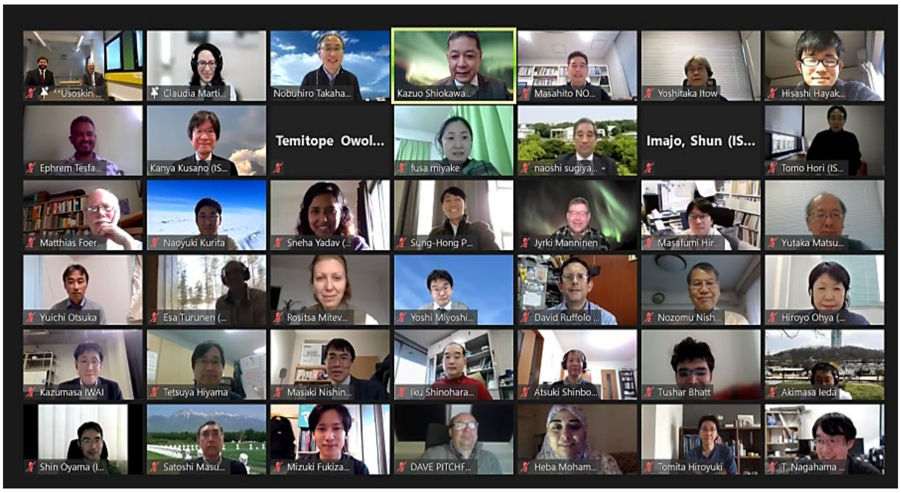
The ISEE has been certified by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as a joint usage/research center for the third medium-term goal/planning period (FY2016–2021) of national universities. Based on proposals from researchers worldwide, we adopt approximately 200 research projects each year and continue active joint research activities. We are planning to continue and further strengthen these joint research activities during the fourth medium-term target and planning period that begins in 2022, and have applied the continuation certification of the Space and Global Environmental Research Center to the MEXT. We are deeply grateful to everyone who has supported us in this program.

In this plan, we emphasized the (1) development of international research collaboration, (2) creation of new science through interdisciplinary studies, and (3) training of young researchers. We aim to add three types of international joint research support programs for young researchers to the existing 12 types of open-call joint research programs. Therefore, we have continued the operation of the three research centers (Center for International Collaborative Research, Integrated Data Science, and Orbital and Suborbital Observations) that promote joint usage and research projects, and established a system to continuously support their work. In particular, to strengthen the international joint research project, Associate Professor Martinez-Calderon Claudia, who has a wealth of international experience, joined the Center for International Collaborative Research. To cultivate new interdisciplinary research, we have started a director leadership project for researchers inside and outside the institute to collaborate and challenge emerging research issues that cross space science and Earth science. Through these new efforts, we aim to continue contributing to the development of related communities and creating new academic fields.

With the expansion of space development, space will become an active area of humankind in the near future. Private space exploration and space travel are already becoming a reality. Therefore, we believe that the perspective of this institute will become even more important. We will consider the Earth, the Sun, and space as one system, and challenge new research to contribute to the solution of global environmental problems and the development of human society expanding into space.

The COVID-19 virus has spread again at the time of writing this article (May 2021), and I think it will have a major impact on future scientific research. However, I would like to make efforts to overcome any related difficulties with the ingenuity of the staff and the people involved, and fully fulfill the role of the institute as a hub of different scientific communities. This annual report provides you with an understanding of the activities of the ISEE, and we appreciate your continued support and cooperation.

Kanya Kusano
Director



The 3rd ISEE Award Ceremony and Commemorative Lecture ware held virtually on Mar. 11, 2021.

The 3rd ISEE Award

Aiming to develop space–Earth environmental research, promote interdisciplinary research, and explore this new research discipline, the ISEE presents an ISEE Award to a prominent research activity based on the ISEE Joint Research Program.

The third ISEE Award was awarded to Professor Ilya Usoskin (University of Oulu, Finland) and Doctor Stepan Poluianov (University of Oulu, Finland) for their great contribution to the space–Earth environmental research through international joint research on extreme solar particle events and their environmental and social impacts. The award ceremony and commemorative lecture were held online via ZOOM on the following date and times.

Date: March 11, 2021

ISEE Award Ceremony: 16:00–16:15

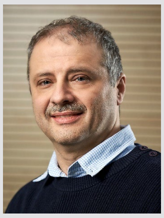
Commemorative Lecture: 16:15–17:15 Speakers; Prof. Ilya Usoskin and Dr. Stepan Poluianov

Title; Extreme solar storms: what we know and what we guess

ISEE Award 2020

Winner: **Prof. Ilya G. Usoskin** (Professor, University of Oulu, Finland)
Dr. Stepan V. Poluianov (Senior Researcher, University of Oulu, Finland)

Title: **: Contribution to solar-terrestrial environmental research through international joint research on extreme solar particle events and their environmental and social impacts**



Prof. Ilya Usoskin

Dr. Stepan Poluianov

Citation: Prof. Usoskin and Dr. Poluianov have established a new paradigm for extreme events of space–Earth environmental change that have not been considered before, through the ISEE International Workshop Program (2018) and the ISEE International Joint Research Program (2019). The award winners are working with the ISEE research team to develop new research fields on extreme solar events and their effects from space and Earth scientific perspectives. These activities are consistent with the mission of ISEE to explore the space–Earth environment.

Career summary of award winners: Prof. Ilya Usoskin (Professor, Head of Oulu Cosmic Ray Station) received his PhD in astrophysics at the A. F. Ioffe Physical-Technical Institute in 1995. He is an expert in solar activity and the variability of cosmic rays and their atmospheric effects and is one of the founders of the space climate research field. Dr. Stepan Poluianov (Senior Researcher) received his PhD in space physics at the University of Oulu in 2016. He is an expert in cosmic rays and their interaction with matter, and has made significant contributions to developing a detailed model of cosmogenic nuclide production.

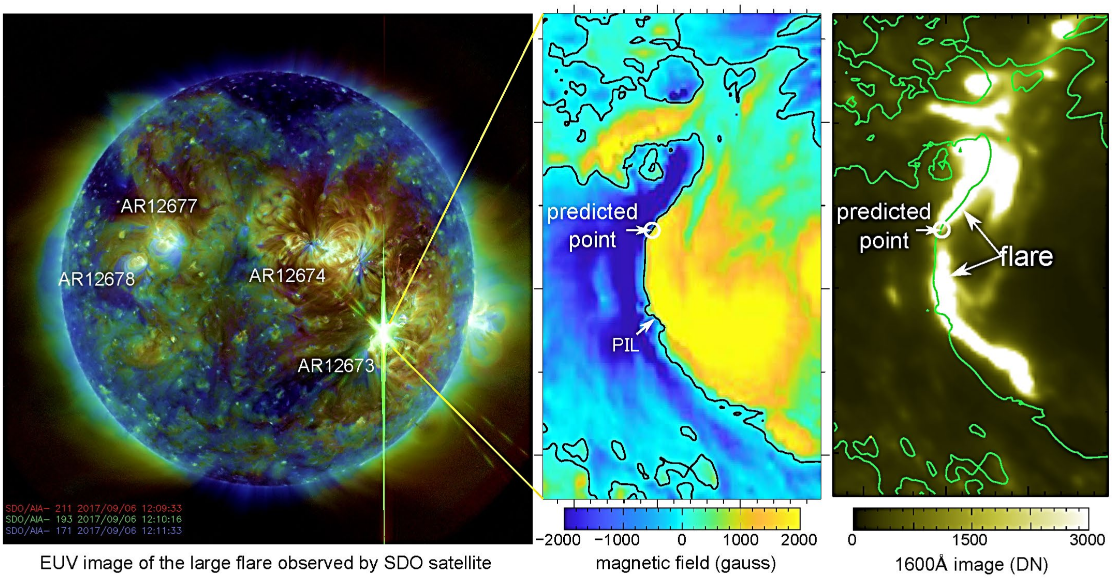


Fig.1

Physics-based prediction of large solar flares

Prof. Kanya Kusano, the director of ISEE, successfully developed a physics-based model that accurately predicts the occurrence of large solar flares based on the theory of magnetohydrodynamic (MHD) instability. This development will contribute to improving space weather forecasts and understanding of the explosive phenomena occurring in space.

Solar flares are the largest explosion phenomenon in solar systems and pose a potential threat not only to astronauts and artificial satellites, but also to social infrastructures such as communications, positioning, electric power, and aviation. Therefore, it is necessary to predict their occurrence in advance. However, conventional prediction relies on empirical methods, and its accuracy is not sufficient.

Prof. Kanya Kusano, the director of this institute, and his coworkers developed for the first time a method to predict large solar flares based on a new theory of MHD instability (double- arc instability). Furthermore, they demonstrated that their method could predict the precise location of the seven out of nine large flares that have occurred in the past 10 years. They also found a new physical quantity "magnetic twist flux density" that determines the occurrence of giant solar flares. This research will greatly advance the sophistication of space weather forecasts and the understanding of explosion phenomena in space.

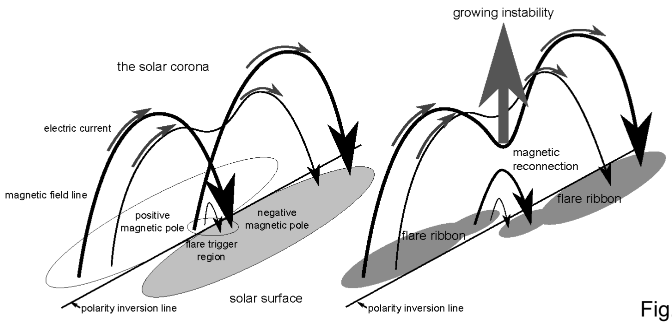


Fig. 2

Paper information
Journal： *Science,* Vol. 369, Issue 6503, pp. 587-591, 2020
Authors： Kusano K, T. Iju Y. Bamba, and S. Inoue
Title： A physics-based method that can predict imminent large solar flares
DOI： 10.1126/science.aaz2511

Fig.1: Images of the large solar flare observed by the SDO satellite on September 1, 2017. Left is the solar disc image in EUV (193Å). Center and right show the magnetic field and the EUV (1600Å) images in the flaring region, respectively. The predicted point on the polarity inversion line (PIL) denoted by a circle is located at the center of the flare.

Fig.2: A magnetohydrodynamic model that can explain the onset mechanism of solar flares. Left and right show the magnetic field line structures before and after the onset of a solar flare, respectively. The small-scale magnetic reconnection between the two magnetic loops triggers the double-arc instability and a solar flare.

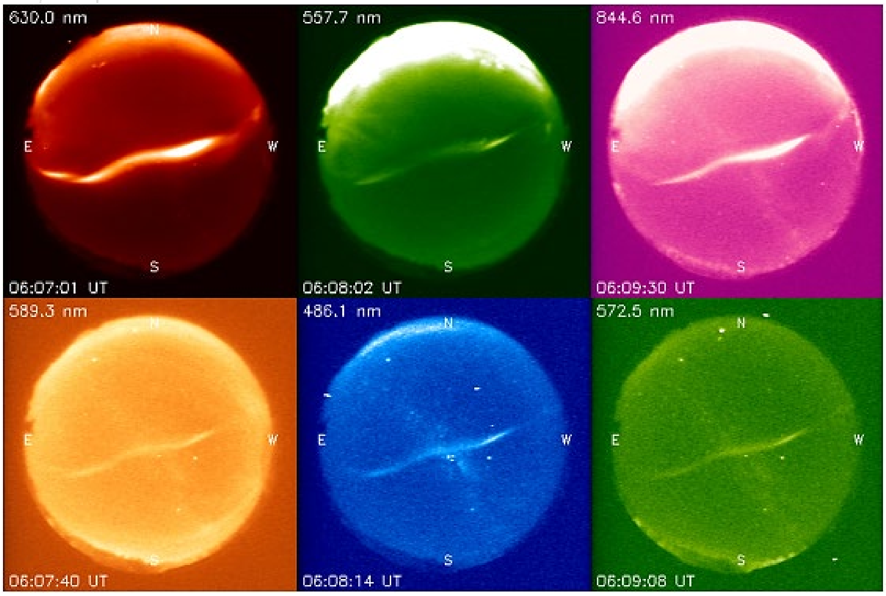


Fig.1

Multi-Wavelength Imaging Observations of STEVE at Athabasca, Canada

Yadav et al. (2021) have reported the first multi-wavelength imaging observations of strong thermal emission velocity enhancement (STEVE), which is a violet color mysterious aurora-like phenomenon in the upper atmosphere at subauroral latitudes.

STEVE is distinctly different from traditional aurora and appears as a violet narrow luminous band extending over thousands of kilometers in the east-west direction. STEVE displays are often accompanied by narrow "streaks" of green color known as "picket fence" aurora. Using Optical Mesosphere Thermosphere Imager (OMTI) at Athabasca, Canada, STEVE emissions were observed for the first time at six specific wavelengths, including nominal background, confirming the continuum nature of STEVE. These monochromatic images unfold several unprecedented features of STEVE such as its evolution, detachment from the main auroral oval, ribbon-like motion, and sharp boundaries. One of its striking features is the presence of dark bands poleward of the picket fence structure, resembling the "black aurora." The results contribute to unravelling the mysteries associated with STEVE and the underlying physical mechanisms.

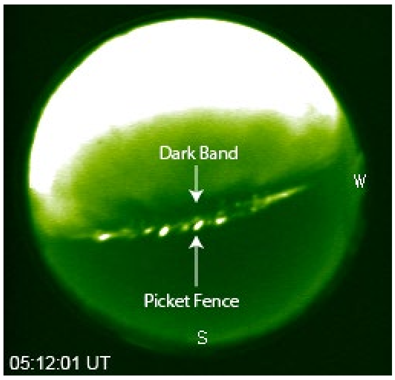


Fig.2

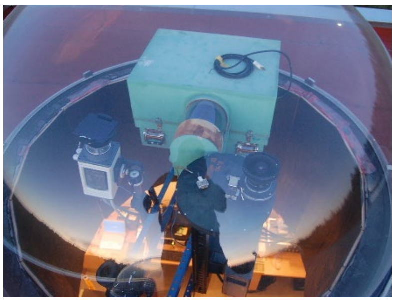


Fig.3

Paper information
Journal： *J. Geophys.Res. Space Physics,* Vol. 126, e2020JA028622, 2021
Authors： Yadav, S., K. Shiokawa, Y. Otsuka, M. Connors, and J.-P. St Maurice
Title： Multi-wavelength imaging observations of STEVE at Athabasca, Canada
DOI： 10.1029/2020JA028622

Fig.1: All-sky images of STEVE at multiple wavelengths on September 6, 2019.
Fig.2: All-sky image depicting "picket fence" structure in the green-line (557.7-nm) on May 2, 2019. The sharp decrease in emission intensity at the immediate poleward edge of picket fence appears as a "dark-band."
Fig.3: All-sky imager (OMTI) operating at Athabasca, Canada.

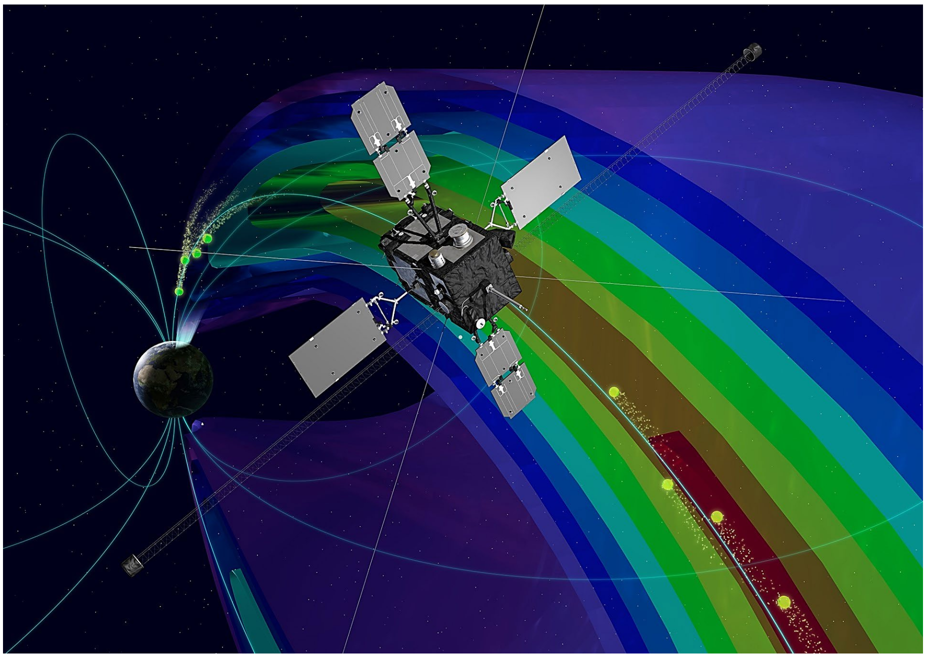


Fig.1

Very high altitude auroral acceleration region

The team at ISEE, led by Dr. S. Imajo, Dr. Y. Miyoshi, and Dr. K. Shiokawa, discovered a very high-altitude auroral acceleration region beyond ~30000 km above an auroral arc, using comprehensive particle and field observations (including high-angular resolution electron observations by LEPe) with the Arase satellite and high spatial-temporal resolution auroral observations with THEMIS ground-based imagers.

The generation mechanism of electrostatic-field-accelerating auroral electrons remains unknown. The altitude distribution of the electrostatic field might provide an important clue for understanding the generation mechanism. In this study, an unexpected discovery, in which auroral electrons were already accelerating at a very high altitude exceeding 30000 km, was made by the Arase satellite, which has a unique orbit and high-performance comprehensive instrument suite. This challenges a conventional view believed for over ~50 years in which the auroral electron is mostly accelerated at altitudes of a few thousand kilometers, and throws up a new mystery of the auroral particle acceleration.

Paper information

Journal：*Scientific Reports*, Vol.11, 1610, 2021

Authors：Imajo, S., Y. Miyoshi, Y. Kazama, K. Asamura, I. Shinohara, K. Shiokawa et. al.

Title：Active auroral arc powered by accelerated electrons from very high altitudes

DOI：10.1038/s41598-020-79665-5

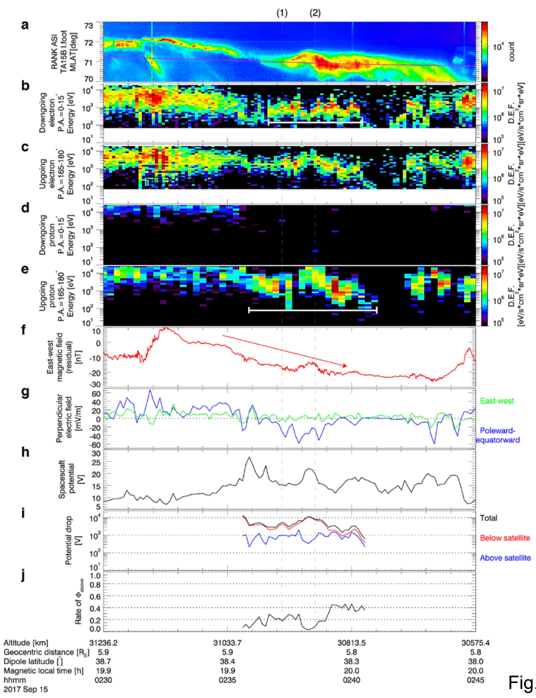


Fig.2

Fig.1: Schematic of the very high altitude electron acceleration powering an auroral arc. The accelerated electron from very high altitudes was observed by the Arase satellite and then precipitated into the auroral emission region.

Fig.2: Timeseries of the latitudinal distribution of auroral emissions and Arase observations. Characteristics of particles and electric and magnetic fields agree with the typical characteristics of the acceleration region observed by previous low altitude satellites.

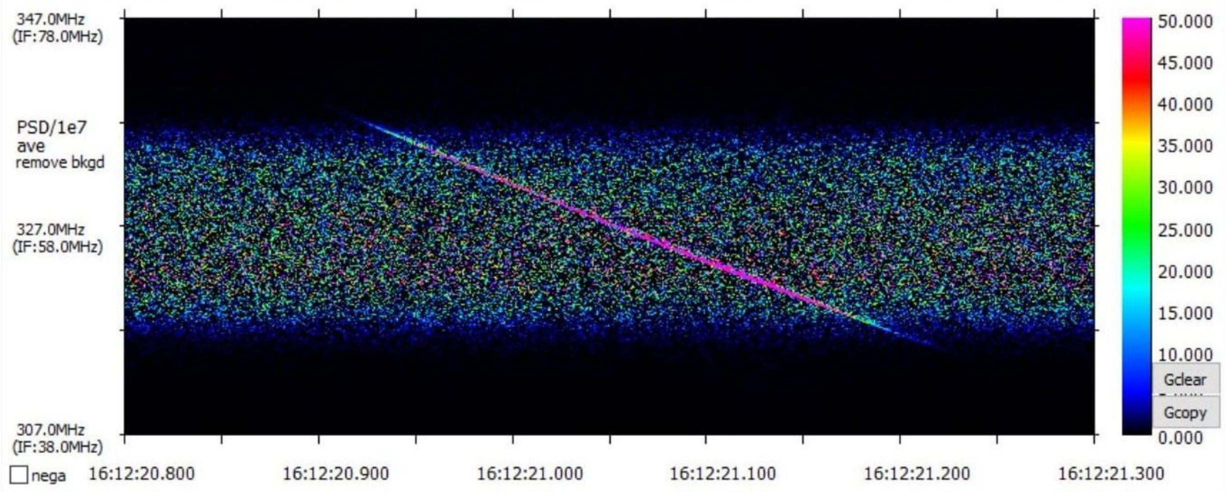


Fig.1

Determination of near-Sun plasma density from Crab pulsar observations

Tokumaru et al. (2020) measured the frequency dispersion of giant radio pulses from observations of the Crab pulsar in 2018 and determined the distribution of the plasma density near the Sun. The obtained results provide an important clue for unraveling the solar wind acceleration mechanism.

A pulsar is a celestial object that emits radio wave pulses at regular intervals. When radio waves from the pulsar are received on Earth, a frequency-dependent delay (frequency dispersion) caused by the plasma along the line of sight is observed. The plasma density of the propagation medium can be estimated from the magnitude of the frequency dispersion (dispersion measure, DM). In this study, the DM was measured for the pulsar in the Crab Nebula (Crab pulsar). The line of sight for the Crab pulsar approaches the Sun every June, and the minimum offset distance is approximately five solar radii. Therefore, DM measurements for the Crab pulsar in June enable the determination of the plasma density distribution near the Sun. The radial distance range between a few and 10 solar radii is a key region for elucidating solar wind acceleration. However, this region has never been explored *in-situ*, and its plasma density distribution is not well understood. Crab pulsar sporadically radiates very strong radio pulses, which are called giant radio pulses, allowing us to measure the DM accurately in a short time. Crab pulsar observations have been conducted since 2018 using the large radiotelescope at the Toyokawa Observatory of the ISEE. Mr. Kaito Tawara, a student in the Graduate School of Science at Nagoya University, made a significant contribution to the data analysis of this study.

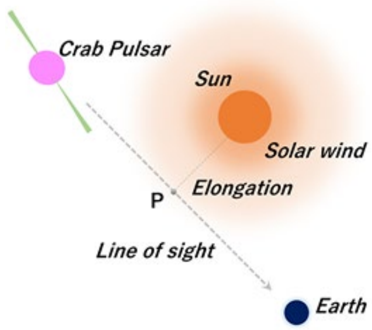


Fig.2

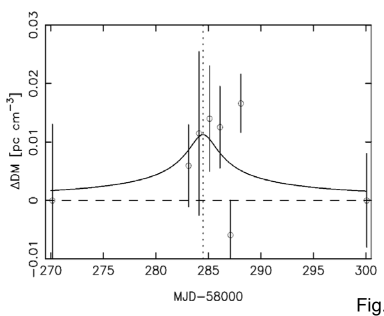


Fig.3

Paper information
Journal： *Solar Physics*, Vol. 295, 80, 2020
Authors： Tokumaru, M., K. Tawara, K. Takefuji, M. Sekido, and T. Terasawa
Title： Radio sounding measurements of the solar corona using giant pulses of the Crab pulsar in 2018
DOI： 10.1007/s11207-020-01644-w

Fig.1： Dynamic spectrum of GRP of Crab pulsar observed at Toyokawa (analyzed by Dr. T. Terasawa).
Fig.2： Schematic illustration of plasma density measurements near the Sun using a pulsar.
Fig.3： Increase in DM observed for the period around the closest approach of Crab pulsar line-of-sight to the Sun.

Contents