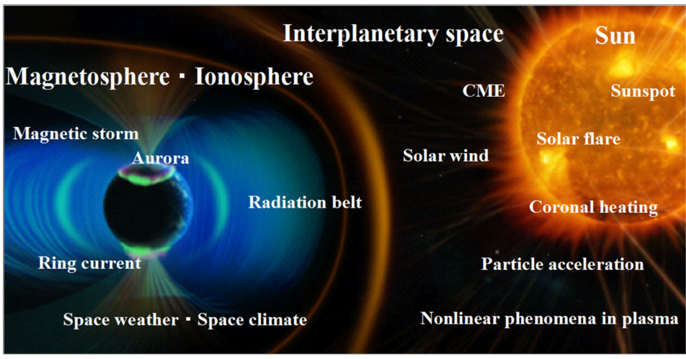
Division for Integrated Studies



- Solar flare · CME
- Inner-magnetosphere · Radiation belt
- Aurora substorm
- Space weather · Space storm
- Space climate · Long-term variations of the Sun
- Space plasma
- Computer simulation
- Data assimilation

In the Division for Integrated Studies, we conduct a study aiming at the comprehensive understanding and prediction of various phenomena in the solar-terrestrial system, using advanced computer simulation and data analysis. In particular, we promote studies leading to the elucidation of various phenomena, such as solar cycle, solar flares, coronal mass ejections (CMEs), geomagnetic storms, and aurora, where the nonlinear interaction and intercoupling reaction between different systems play an important role. We are leading a nationwide project for the understanding and prediction of solar-terrestrial environment variability and the various influences of these phenomena on social life based on the Grant-in-Aid for Scientific Research on Innovative Area from Ministry of Education, Culture, Sports, Science and Technology (MEXT). We are also promoting scientific projects of satellite missions (Hinode and ERG satellites) observing the Sun and geo-space in cooperation with the Institute of Space and Astronautical Science, JAXA, and National Astronomical Observatory of Japan. The faculty members of this division are responsible for the education in Graduate Schools of Science and Engineering at Nagoya University. The graduate students of both schools and the undergraduate students of the Engineering School cooperate in a multilateral way and advance the integrated study of the solar-terrestrial environment.

Main Activities in FY2019

Operational solar flare forecasting: International workshop on benchmarks, performance, and future challenges

Solar flares are sudden, explosive brightenings in the solar corona; they and their associated phenomena can have major impacts not only on the space environment, but also on social infrastructure such as satellites, astronauts, electric power, communication, and aviation. For this reason, predicting the occurrence of solar flares is a critical issue both scientifically and socially, and many space weather forecasting organizations across the world, including government agencies and research centers, work to predict solar flares every day. However, a quantitative comparison of operational flare prediction performance had not been previously conducted. Prof. Leka and Dr. Park of the Division for Integrated Studies organized the ISEE international workshop “Benchmarks for Operational Solar Flare Forecasts,” cooperating with 16 institutes from Japan, the USA, the UK, Korea, Australia, Ireland, Greece, and Belgium, to undertake this task for the first time. The comparison focused on the predictive ability of 18 different methods over the January 2016 to December 2017 timeframe. The analysis involved both overall quantitative evaluation metrics and an investigation into why the various methods performed differently. The results found no particularly excellent predictive system but did give some indication of how the systems might be improved. Of note, Leka and Park developed a new method of evaluating multi-day forecasts, a crucial measure of performance when the solar flaring rate fluctuates. Unfortunately, it was found that none of the operational systems could reliably predict the first large flare from a solar active region. The developed methodologies and results clarify our present prediction capabilities and will play an essential role in the advancement of space weather forecasting in the future.（Leka et al., *ApJ Suppl*, 2019, Leka et al., *ApJ*, 2019, and Park et al., *ApJ*, 2020)

Effect of the morphological asymmetry of sunspot on solar cycle prediction

Leading sunspots are more coherent than following spots. This well-known feature of sunspots was first described in the 1950s. However, the impact of this asymmetry on the evolution of the solar surface magnetic field have not been discussed. We, for the first time, investigated the importance of the morphological asymmetry between leading and following sunspots to solar cycle prediction. Using the surface flux transport model to mimic the evolution of the magnetic field on the solar surface, we found that this morphological asymmetry strongly reduces the polar magnetic field, resulting in the reduction of the next cycle amplitude. SFT simulations based on the observed sunspot record show that the introduction of morphological asymmetry reduces the difference from the observed polar magnetic field by 30%–40%. These results indicate the strong impact of morphological asymmetry on solar cycle prediction. (Iijima, Hotta, and Imada, *ApJ*, 2019)

Ion–neutral collision frequencies for calculating ionospheric conductivity

Molecular oxygen collides with its first positive ion in the Earth's ionosphere. The collision frequency of this particle pair is used to calculate the electric conductivity of the ionosphere. However, for this parental pair there are two collision types, resonant and nonresonant, and the selection of the collision type has differed among previous studies on the calculation of conductivity. In the present study, we clarify that nonresonant collision is physically essential for this pair because the relevant temperatures are low. The ionospheric conductivity peak occurs at altitudes between 100 and 130 km, where the temperatures of the ions and neutral particles are usually lower than 600 K, and at these temperatures nonresonant collisions are dominant. The collision frequency would be underestimated by 30% if resonant collision was assumed at an altitude of 110 km (where the temperature is 240 K). The impact of this difference on the conductivity is estimated to be small (3%), primarily because molecular nitrogen is much more abundant than molecular oxygen. Although we have confirmed that nonresonant collision is essential, we also include resonant-type collision, primarily to allow for possible elevated temperature events. A set of ion–neutral collision frequency coefficients for calculating the conductivity, including other particle pairs, are summarized in the Appendices. Small corrections to the traditional coefficients are mad. (Ieda, *JGR Space Physics*, 2020)

Vlasov-code simulation of contact discontinuities

The stability of contact discontinuities formed by the relaxation of two Maxwellian plasmas with different number densities but the same plasma thermal pressure was studied by means of a one-dimensional electrostatic full-Vlasov simulation. Our simulation runs, with various combinations of ion-to-electron ratio in the high-density and low-density regions, showed that transition layers of density and temperature without a jump in plasma thermal pressure, are obtained when the electron temperatures in the high-density and low-density regions are almost equal to each other. However, a stable structure of the contact discontinuity with a sharp transition layer on the Debye scale is not maintained. It is suggested that non-Maxwellian velocity distributions are necessary for a stable structure of contact discontinuity. (Umeda et al., *Phys. Plasma*, 2019)

Propagation and mode conversion of plasmaspheric equatorial noise

We investigated the propagation process of equatorial noise (X-mode whistler waves from Arase and the Van Allen Probes). We discovered a mode conversion from equatorial noise to electromagnetic ion cyclotron (EMIC) waves, associated with ion composition variations, which contributes to the origin of plasmaspheric EMIC waves. Moreover, we found that equatorial noise contributes to the significant heating of a few keV ions inside the plasmasphere. (Miyoshi et al., *GRL*, 2019)

Ion outflow and transportation of oxygen ions, from Arase and MMS observations

Whether the oxygen in the plasma sheet and the inner magnetosphere originates from the dayside cusp and/or nightside aurora region is not well understood. Using simultaneous observations of Arase and MMS, together with particle trajectory tracing, we found that the oxygen ions in the lobe regions come from the cusp, while the oxygen burst comes from the night side aurora region. (Kistler, Miyoshi, Hori et al., *JGR Space Physics*, 2019)

Meridional distribution of plasma parameters and currents in the inner magnetosphere

We examined the average meridional distribution of plasma parameters and pressure-driven currents in the inner magnetosphere using data from the Arase satellite. We found that plasma pressure decreases significantly with increasing magnetic latitude (MLAT). The pressure anisotropy, derived as the perpendicular pressure divided by the parallel pressure minus 1, decreased with radial distance and showed a weak dependence on MLAT. The theoretical value of the plasma pressure, estimated from the magnetic strength and anisotropy, was roughly consistent with the observed plasma pressure. The azimuthal pressure-gradient current derived from the plasma pressure was distributed over MLAT 0–20°, while the curvature current was limited within MLAT 0–10°. We suggest that latitudinal dependence should be considered in the interpretation of plasma parameters in successive orbits during magnetic storms. (Imajo et al., *JGR Space Physics*, 2019)

Nonlinear wave–particle interaction analysis between EMIC waves and ions: Arase observations

EMIC emissions with various frequency changes are observed by the Arase spacecraft. The EMIC rising tone wave has been previously studied by applying a wave–particle interaction analysis (WPIA) method to the spacecraft data. By the same method, we obtain the phase angle between the particle and the wave field, to analyze the nonlinear resonant currents controlling the energy transfer and wave frequency drift. We use the WPIA method with Arase electromagnetic field and ion particle data to analyze the nonlinear mechanisms of the EMIC emissions with different frequency evolutions. The WPIA of an EMIC falling tone emission, observed on November 15, 2017, indicated that nonlinear resonant currents controlled the frequency decrease and significant wave growth. The existence of the proton hill predicted by the nonlinear growth theory is shown in the phase angle distribution of the proton flux. The motion of the proton hill in phase space, which forms the nonlinear resonant currents, is also discussed. Concurrent generation of rising and falling tone emissions at different frequencies with the same proton energy is also suggested by the WPIA results.

Azimuthally propagating ionospheric flow fluctuations

Ionospheric flow fluctuations observed by the Super Dual Auroral Radar Network (SuperDARN) radars during magnetic storms were examined using plasma and field observations made by satellites in the Earth's inner magnetosphere. The radar observations showed that the flow fluctuations had a frequency of ~1 mHz and propagated westward with a speed of several hundreds of m/s. Simultaneous satellite observations at conjugate points in the magnetosphere revealed an association between flow fluctuations and ring current pressure enhancement. These results indicate that westward-propagating ionospheric flow fluctuations could be directly driven by westward-drifting ring current ions.

Statistical investigation of chorus wave propagation in the inner magnetosphere

Chorus emissions are electromagnetic waves in nature that are spontaneously generated in the magnetosphere. These waves have attracted attention as they play crucial roles in the acceleration and loss of high-energy electrons in the inner magnetosphere. Chorus waves are generated near the magnetic equator, and propagate toward higher latitudes. Based on ray tracing studies, it is predicted that the wave-vector of chorus waves deviates from the local magnetic field as the wave propagates toward higher latitudes. However, based on the statistical investigation of chorus observations by the Arase satellite, we found that the majority of chorus wave vectors are aligned to the local magnetic field, even when the waves are observed at higher latitudes. These results indicate that canonical ray tracing studies require correction to explain the wave-vector direction observed by the Arase satellite.

Investigation of ion transportation: Arase observations

We investigated the "trunk structures" that show specific ion distribution characteristics in the energy–time diagram. Using two-year data from the Arase/LEPi instrument, we found that: 1) most of the trunk structures were seen pre-midnight; 2) the MLT distribution depends on the ion energy; and 3) trunk structures can frequently be found for He^+, while their occurrence for H^+ is very rare, suggesting that charge exchange controls trunk occurrence. We conducted a particle tracing computer simulation, and found that not only large-scale potential electric fields, but local electric fields like subauroral polarization streams, are essential to form trunk structures. This result suggests that the deformation of the electric fields associated with substorms plays an essential role in the transport of plasma sheet ions into the inner magnetosphere.

Spatial distributions of EMIC waves, depending on geomagnetic conditions

EMIC waves are known to be excited in the magnetic equator of the magnetosphere by ion cyclotron instability owing to energetic ion temperature anisotropy. To determine the influence of geomagnetic conditions on the generation of EMIC waves, Arase and the Van Allen Probes observed EMIC waves in the inner magnetosphere, under various geomagnetic conditions, in 2017–2018. We found that the occurrence of EMIC waves shows clear dependence on geomagnetic conditions. During quiet geomagnetic conditions, H^+ EMIC waves have peak occurrences in the morning sector at higher L shells, without any energetic particle input, while He^+ EMIC waves are frequently observed on the dayside of the magnetosphere where the cold plasmaspheric ions and hot ring current plasma are mixed. In contrast, during disturbed conditions, EMIC waves were mainly detected in the noon to afternoon sector, owing to the increasing temperature anisotropy caused by injected energetic ions and ring current development. The present study provides observational evidence that the major driver of EMIC waves is dependent on geomagnetic conditions and generation region.

Modulation of Pc1 wave ducting by equatorial plasma bubbles

Based on the Swarm satellite observations, Kim and his colleagues presented the first observational evidence that ducting Pc1 waves are modulated by equatorial plasma bubbles. They also showed excellent correspondence between wave intensity and electron density. (Kim, Shiokawa et al., *GRL*, 2020)

Establishment of a scheme for predicting extreme ultraviolet radiation associated with solar flares

Extreme ultraviolet radiation from solar flares can cause serious harm, such as loss of communication or satellite drag. Therefore, there is an urgent need to establish a method for predicting extreme ultraviolet emissions from solar flares. We performed a prediction of the flare soft X-ray light curve using a convolutional neural network 2 h before the occurrence of the flare, and calculated the extreme ultraviolet radiation using the soft X-ray light curve and numerical simulations. We attempted to reproduce the extreme ultraviolet spectrum of past flares using this method, and were able to reproduce the observations of the EVE onboard the SDO. (Kawai, Imada et al., submitted to *J. Atmos. Sol.-Terr. Phys*.)

Simulation study on precursory phenomenon of solar prominence eruption

The interior of a solar prominence contains turbulent flows. Recent observations revealed that the standard deviation of the internal velocity field increases before eruption, suggesting a relationship between turbulence and magnetohydrodynamic (MHD) instability. In this study, we carried out MHD simulations, including radiative cooling, thermal conduction, and gravity. We confirmed that the increasing standard deviation of the internal velocity field is caused by Kelvin-Helmholtz instability (KHI). We also found that KHI gradually changes the coronal magnetic field sustaining the prominence and facilitates the onset of MHD instability.

Relationship between microwave intensity and hard X-ray intensity in solar flares

Microwave intensity and hard X-ray intensity were compared for all solar flares (40 events) above GOES M7-class that were simultaneously observed with the Nobeyama Radioheliograph/Nobeyama Radio Polarimeters and the RHESSI satellite. Although the emission mechanism and energy range of the accelerating electrons are different, they showed a very strong correlation, with a correlation coefficient of about 0.9. Considering that microwave emission depends strongly on magnetic field strength, this result may indicate that there is no difference in magnetic field strength in the region where the accelerated electrons exist. This work was undertaken by the ISEE International Joint Research Program. (Krucker, Masuda, and White, *ApJ,* 2020)