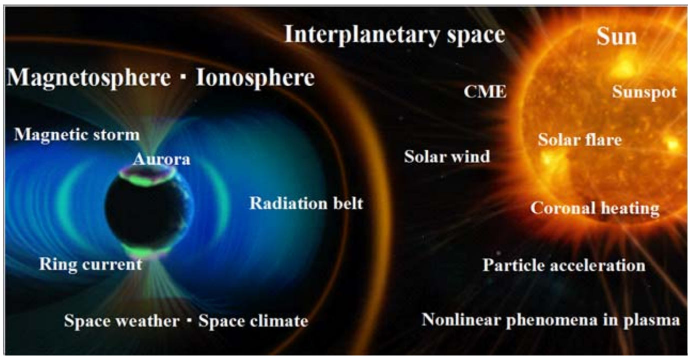
Division for Integrated Studies



- 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 FY2018

Surface velocity estimation for solar cycle prediction

Predicting the next solar cycle is crucial for space weather studies. So far, we have developed the surface flux transport (SFT) code for predicting the solar cycle activity and improved the accuracy of parameters necessary for SFT calculation. In this fiscal year, we especially concentrate on obtaining the velocity field, which is a necessary parameter for this model calculation, through satellite observation. As a result, we found that the flow in the meridional plane in a strong-magnetic-field region is slower than that in a weak-magnetic-field region. This result has already been reported in Imada & Fujiyama, The Astrophysical Journal Letters, 864, L5, 2018.

Magnetic field characteristics related to the onset condition of solar flares

Coronal magnetic fields are responsible for the onset of solar flares and eruptions. However, the type of magnetic field parameters that can be used to measure the critical condition for a solar eruption is still unclear. As an effort to understand the possible condition for a solar flare, we examined the nondimensional parameter κ introduced by Ishiguro and Kusano (2017), which contains information about magnetic twist distribution and magnetic flux in an active region (AR). We introduced a new parameter κ^*, as a proxy for κ, and analyzed its evolution during the flaring period of AR NOAA 11158 using the nonlinear force-free field extrapolated from the photospheric vector magnetic field data. As a result, we found that κ^* increased to a certain level before two large flares and decreased significantly after their onset. The results suggest that κ^* can be used as an indicator of the necessary condition for the onset of a solar eruption in AR.

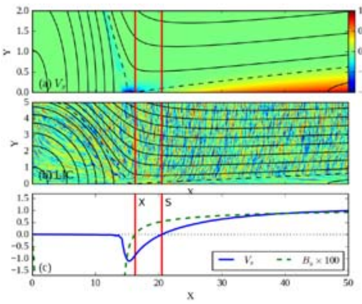
Based on this result, we propose a new method to assess the possibility of a large solar eruption from AR by combining the parameter κ* and information about the magnetic energy of AR. The result of this study was published in The Astrophysical Journal by Muhamad, et al. (2018).

MHD simulation of the largest solar flare observed in solar cycle 24

We performed a magnetohydrodynamic (MHD) simulation for the X9.3 flare, which is the largest solar flare in solar cycle 24. First, we found that the multiple magnetic flux ropes (MFRs), which are a bundle of twisted field lines, exit along the polarity inversion line at an early time. Once a part of the MFRs loses stability or equilibrium, a large and coherent MFR can be formed through a reconnection among the pre-erupting MFRs. The current sheet and post-flare loops are formed under the erupting MFR. As the simulation showed the rotation of the erupting MFR, we suggest that this rotation is related to the formation of a southward magnetic field, which exerted much influence on the geospace (Inoue et al., 2018, *The Astrophysical Journal*, 867, 83)

Mechanism of non-steady Petschek-type reconnection with uniform resistivity

Recent findings on magnetic reconnection in high-Lundquist-number plasmas have indicated that a Sweet-Parker-type plasmoid chain reconnection can play a role in affecting fast reconnection. By contrast, it has proven difficult to achieve Petschek model reconnection in plasmas with uniform resistivity because sustaining it requires localization of the diffusion region. However, Shibayama et al. (2015) noted that Petschek-type reconnection can be achieved spontaneously in a dynamical manner even under uniform resistivity through the so-called “dynamical Petschek reconnection.” In this new type of reconnection, Petschek-type diffusion regions can be formed in connection with plasmoids. In this study, we performed a two-dimensional resistive MHD simulation under uniform resistivity, which was undertaken to determine the diffusion region localization mechanism under dynamical Petschek reconnection. Through the simulation, we found that the separation of the X-point from the flow stagnation point (S-point) plays a crucial role in the localization of the diffusion region because the motion of the X-point is restricted by the strong flow emanating from the S-point. This mechanism suggests that dynamical Petschek reconnection is possible even in large systems such as the solar corona. The result of this study is published in Physics of Plasmas by Shibayama et al. (2019).



(a) Outflow structure (vx), (b) line integral convolution plot of the flow, and (c) outflow and reconnected magnetic field profile along the current sheet. The vertical solid lines correspond to the location of the X- and S- points on the x-axis.

New electromagnetic linear dispersion solver for plasma with a drift across magnetic field

A current across the magnetic field is formed in various situations in plasma. The relative drift between ions and electrons due to the cross-field current becomes a source of various microscopic instabilities. A new fully electromagnetic and kinetic linear dispersion solver for plasma with a drift across the magnetic field is developed by assuming a uniform background plasma (Umeda and Nakamura, 2018, *Physics of Plasmas*, 25 (10), 102109).

Auroral substorm onset in satellite-based global images and ground-based all-sky images

The field of view (FOV) of ground-based all-sky images is limited. Thus, it is generally difficult to distinguish whether an observed substorm was initiated inside or outside FOV. Accordingly, satellite-based global images with a wider FOV have been supposed to be the most reliable dataset to identify substorm onsets. Although the sensitivity of satellite images is low, this caveat has not been supposed to have significant impacts because the identified onsets have been consistent with Pi2 geomagnetic pulsations. In the present study, we directly compared substorm onset signatures in global images and all-sky images for the first time. Accordingly, the onsets in global images and Pi2s were delayed relative to the onset in all-sky images, and in fact, agreed with poleward expansion.

Instantaneous frequency analysis of nonlinear EMIC emissions in the inner magnetosphere: Arase observation

In the inner magnetosphere, the Arase spacecraft has observed electromagnetic ion cyclotron (EMIC) emissions with both rising and falling frequencies. The instantaneous frequency analyses on the electromagnetic fields of the EMIC rising tone emission have been performed by the Hilbert-Huang transform. The time variation of the instantaneous frequency shows a good agreement with the nonlinear theory for the frequency evolutions. Rapid instantaneous frequency modulation is also found during the rising tone emission. We estimated the peak-to-peak time of fluctuation in the frequency, and found that it is caused around half of the particle-trapping time. From the motion of the phase-bunched particle around the resonant velocity, it is expected that the nonlinear resonant current that induces the falling frequency is formed in half the trapping time (Shoji et al., 2018, *GRL*).

Inter-channel comparison of the HEP instrument onboard the ERG satellite

A comprehensive inter-channel comparison of the detection efficiency of the high-energy electron experiment (HEP) instrument aboard the ERG satellite was made with in-orbit observation data obtained by the instrument. Evaluation of relative count ratios between directional channels of HEP revealed that the outermost channels of each detector show a nonlinear, varying response as compared to the other channels. Further correlation analyses indicated that the nonlinearity of count variation stemmed from a combined effect of the oblique incidence of electrons on the detectors and electron scattering by an aluminum plate mounted above the detectors.

Mode conversion to generate plasmaspheric EMIC waves

We identified generation of plasmaspheric EMIC waves via the mode conversion from Equatorial Noise that is X-mode whistler waves at the low altitudes. The existence of M/Q=2 ions are essential for this mode conversion, which changes the dispersion relation of the plasma waves. From estimation of cut-off and cross-over frequencies of X-mode whistlers and EMIC waves, we found that the maximum composition ratio of M/Q=2 ions are ~10% in the low altitudes.

Rapid loss of relativistic electrons by EMIC waves observed by ERG, Van Allen Probes, and ground stations

There has been increasing evidence for pitch angle scattering of relativistic electrons by EMIC waves. Theoretical studies have predicted that the loss time scale of MeV electrons by EMIC waves can be very fast, suggesting that MeV electron fluxes rapidly decrease in association with EMIC wave activity. We have found a unique event of rapid loss of MeV electrons in association with EMIC wave activity. During the event, the ERG satellite observed a signature of MeV electron loss by EMIC waves, and the satellite and ground-based observations constrained the spatial-temporal variations of the EMIC wave activity during the loss event. The multi-satellite observation of MeV electron fluxes showed that these fluxes substantially decreased within a few tens of minutes where the EMIC waves were present. The present study provides an observational estimate of the loss time scale of MeV electrons by EMIC waves.

Simulation study on internal velocity variation in eruptive prominence

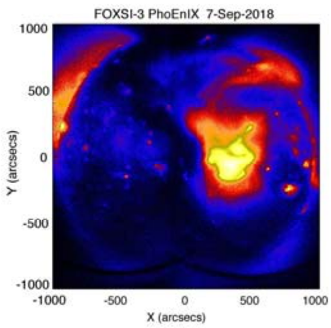
Recent observations by SMART/SDDI of Hida Observatory found an increase in velocity dispersion inside prominence prior to eruption (Seki et al., 2017). The precursory phenomenon can be helpful for developing a prediction scheme for prominence eruptions. To understand the physical mechanism of the phenomenon, we performed three-dimensional MHD simulations, including radiative cooling and thermal conduction. We modeled an eruptive prominence with a dynamic interior by combining the prominence formation model (Kaneko and Yokoyama, 2018) and the flare trigger model (Kusano et al., 2012). Our simulation quantitatively reproduced the observed increase in velocity dispersion. We found that the growth of upflows driven by magnetic forces sustaining prominence leads to an increase in velocity dispersion. We propose that plasma flows inside prominence locally enhance the current density, facilitating MHD instability (Kaneko and Yokoyama, 2018, *The Astrophysical Journal*, 869, 136).

Numerical studies on solar sunspot cycle

We studied the solar sunspot cycle using numerical simulations. In recent years, the SFT model has been used for predicting the solar sunspot cycle. A large assumption in the SFT model is that the large-scale magnetic field is nearly vertical (or radial) on the solar surface. We carried out direct MHD simulations to test the validity of this assumption by estimating the transport parameters through the thermal convection in the Sun. The numerical results showed the supporting evidence of the SFT model. We also studied the effect of asymmetry in the spatial size of the sunspot pair on polar field formation. Although the existence of this asymmetry has been a well-known feature of sunspot, very few studies have focused on its role in polar field formation or the sunspot activity cycle. We found that the asymmetry in the size of sunspots efficiently prevents polar field formation.

First soft X-ray imaging spectroscopy of the Sun with FOXSI-3 sounding rocket

On September 8, 2018, in JST (September 7 in local time), the third flight of the Focusing Optics Solar X-ray Imager (FOXSI-3) sounding rocket experiment was successfully performed from White Sands, New Mexico, USA. FOXSI is an international experiment for high-sensitivity X-ray observation of the Sun using X-ray focusing optics, and the Japanese team provides focal plane detectors. FOXSI-3 successfully observed the Sun for 6 min, as planned, during the ~15 min flight. One of the FOXSI-3 detectors is a high-speed X-ray CMOS camera developed by Ishikawa at ISEE, and the first ever soft X-ray imaging spectroscopy of the Sun in the 0.5–5 keV energy range was successfully performed with the new detector. The obtained data are qualitatively new as compared to those obtained by past instruments, and enable us to investigate the physical properties of coronal plasma.



Soft X-ray image of the Sun obtained with FOXSI-3. We can create an X-ray spectrum at any point in the image.

International collaborative research between Nobeyama Radioheliograph and Chinese new solar radio telescope

We began international collaborative research in the earnest between Nobeyama Radioheliograph and the Chinese new solar radio telescope (MUSER). Researchers from Japan and China visited each other's partner country and learned the details of the instrument and data analysis method. At first, we began analyzing data of a solar flare that were simultaneously observed with these two telescopes. We are also discussing a plan to prepare MUSER’s data analysis environment in ISEE.