Microinstabilities in a supercritical perpendicular shock revisited

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It is considered that reflected ions play decisive roles in the dissipation processes at a supercritical collisionless shock. Local non-equilibrium plasma distribution function in the foot of a perpendicular shock leads to a variety of microscale instabilities. Two of the major instabilities which have been extensively studied for the parameters of typical heliospheric shocks are the electron cyclotron-drift instability and the modified two-stream instability. They have been often discussed separately, because of the large difference in dominant wave frequency between them. Although only a few of the past studies tried to examine the nonlinear evolutions and competing processes of them, the physical parameters used in the past numerical simulations were not realisitic. The relative importance of the instabilities may be a function of ion-to-electron mass ratio as well as the ratio of electron plasma to cyclotron frequiencies, while these two ratios are hard to be simultaneously realistic in a full particle-in-cell simulation due to the limited computational resources.

In this study microinstabilities in the foot of a supercritical perpendicular shock is revisited. We perform a number of local simulations representing a part of the foot region with systematically changing the two ratios, mass ratio and frequency ratio, by using two-dimensional full particle-in-cell code. The foot plasma is assumed to be consist of incoming ions, electrons, and reflected ions. The system size is smaller than ion gyro radius in X, which is parallel to the shock normal, and a few times ion inertial length in Y, which is along a shock surface and the ambient magnetic field. The boundary conditions are periodic in both directions. We will report the results of the simulations in which the mass ratio and the frequency ratio are systematically varied with fixing the local Alfven Mach number, plasma beta, and relative density of the reflected ions.

Keywords: collisionless shock, microinstability, numerical simulation

Second order Fermi acceleration of ions in the earth's foreshock: wave dispersion effects

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It is well known that the second order Fermi acceleration can efficiently operate when there exist multiple electromagnetic waves traveling in two opposing directions. The process has been discussed using turbulence composed of non-dispersive Alfven waves (e.g., Terasawa, 1989; Kuramitsu and Hada, 2000), and has been applied to ion acceleration in the earth's foreshock. However, upstream waves in the earth's foreshock have a wide frequency spectrum extending beyond the ion cyclotron frequency, where the effects of finite wave dispersion cannot be neglected.
In this presentation, we discuss the second order Fermi process by performing test particle simulations, paying particular attention to the effects of finite wave dispersion on the ion acceleration efficiency. We consider the right- and left-hand polarized electromagnetic waves, with both parallel and anti-parallel propagation directions along the background magnetic field. A power-law spectrum of each wave component is assumed. The waves obey the cold plasma dispersion relation. We evaluate the acceleration efficiency as a function of the initial ion kinetic energy. We will discuss implications of our results to Cluster observations (Kis et al., 2004).

Keywords: second order fermi acceleration, particle acceleration and energy diffusion, wave dispersion

Density estimation utilizing the group-standing frequency of upstream whistlers in the solar wind

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Upstream whistlers, so-called 1 Hz waves, have been observed in upstream regions of most solar system bodies including Mercury, Venus, Earth, the Moon, Mars, Saturn, and Uranus [e.g., Orlowski and Russell, 1995; Russell, 2007]. Their frequencies in the spacecraft frame concentrate around 1 Hz at 1 AU and slightly decrease with distance from the Sun. They exhibit similar spectral properties even in different situations, suggesting that common generation and propagation processes are responsible for the waves throughout the solar system.
Based on statistical and comparative studies, we proposed that the waves are essentially group-standing, i.e., their group velocities become rather small in the body's rest frame [Tsugawa et al., JGR 2014]. In the group-standing condition, the waves can behave as if they are at a resonance frequency because the group refractive index approaches infinity in the spacecraft / solar system body rest frame. This suggests that the group-standing frequency can be utilized as an indicator of plasma parameters, in analogous to the upper-hybrid resonance frequency, which is used to determine the plasma density in the magnetosphere. We propose a method to estimate the plasma density utilizing the group-standing frequency and evaluate the feasibility of the proposed method by using Geotail in-situ observations. The method possibly estimates the absolute value of number density with an accuracy of <~0.1, although there remains some considerable difficulties. We discuss pros and cons of the proposed method.

Comparison between Polarization and Spectral Characteristics of Zebra Pattern in Solar Radio Bursts

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Zebra pattern (ZP) is one of the spectral fine structures superimposed on the broadband type IV continuum, which has a characteristic spectral pattern with a number of parallel drifting stripes. Since these spectral fine structures reflect their emission mechanisms, we can obtain information from their characteristics about physical processes such as particle acceleration, excitation of electrostatic waves and their conversion to electromagnetic waves. Polarization of emission is important to know its emission mechanism. However, the relationship between spectral characteristics of ZP and its polarization has not been understood. In this study, we aim to reveal the generation mechanism of ZP by investigating their polarization characteristics.
In Kaneda et al. (2015, ApJL), we analyzed polarization characteristics of a ZP event and suggested from its frequency dependence that the ZP was originally generated polarized in the O-mode and was partly converted into the X-mode near the emission source. In order to examine these results, we analyzed totally 17 ZP events observed with AMATERAS, a solar radio telescope developed by Tohoku University in the frequency range of 100-500 MHz (Iwai et al., 2012). The analysis was made focused on three aspects: degree of circular polarization, temporal delay between the two polarization components and frequency separation between adjacent stripes. We derived these three parameters using highly resolved spectral data from AMATERAS. As a result, we found the following characteristics; degree of polarization in the range of 10-80%, temporal delay of 0-70 ms and frequency separation of 1-5 MHz, and that these characteristics of ZP were rather different from event to event. The difference in these parameters implies the difference in physical mechanisms at a certain stage of the generation of ZP emission. Based on the obtained results, possible generation mechanisms of ZP will be discussed.

Keywords: Solar corona, Radio bursts, polarization, AMATERAS

Injection of solar wind electrons into the plasma void and associated magnetic fluctuations in the ELF range

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Generation mechanism of the magnetic fluctuations in the ELF range detected by MAP-LMAG magnetometer onboard Kaguya in the deepest wake behind the moon associated with the type-II entry protons is studied. Most of the waves were detected on the magnetic field lines which were not connected with the lunar surface, along which the solar wind electrons were injected into the wake. The waves had compressional components of field variation, suggesting that the direction of the wave number vector was oblique with respect to the background magnetic field. Interaction between the field-aligned hot electron beam and oblique whistler and electrostatic waves is considered.

Keywords: electron beam, magnetic field variation, lunar wake, type II entry protons, whistler mode wave, oblique propagation

10-sec magnetic field enhancement detected by Kaguya orbiting around the moon in the solar wind

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Short-period magnetic enhancements were detected by LMAG magnetometer onboard Kaguya spacecraft orbiting the moon in the solar wind. The magnitude of the magnetic field enhanced up to 1.5 to 3.6 times as large as that of the preceding quiet periods which lasted for more than 5 minutes. The duration of the enhancements was specifically 10 seconds, ranging from 8 to 46 sec. Some of them showed rotation of the magnetic field, but the others did not. The short-period magnetic enhancements were not detected above the major magnetic anomaly of the moon. They were not detected recursively on the same location on the moon. They were found both on the dayside and nightside of the moon, with a slight preference above the terminator. Similar magnetic field enhancement was searched for in the simultaneously observed solar wind magnetic field data obtained by GEOTAIL spacecraft, but no intensification of the magnitude was found although similar waveforms of each magnetic field components were found. At present, it is not certain whether they originate from the lunar crustal field, the solar wind, or the interaction between them.

Keywords: Kaguya/LMAG, solar wind, magnetic enhancement, 10sec

Spherical Harmonic Expansion of Solar Wind Speed

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The Institute for Space-Earth Environmental Research, Nagoya University has observed solar wind speed (SWS) by the interplanetary scintillation (IPS) method. Drs. Tokumaru and Fujiki have been constructing synoptic charts of SWS by the technique of Computerized Axial Tomography (CAT). SWS synoptic charts show the distribution of solar wind speed on the spherical surface sorrounding the sun named "source surface"; the ordinate shows solar latitude and the abscissa shows Carrington longitude in the chart. We can get one synoptic chart during every one solar rotation called Carrington rotation. The spatial resolution of this chart is one degree for both in longitude and in latitude. We frequently found wide region of data gap in the chart, especially in high latitudes. In this paper, in the first, (1) we try to expand the SWS on the synoptic chart into spherical harmonic series (N=0--90, M = 0--N) and to calculate about (90 x 90) coefficients (Anm and Bnm) of expansion series. And next, (2) we try to estimate continuously the SWS in both the direction of longitude and the one of latitude in the synoptic chart. It is found that this technique can estimate well the SWS, especially in low latitudes of chart.

Keywords: Solar Wind Speed, Source Surface, Spherical Harmonic Function

Comparison of calculated and observed IMF near magnetic cloud start times

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The solar source of magnetic clouds (MCs) is considered to be either coronal mass ejections (CMEs) or prominence eruptions [Bothmer et al., 1994, 1998]. We suppose that the coronal magnetic fields above CME or prominence eruption sites move outward and are then convected into interplanetary space to arrive at the Earth a short time before the MC start time. We extract the magnetic field close to the solar surface at different heights using the PFSS model [Hakamada, 1998] and propagate this field outward to 1 AU using 3D-reconstructed solar wind velocity [Jackson et al., 2010]. The purpose of our work is to examine whether the direction of interplanetary magnetic field (IMF) agrees with the observed vector field prior to a MC arrival at the Earth. We compare the sign of each component of modeled IMF (in RTN coordinates) with that of IMF observed by ACE three hours before the MC start time (pre MC time) and at the MC start time (MC time). These comparisons are made for six MC events during 2006 - 2007. We find that the sign of B_n, the normal component of IMF in RTN coordinates, extracted from 1.4 R_s (1.2 R_s) agrees best with ACE observations at the pre MC time (at the MC time) for all MC events analyzed here. However, the other two components B_r and B_t , the radial and tangential components of IMF in RTN coordinates, extracted from 1.4 R_s (1.2 R_s) do not agree as well with ACE observations at the pre MC time (at the MC time). We conclude that B_n observed by ACE at the pre MC time (at the MC time) is related to that at 1.4 R_s (1.2 R_s) at the location of the sub-Earth point on the Sun. This result shows that we can infer the sign of B_n at the MC time (pre MC time) from the value present at 1.2 R_s (1.4 R_s) at the location of the sub-Earth point, and thus this is an important finding for space weather forecasts. Future work will extend this result to additional MC events.

Keywords: coronal magnetic field, magnetic cloud, space weather, solar wind

A Statistical Study of the Radial and North-South Component Values of Heliospheric Magnetic Field

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Determination of interplanetary magnetic field (IMF) north-south component of magnetic field (B_z) is important from the space weather perspective because this field interacts with Earth's magnetic field causing geomagnetic storms. Lyatsky et al. (2003) and Youssef et al. (2011) show that there is a correlation between IMF B_z (south is positive) and the absolute value of the radial field B_x ($|B_x|$) during solar minima. They find a positive correlation when the dominant solar field has a positive polarity and negative for a dominant negative field polarity. The negative and positive polarities correspond to whether the Sun's magnetic field in the northern hemisphere is directed toward or away from the Sun, respectively. We calculate the correlation between IMF B_z and $|B_x|$ using the OMNI dataset from 1965 - 2015, and Helios in-situ measurement data from 1975 - 1977. In a similar study, we find that the correlation between B_z and $|B_x|$ shows a sinusoidal variation associated with ~11 year solar cycle, and also that an even more significant correlation between B_z and $|B_x|$ exists for solar distances between 0.3 and 0.4 AU in the Helios measurements. In an ongoing study, we extrapolate the Potential Field Source Surface (PFSS) model [Hakamada, 1998] to the Earth's location by using the UCSD 3D tomography model [Jackson et al. 2010] and compare the radial component (B_r) of modeled magnetic field with the normal (north-south) component (B_n) observed by ACE spacecraft. This study finds a significant positive correlation between B_r and B_n (north is positive). Thus, this study strongly suggests that the IMF B_z is generated, not in interplanetary space, but at the corona. In the future, we will study why this correlation between B_z and $|B_x|$ exists.

Keywords: solar wind, interplanetary magnetic field, space weather, heliosphere

Analysis of solar wind turbulence using interplanetary scintillation measurements

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The power spectrum of interplanetary scintillation (IPS) provides with crucial information on physical properties of the solar wind turbulence with a spatial scale of ~100-~10 km; so-called micro-turbulence. In this study, the spectral index and anisotropy of the solar wind turbulence are determined by fitting a theoretical model to IPS spectra observed for two strong sources 3C273 and 3C48 with the Solar Wind Imaging Facility Telescope (SWIFT) of the Institute for Space-Earth Environmental Research (ISEE), Nagoya University. In this fitting analysis, free parameters are the power-law index of the turbulence spectrum, the axial ratio of the anisotropy, and the turbulence level. The solar wind speed derived ISEE multi-station IPS observations is used as a fixed parameter to calculate the IPS spectrum model. The apparent size of IPS sources is another fixed parameter, and 60 mas and 100 mas are used for 3C273 and 3C48, respectively. The spectral indices obtained here (4.1+/-0.7) are close to but slightly higher than the Kolmogorov value (11/3), and the axial ratios (1.0+/-0.4) are nearly equal to a unity, suggesting that the turbulence is isotropic. The important point to note here is that there is a significant negative correlation between spectral indices and axial ratios; i.e. the turbulence spectrum becomes flatter, as it becomes more anisotropic. The spectral indices and axial ratios are also compared with solar wind speeds, and poor (positive) correlations are found between them. These results are unchanged when the solar wind speed is assumed to be a free parameter in the fitting analysis.

Keywords: solar wind, interplanetary scintillation, turbulence

Turbulent transport model in a three-dimensional structured solar wind

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Turbulence plays an essential role in the heating of coronal and solar wind plasma and the acceleration of the solar wind, as well as acceleration of energetic particles associated with interplanetary shocks. Turbulence can be produced by energetic particles and shocks and the radial and lateral inhomogeneity of the global interplanetary magnetic field and solar wind plasma distribution. Because of the close coupling of turbulence, plasma heating, the global solar wind structure, and energetic particles, a comprehensive model describing not only turbulence but also the large-scale inhomogeneity of the solar wind and the interplanetary magnetic field is necessary to understand the physics of these phenomena.

Recently we have developed a solar wind MHD model for the inner heliosphere based on synoptic observations of the photospheric magnetic field (Shiota et al. 2014). The numerical results show reasonable agreement with in situ measurements of the solar wind at the orbits of Earth, Venus, and Mars. This MHD model is now used as part of the real-time space weather forecast system SUSANOO (http://st4a.stelab.nagoya-u.ac.jp/susanoo/).

We have extended our 3D MHD model to include the transport and dissipation of turbulence using the theoretical model developed by Zank et al. (2012). We solve a coupled model that describes the 3D inhomogeneous solar wind and the temporal and spatial evolution of three moments or variables that describe turbulent fluctuation intensities (the energy in forward and backward modes and the residual energy) and their corresponding correlation lengths. We find that the radial profiles for the three moments of the solar wind turbulence predicted by our model show good agreement with those of in situ measurements obtained from Ulysses and Helios observations. Based on the detailed analysis of the numerical results, we will discuss the connection between turbulence generation and global solar wind structure.

Keywords: solar wind , MHD, turbulence

A Test-Particle Simulation of ISM Oxygen over Heliosphere and Analysis for IBEX observations

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The result of a test particle simulation will be presented and discussed as a possible interpretation on Interstellar Boundary EXplorer (IBEX) observations of InterStellar Medium (ISM) Oxygen. Due to the physical characteristics of Oxygen atom, neutral Oxygen had interacted with Hydrogen-dominated Heliosphere before they were observed by IBEX, and such Oxygen may contain some information of Heliospheric structure within its flux distribution over the sky. In order to understand this observation, we must classify the particles based on their histories of interactions with Heliosphere. We provide a unique classification on the test particles which makes the simulation result provide an insight on the IBEX observations.

Keywords: Heliosphere, Heavy particle, Interstellar Boundary EXplorer (IBEX)

