Rarefaction of the Very-Slow (<350km/s) Solar Wind in Cycle 24

*Munetoshi Tokumaru[1], Tomoya Shimoyama[1], Ken'ichi Fujiki[1]

1. Institute for Space-Earth Environmental Research, Nagoya University

The fast (700-800 km/s) and slow (300-400 km/s) solar wind are known to be associated with rarefied and dense plasma, respectively. A similar inverse relation is found between the speed and the density micro-turbulence level, delta Ne, derived from interplanetary scintillation (IPS) measurements; that is, the fast (slow) wind is associated with low (high) delta Ne (Asai et al., 1998). This fact suggests a certain level of proportionality between the density and delta Ne. Our earlier study demonstrated that delta Ne sometimes deviates from this inverse relation at a speed lower than 350 km/s, showing a marked drop in delta Ne for the very-slow solar wind (VSSW). To explore this finding further, we analyze IPS measurements during the period between 1997 and 2015; i.e. from Cycles 23 minimum and Cycle 24 maximum. As the result, we find that VSSW increases in the maximum phase of the solar cycle, and it is mostly associated with high delta Ne in Cycle 23. However, VSSW is found to be more associated with low delta Ne in Cycle 24. This fact is consistent with an increased occurrence of low-density VSSW observed in situ in Cycle 24, and it is considered as a manifestation of peculiar activity of this cycle. Our IPS data show that the significant growth of low delta Ne VSSW occurs at mid latitudes on the source surface. We investigate magnetic field properties of the source region for VSSW using the potential field analysis, and find that low-delta Ne VSSW is associated with a smaller expansion factor, a weaker photospheric field strength, and a higher source latitude than the average of all VSSW. These results suggest that more open magnetic field areas producing VSSW are formed in the quiet Sun region, and that the mass flux supply from those regions into the corona decreases in Cycle 24 owing to the weakening of the Sun’s magnetic field.

Keywords: solar wind, interplanetary scintillation, solar cycle

Turbulent transport MHD model in a structured three-dimensional solar wind

*Daikou Shiota[1], Gary P. Zank[2], Laxman Adhikari[2], Peter Hunana[2], Daniele Telloni[3], Roberto Bruno[4]

1. Institute for Space-Earth Environmental Research, Nagoya University, 2. Center for Space Plasma and Aeronomic Research (CSPAR), Department of Space Science, University of Alabama in Huntsville, 3. INAF - Astrophysical Observatory of Torino, 4. INAF-IAPS Istituto di Astrofisica e Planetologia Spaziali

Turbulence in the solar wind can play essential roles in the heating of coronal and solar wind plasma and the acceleration of the solar wind and energetic particles. Turbulence sources are not well understood and thought to be partly enhanced by interaction with the large-scale inhomogeneity of the solar wind and the interplanetary magnetic field (IMF) and/or transported from the solar corona.
To investigate the interaction with background inhomogeneity and the turbulence sources, we have developed a new 3D MHD model that includes the transport and dissipation of turbulence using the theoretical model Zank et al. (2012). We solve for the temporal and spatial evolution of three moments or variables, the energy in the forward and backward fluctuating modes and the residual energy and their three corresponding correlation lengths. The transport model is coupled to our 3D model of the inhomogeneous solar wind. We present results of the coupled solar wind-turbulence model assuming a simple tilted dipole magnetic configuration that mimics solar minimum conditions, together with several comparative intermediate cases. By considering eight possible solar wind configurations, we show that the large-scale solar wind and IMF inhomogeneity and the strength of the turbulence sources significantly affect the distribution of turbulence in the heliosphere within 5 AU. We compare the predicted turbulence distribution results from a complete solar minimum model with in situ measurements made by the Helios and Ulysses spacecraft, finding that the synthetic profiles of the turbulence intensities show reasonable agreement with observations.
We will also discuss the capability of this model and a future direction of development of a more advanced model.

Keywords: solar wind, turbulence, MHD simulation

Electron Acceleration in the Heliosphere

*Mitsuo Oka[1]

1. University of California Berkeley

Electrons are accelerated to very high, non-thermal energies during explosive energy-release phenomena such as solar flares and terrestrial substorms. While it has been established that magnetic reconnection plays a key role in these phenomena, the precise mechanism of electron acceleration via reconnection remains unclear. Here we show, based on a compilation of recent observations, that the power-law index d is often ˜4 or larger in solar hard X-ray coronal sources and in the plasma sheet of Earth's magnetotail, where d is defined in the flux density (differential flux) distribution. This is in stark contrast to the case of electron acceleration at shocks (such as interplanetary shocks and the terrestrial bow shock) whose power-law index d is often smaller than ˜4. We suggest that reconnection-related phenomena (in solar corona and in Earth's magentotail) may not be as efficient as shocks in terms of accelerating electrons at least in the heliospheric, non-relativistic environment of plasmas.

Keywords: electron acceleration, shock, magnetic reconnection

Temporal Variation of Zebra Stripes in Type IV Solar Radio Bursts

*Kazutaka Kaneda[1], Hiroaki Misawa[1], Kazumasa Iwai[2], Satoshi Masuda[3], Fuminori Tsuchiya[1], Takahiro Obara[1], Yuto Katoh[4]

1. Planetary Plasma and Atmospheric Research Center, Graduated School of Science, Tohoku University, 2. National Institute of Information and Communications Technology, 3. Institute for Space-Earth Environmental Research, Nagoya University, 4. Graduate School of Science, Tohoku University

It is known that type IV solar radio bursts, which are emitted in association with flares, show various spectral fine structures. Zebra Patterns (ZPs) are one kind of such fine structures showing a number of nearly parallel drifting narrowband stripes, superimposed on the background broadband type IV bursts. Although many theoretical models for explaining the generation of the ZP are proposed, there is no widely accepted model which is consistent with all of observational characteristics. Tan et al. (2014) performed a statistical analysis on microwave ZPs and showed that microwave ZPs can be classified into three types according to the variation of frequency separation () with respect to its frequency. They also suggested that three types of ZPs are generated by three different mechanisms. As described above, the variation of is important information to discuss generation mechanisms of ZPs. However, its temporal variation has not been studied before. For the purpose of revealing the temporal variation of , we analyzed highly resolved spectral data obtained with AMATERAS, a solar radio telescope developed by Tohoku University. As a result, we found different types of the variation of (equidistant ZP, varying distant ZP, and growing distant ZP) as mentioned in Tan et al. (2014). However the variation of was not same throughout the ZP lifetime and it changed from one type to another during one continuous ZP. In this presentation, we will show the temporal variation of in detail and discuss possible reasons for the variation.

Keywords: Solar corona, Radio burst, AMATERAS

North-south asymmetry of sense of polarization of magnetic fluctuations at the wake boundary in the By-dominated solar wind magnetic field

*Tomoko Nakagawa[1], Hideo Tsunakawa[2], Yoshifumi Saito[3]

1. Information and Communication Engineering, Tohoku Institute of Technology, 2. Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 3. Institute of Space and Astronautical Science, JAXA

North-south asymmetries of sense of polarization of magnetic fluctuations were detected by Kaguya MAP/LMAG at the lunar wake boundary in the By-dominated solar wind magnetic field. The sense of rotation was consistent with the Kelvin-Helmholtz instability. The frequency was higher at the wake boundary and lower in the central wake. The waveform was steepened at the wake boundary, and was sinusoidal in the central wake. The magnetic field configuration is similar to that of the Earth’s magnetopause, while the thickness of the transition region at the lunar wake is as small as 40km due to the steep density gradient. The thin boundary would account for that the wake did not decay in the central wake far beyond the boundary.

Keywords: Solar wind, wake boundary, Kelvin-Helmholts instability, surface wave, polarization

Diffuse magnetic fluctuations in the frequency range 1-12Hz detected by Kaguya above the polar regions of the moon

Yoshiki Sugata[1], Sho Ito[1], *Tomoko Nakagawa[1], Hideo Tsunakawa[2]

1. Information and Communication Engineering, Tohoku Institute of Technology, 2. Department of Earth and Planetary Sciences, Tokyo Institute of Technology

Kaguya found a type of magnetic fluctuations in the frequency range between 1 and 16 Hz with gradual appearance and disappearance, at a 100km altitude above the polar regions of the moon in the solar wind. They were found in the 32Hz sampling magnetic field data obtained by MAP/LMAG onboard Kaguya. The data were Fourier Transformed every 32Hz. In the dynamic spectra, the magnetic fluctuations appear diffuse like a haze, due to the broad bandwidth and gradual appearance with no discrete boundary. The bandwidth was 4Hz -- 12Hz. Eight events were found during the period from January 1, 2008 to March 31, 2009. They were found mostly on the dayside and predominantly above the polar region, where the orbit of Kaguya crosses the terminator. Six of 8 events were found in the northern hemisphere. Half of the events showed gradual decrease of frequency according as the spacecraft approached the North Pole. The solar wind speed was not high during the evens, but the intensities of the magnetic fluctuations was higher when number flux of the solar wind was higher.

Keywords: Kaguya, ELF, Terminator, Solar wind, Moon, MAP/LMAG

Nonlinear evolution of solar wind Alfven waves: An empirical model of the ion kinetic effect

*Yasuhiro Nariyuki[1]

1. Faculty of Human Development, University of Toyama

It is well know that solar wind plasma is usually at the thermally non-equilibrium state. Kinetic effects due to collisionless damping also cause the deviation from the fluid description, in which the local equilibrium states are assumed. In this presentation, we discuss an empirical model of the thermodynamic property of the solar wind plasma with non-constant heat capacity of the semi-ideal gas. Analytical and numerical models (the derivative nonlinear Schrodinger equation and the triple-degenerated derivative nonlinear Schrodinger equation) including the ion kinetic effect are used to evaluate the empirical relationship between the plasma density and the magnetic pressure.

Keywords: solar wind, Alfven waves, Thermodynamic property of solar wind plasma

Generation of Intermittent Ion Acoustic Waves in Whistler Turbulence: Particle-In-Cell Simulation

*Shinji Saito[1], Yasuhiro Nariyuki[2], Takayuki Umeda[3]

1. Graduate School of Science, Nagoya University, 2. Faculty of Human Development, University of Toyama, 3. Institute for Space-Earth Environmental Research

Quasi-perpendicular collisionless shocks can be a cause of several microinstabilities which enhance ion acoustic waves, whistler waves, and etc. Cross-field currents associated with the shock transition region and reflected ions by the shock front are considered as energy sources of the wave enhancements. Recent observations found finite amplitude whistler waves propagating in directions highly oblique to the background magnetic field in the shock transition region. It is expected that nonlinear interactions of finite amplitude whistler waves develop into whistler turbulence and are dissipated through kinetic processes. Here we demonstrated by using a fully kinetic particle-in-cell simulation that nonlinear development of whistler turbulence enhances intermittent ion acoustic waves through ion/ion streaming instability. The instability is driven by interaction between two ion components in ion velocity space at local areas. Wavenumber of the ion acoustic waves is quasi-parallel to the background magnetic field, which is consistent with the waves observed in the shock transition region. The simulation results suggest that finite amplitude whistler turbulence can be an additional source of ion acoustic waves observed in interplanetary shocks and earth’ s bow shock. The positive roles of the enhancement process of ion acoustic waves by whistler turbulence in quasi-perpendicular collisionless shocks are discussed.

Keywords: whistler turbulence, ion acoustic wave, Collisionless shocks

Upstream wave evolution, particle diffusion and acceleration in the earth's foreshock: One-dimensional PIC simulation

*Fumiko Otsuka[1], Shuichi Matsukiyo[1], Tohru Hada[1]

1. Interdisciplinary Graduate School of Engineering Sciences Kyushu University

We have systematically studied wave excitation, particle diffusion and acceleration in the earth's foreshock by making use of quasi-linear theory, test particle simulation, and particle-in-cell (PIC) simulation. In the previous presentation, we reported the preliminary results of one-dimensional PIC simulation of a quasi-parallel shock with Alfven Mach number 6.6 and electron and ion beta 0.5. The field-aligned beam (FAB) ions, backstreaming away from the shock, were generated by the solar wind ions specularly reflected at the shock. They excited Alfvenic waves via resonant beam instability. We also showed the upstream ion distributions as a function of the distance from the shock.

In this presentation, we discuss how the waves excited by the FAB contribute to the particle diffusion and acceleration in their spatial as well as temporal evolutions. We analyze electromagnetic and electrostatic wave spectra in the foreshock region, and discuss the relation between the evolution of wave spectra and the distribution functions of the solar wind plasma and the FAB. Further we will investigate trajectories of highly accelerated particles and discuss the diffusion and acceleration processes of them.

Keywords: earth's foreshock, waves, particle diffusion and acceleration

Electron acceleration via interaction between the Earth's bow shock and an interplanetary shock

*Masaru Nakanotani[1], Christian Mazelle[2,3], Shuichi Matsukiyo[1], Tohru Hada[1]

1. Earth System Science and Technology, Kyushu University, 2. IRAP, CNRS, France, 3. IRAP, Univsersity of Toulouse, France

In space, two shock waves often approach and even collide with each other (we call a shock-shock interaction).
For example, it is commonly observed that an interplanetary (IP) shock interacts with planetary bow shocks or the heliospheric termination shock.
Beyond the heliosphere, shock-shock interactions can be seen in many astrophysical objects.

It is natural to consider that particle acceleration through a shock-shock interaction is more efficient than that occurring in a single shock wave.
However, we have little direct evidence of particle acceleration by a shock-shock interaction
Hietala et al.[2011] discussed ion acceleration between an IP shock and the Earth's bow shock by mainly using ACE, WIND and GEOTAIL data.
They argued that ions can be accelerated between the two shocks through a Fermi like acceleration mechanism.
Up to now, on the other hand, we do not still have a direct evidence of electron acceleration by a shock-shock interaction.

We report a Cluster observation representing electron acceleration due to the interaction between an IP shock and the Earth's bow shock.
It is confirmed that electron acceleration occurs when the IP shock and the bow shock are magnetically connected.
The electrons have a bi-directional pitch angle distribution implying that they come and go between the two shocks.
We discuss the acceleration mechanism in detail and compare its efficiency to the case of single shock acceleration (usual diffusive shock acceleration).

Keywords: The Earth's bow shock, Shock-shock interaction, Electron acceleration

Test particle simulation of invading process of galactic cosmic rays into the heliosphere

*Shuichi Matsukiyo[1,2], Keisuke Shimokawa[1], Haruichi Washimi[2], Tohru Hada[1,2]

1. Faculty of Engineering Sciences, Kyushu University, 2. ICSWSE, Kyushu University

Heliospheric boundary plays an important role in preventing galactic cosmic rays (GCRs) from entering into the heliosphere. Nevertheless, particles having energies higher than GeV invade the heliosphere and are observed at the Earth. For a long time, detailed invading process has been unclear, since the structure of heliospheric boundaries have been poorly understood.

After that Voyager spacecraft, for the first time, explored in-situ this region in space, the structure of heliospheric boundaries are intensively studied. Recently, high accuracy MHD simulation of global heliosphere interacting with interstellar medium can be performed and detailed structures of the boundary region are getting revealed.

Here, we perform test particle simulation of GCRs by using electromagnetic fields obtained from global MHD simulation of the heliosphere. Initially a number of monoenergetic test particles are uniformly distributed in a certain region of interstellar space with velocity along the interstellar magnetic field. Trajectories of those particles are calculated numerically and examine how and from where the particles enter into the heliosphere. We will discuss the characteristics of the particles for various energies.

Keywords: galactic cosmic ray, heliospheric boundary, numerical simulation

Pickup ion dynamics in the velocity shear layer across the heliopause

*Ken Tsubouchi[1]

1. Tokyo Institute of Technology

Consequences of the charge exchange between solar wind plasmas and interstellar neutral particles substantially control the environment of the heliospheric boundary. Recent in-situ observations by Voyager 1/2 and energetic neutral atom (ENA) observations by the Interstellar Boundary Explorer (IBEX) have verified many new features in this region. One of such findings is known as "IBEX ribbon", the bright ENA emissions concentrated in a narrow area. The ribbon geometry is well associated with the local interstellar magnetic field draped on the heliopause, so that the vicinity of the heliopause is its likely source region. The dominant energy range in this ribbon structure (a few keV) indicates that interstellar pickup ions (PUIs) must be the primary source. The purpose of this study is to clarify the physical properties of the ribbon. In this study, we demonstrate hybrid simulations to investigate the dynamics of those PUIs around the heliopause, where the velocity shear might be present between the flow of the solar wind and the interstellar medium. The growth of the Kelvin-Helmholtz instability (KHI) is then expected. We will verify the impact of the presence of PUIs on the KHI properties, the efficiency of the charge exchange, and local concentration of the energetic population and its nonstationarity.

Keywords: pickup ion, heliopause, instability