

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

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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, δN_e , derived from interplanetary scintillation (IPS) measurements; that is, the fast (slow) wind is associated with low (high) δN_e (Asai et al., 1998). This fact suggests a certain level of proportionality between the density and δN_e . Our earlier study demonstrated that δN_e sometimes deviates from this inverse relation at a speed lower than 350 km/s, showing a marked drop in δN_e 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 δN_e in Cycle 23. However, VSSW is found to be more associated with low δN_e 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 δN_e 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- δN_e 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

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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

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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 magnetotail) 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

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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 (Δf) 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 Δf 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 Δf , 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 Δf (equidistant ZP, varying distant ZP, and growing distant ZP) as mentioned in Tan et al. (2014). However the variation of Δf 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 Δf 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

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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

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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 events, 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 Alfvén waves: An empirical model of the ion kinetic effect

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It is well known 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 Schrödinger equation and the triple-degenerated derivative nonlinear Schrödinger equation) including the ion kinetic effect are used to evaluate the empirical relationship between the plasma density and the magnetic pressure.

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

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

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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

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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 Alfvén 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 Alfvénic 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

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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

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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

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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

Introduction to the THOR mission

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Fundamental plasma processes at kinetic scales such as wave-particle and wave-wave interactions play an important role in the heliosphere and various astrophysical systems. Turbulence Heating Observer (THOR) is the first mission under a study for ESA M4 candidate ever flown in space dedicated to understanding the heating process in collisionless plasma turbulence. THOR explores the kinetic plasma processes that determine the fundamental behavior of the majority of baryonic matter in the universe. THOR aims to find answers to the fundamental questions on the turbulent plasma processes by achieving the highest-resolution in the particle and electromagnetic field measurements in the solar wind and the regions around Earth's bow shock. Toward the launch in 2026, the spacecraft design, the instrument design, the orbit plan, and the analysis tools are presented on the THOR mission.

Keywords: plasma turbulence, spacecraft mission, solar wind, bow shock

Two-fluid tearing mode instability in cylindrical geometry

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The two-fluid tearing mode instability in a plasma cylinder of finite aspect ratio is investigated. An analytic dispersion relation for a force-free equilibrium with constant density and temperature in the cylindrical geometry for general ion skin depths, the characteristic length of the two-fluid effect, has been derived by extending the theory for the slab geometry [1]. The dispersion relation shows the continuous dependence of the growth rate and the real frequency on the ion skin depth d_i ranging from single MHD limit ($d_i \ll L$) to electron MHD ($d_i \gg L$). Analytic representations of dispersion relations that cover a wide range of parameters are useful to carry out benchmark tests of extended-MHD simulation codes [2]. It is found that the real frequency appears due to the combination of the two-fluid and curvature effects. The scaling law for the real frequency in the regions of small and large skin depth as well as for the growth rate is also found. The numerical analysis shows good agreement with analytical dispersion relation and inner solutions of eigenfunctions for a wide range of the ion skin depth and resistivity.

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Keywords: tearing instability, two-fluid MHD, force-free equilibrium

Flare Productivity in Different Magnetic Types of Active Regions

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It is believed that intense flares preferentially originate from the large-size active regions (ARs) with strong magnetic fields and complex magnetic configurations. Based on two datasets of daily sunspot and flare information as well as the GOES soft X-ray measurements and HMI vector magnetograms, we investigate the dependence of flare activity on the AR properties and clarifies the influence of AR magnetic parameters on the flare productivity. We find that flare behaviors are quite different in the short- and long-lived complex ARs and the ARs with more complex magnetic configurations are likely to host more impulsive and intense flares. Moreover, our results demonstrate that the total source field strength on the photosphere has a good correlation with the flare activity in complex ARs. Intense flares tend to occur at the regions of strong source field in combination with an intermediate field-weighted shear angle, which implies that the magnetic free energy provided by a complex AR could be high enough to trigger a flare eruption even with a moderate magnetic shear on the photosphere. We thus suggest that the magnetic free energy represented by the source field rather than the photospheric magnetic complexity is a better quantity to characterize the flare productivity of an AR, especially for the occurrence of intense flares.

Keywords: solar flare, active region

Relationship between north-south component of magnetic field in sheath regions and coronal magnetic fields

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Southward interplanetary magnetic field (IMF) is a crucial factor that causes geomagnetic storms. A majority of geomagnetic storms is associated with magnetic clouds (MCs) or sheath regions, since a large southward component of IMF is likely to occur in these regions. Therefore, it is important to understand north-south (NS) component of IMF associated with MCs and sheath regions for space weather forecast. MCs are studied by many researchers using flux rope models. However, the origin of IMF at sheath regions is poorly investigated and it is still not clear how IMF in sheath regions is related to coronal magnetic fields. We investigate the relationship between the NS component of IMF in sheath regions and coronal magnetic fields. Here, we assume that coronal magnetic fields around prominence eruption sites move outward and are then convected into the interplanetary space to be observed at the Earth during the passage of sheath regions. In this study, we calculate coronal magnetic fields from the Kitt Peak/NSO photospheric magnetic field data using the PFSS model [Hakamada, 1998] and extrapolate these fields radially outward to 1AU at background solar wind velocity. The background solar wind velocity is given from interplanetary scintillation observations at ISEE via the tomographic analysis. The coronal magnetic fields are projected to 1AU using the background solar wind velocity data and the 1D-HD solar wind model developed by K.Hayashi. We examine whether the sign of the NS component (in RTN coordinates) of the projected coronal magnetic field agrees with that of the field observed by ACE spacecraft prior to MC arrival at the Earth. We make the comparison three hours before the MC start time (pre MC time) and at the MC start time (MC time) for five MC events during 2006–2007. As a result, we find that the sign of NS component of the magnetic field extracted from 1.1 solar radius (R_s) or 1.2 R_s agrees with ACE observation at the MC time for all MC events analyzed here. The same result is obtained from the analysis that uses UCSD time-dependent tomography [Jackson et al., 2013] for solar wind model (this result was reported at the JPGU 2016). The result indicates that the coronal magnetic field at low height erupts and the field is observed at the MC time. We also determine the solar sources of the MCs and those of the projected coronal magnetic fields. We find that the sign of NS component at the source of projected coronal magnetic field agrees better with that of NS field observed at the Earth at the MC time than the source of MC. This result indicates that the IMF observed at the sheath comes from the source region of the background solar wind, not from the source region of MC.

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

Occurrence characteristics of Type-III solar radio bursts in the solar quiet period

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Type III bursts are impulsive radio bursts generated in association with solar flare. A characteristic spectral nature of Type III burst is its first negative frequency drift, which is considered to reflect energetic electrons moving upwards from the sun along an open magnetic field line generated by the magnetic reconnection process near the sun. On the other hand, it is also considered that simultaneously generated downward energetic electrons move into the dense chromosphere and make thermalized plasma, which enhances soft X-ray emissions (SXR) and is recognized as occurrence of flare. Thus, it is expected that solar flares in SXR have a tight relation with Type III bursts. However, there seems to be no small number of examples of Type III bursts which occur in weak or no SXR flare event.

We have derived characteristics of Type III bursts appeared in the solar quiet period and have compared them with SXR variations to investigate their mutual relation. For this purpose, we have analyzed dozens of Type III bursts appeared after 2014 using the database of the meter-wave range solar radio telescope in Tohoku University (IPRT/AMATERAS). For estimating SXR variations we have used the database of GOES SXR. As the result, it is indicated that the correlation between energy of Type III burst and corresponding variation of SXR is low actually, and Type III bursts with similar intensity appeared in a few orders of SXR variations. Then, we have also investigated expected solar surface phenomena corresponding to each Type III burst for revealing causalities of the low correlation. We referred to the RHESSI flare list and surveyed solar surface phenomena using the SDO/AIA image data. It is suggested that Type III bursts with very weak or no variation in SXR were related to compact solar surface phenomena such as EUV spot or jet. This result implies a possibility that a causality of the low correlation is due to the height or scale size of magnetic reconnection region which affects SXR intensity.

In the presentation we will introduce results of the statistical and event analyses of Type III bursts in the solar quiet period precisely and discuss expected causalities of the low correlation.

Acknowledgements: We thank the GOES, RHESSI and SDO teams for providing the solar data.

Keywords: sun, type III burst, flare

Software for virtual 3-dimensional display of Kaguya in-situ observation of magnetic field and the magnetic anomalies on the moon

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A variety of magnetic fluctuations were found by Kaguya in its orbit around the moon. They manifest the interaction between the solar wind and the lunar surface or the lunar crustal magnetic field. To understand the generation mechanisms of those phenomena, it is crucial to examine the relative position of the spacecraft with respect to the moon in the solar wind and the magnetic anomaly on the surface, as well as the magnetic connection between the spacecraft and the moon.

In order to make it easier to realize the 3-dimensional configuration, we have developed computer software which enables a virtual 3-dimensional display of magnetic field vectors observed by Kaguya on the position of the spacecraft, together with the lunar magnetic field displayed on the moon. The data used are the 1-s averages of the Kaguya/LMAG magnetometer and SVM data (Tsunakawa et al., 2015, JGR Planet).

Keywords: Kaguya, MAP/LMAG, 3D display, crustal magnetic field, magnetic anomaly, Solar wind

Optical observation of neutral helium distribution in interplanetary space by Hisaki

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The Hisaki (SPRINT-A) satellite has a main scientific topic of the planetary continuous observation for a long term, but carried out the non-planet observation at the time when no planet during a good observation opportunity phase exists. One case of those is observation of helium atom resonance scattering from the interplanetary space.

The interstellar wind flows into the heliosphere over the heliopause by the relative velocity of the heliosphere and the interstellar medium. The helium atom can travel into about 0.5Au from the neighboring of the sun without ionizing because of its high ionization energy. The travelling orbit is bent by sun gravity and forms a high density region on the downwind side. It is called helium cone. The distribution of helium atoms in the helium cone can estimate the speed and direction of the interstellar wind, and the density and the temperature of the helium atom in interstellar space. Such a study was carried out from the 1970s.

Recently the study of interstellar space is one of interesting topics owing to the IBEX satellite observation results. Frisch (2013) shows that the interstellar wind direction gradually changes for this several decades. However, it is shown that the direction is stable from the re-analysis of the IBEX observation (Mebius et al., 2015) and the hydrogen scattering emission distribution observed by SOHO/SWAN (Koutroumpa et al., 2017).

The Hisaki satellite carried out the optical observation of the resonance scattering from helium cone. It is a different method from the IBEX and SOHO observations and it is important to confirm the interplanetary helium distribution continuously. In 2015 and 2016 seasons, Hisaki observed the helium cone including a ecliptic longitude with the maximum density of the helium. In this presentation, the helium cone observation results are reported and it is discussed whether the change of the wind direction or not.

Keywords: HISAKI satellite, EUV spectral observation, Interstellar wind and gas, Interplanetary neutral helium