サイクル２４における超低速（350km/s以下）太陽風の低密度化
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, 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.

キーワード：太陽風、惑星間空間シンチレーション、太陽活動周期
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.

キーワード：太陽風、乱流、MHDシミュレーション
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 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

太陽電波ゼブラパターンにおける縞構造の時間変動
Temporal Variation of Zebra Stripes in Type IV Solar Radio Bursts

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フレアに伴って放射される太陽電波IV型バーストには、多様なスペクトル微細構造が存在することが知られている。ゼブラパターン（ZP）は、IV型バーストの広帯域放射を背景に、多数の狭帯域放射が周波数方向にならんだ縞模様状のスペクトルを示す微細構造の一種である。ZPの縞構造の解釈として多くのモデルが提唱されているが、全ての観測的特徴を説明できるようなモデルは報告されていない。Tan et al. (2014)は、マイクロ波帯のZPについての統計調査を行い、縞の周波数間隔（Δf）が放射周波数に対してどのように変化するかによってZPを３種類に分類し、それぞれが異なる放射機構で生成されている可能性を示した。このように、Δfはの発生機構を理解する上で重要であるが、その時間変化については研究されていない。そこで本研究では、Δfの時間変動を明らかにするため、東北大学所有の太陽電波観測システムAMATERASにより取得された高分解スペクトルデータの解析を行った。2010年7月～2016年7月の期間に観測された２１例のZPについて解析した結果、Tan et al. (2014)の報告と同様に、放射周波数に対するΔfの変化のパターン（等間隔、放射周波数とともに増加、不規則変化）が３種類確認された。しかし、それらの変化のパターンはZPの継続時間を通して常に一定ではなく、時間によって様々な変動のパターンを示すことがわかった。本講演では、観測されたΔfの変動の詳細を示すとともに、想定される変動要因について考察する。

キーワード：太陽コロナ、電波バースト、AMATERAS
Keywords: Solar corona, Radio burst, AMATERAS

IMF-Byの卓越した太陽風中の月のウェイク境界における磁場擾乱の偏波非対称について

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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太陽風磁場のBy成分が卓越しているとき、極軌道で月を周回するかぐや衛星の磁場観測によって、北半球と南半球で磁場に対する偏波が逆になる低周波(0.1-0.3Hz)の磁場変動が見られた。IMF-BygSSE座標で正（duskward)のときは北半球で左回り、南半球で右回り、IMF-Byが負（dawnward)のときは北半球で右回り、南半球で左回りであった。これはIMF-Byの極性に関わらず、rotBが北半球でdawnward、南半球でduskwardを向いていることを示し、Kelvin-Helmholz不安定と同じ向きである。

ウェイク境界では周波数が高め(0.5Hz)でかつ周波数幅が広く、波形も三角であるが、衛星が月の真裏のウェイク中心に進むにつれ、周波数は下がり(0.05Hz)、sinusoidalな波形となっていた。この状況は、地球の磁気圏境界を太陽風が吹きすぎる際の表面波の場合と類似している。Chen and Hasegawa (1974, JGR)は境界層に厚みがあると表面波が減衰することを示していたが、月のウェイク境界は密度勾配が急峻で、1.0RLから0.88RLまでの距離0.12RLで100分の 1 になることから、exp(-z/L)の形に書いた際のLは40km程度であり、そのために表面波の減衰が弱く、境界から遠いウェイク中心でも波が残っていたと考えられる。

キーワード：太陽風、ウェイク境界、ケルビンヘルムホルツ不安定、表面波、偏波
Keywords: Solar wind, wake boundary, Kelvin-Helmholts instability, surface wave, polarization

月周回衛星かぐやによって観測された1-12Hzの霧状の磁場変動について
Diffuse magnetic fluctuations in the frequency range 1-12Hz detected by Kaguya above the polar regions of the moon

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月面及び月固有磁場と太陽風との相互作用によって、月周辺には様々な磁場変動が生じていることがかぐや衛星をはじめとする近年の月探査衛星によって次々と明らかにされてきた。本研究では、1-12Hzの下部ELFの周波数帯に、ダイナミックスペクトル上で霧状にみえる磁場変動を発見したのでその特徴及び発生特性について報告する。

この磁場変動は2008年6月14日20:40から21:00にかけて、月の北極付近で検出された。周波数域は1-12Hzと広く、明確なピーク周波数はなくdiffuseである。時間的にも、明確な開始・終了ではなく、ぼんやりと始まり徐々に消えていくため、ダイナミックスペクトル上では霧のように広がって見える。沿磁力線電子流の有無や磁力線の月面とのつながりの有無やによって強さが切り替わる広帯域ホイスラとはこの点が異なっている。

同様な霧状の磁場変動を、かぐや搭載磁力計LMAGによって2008年1月1日から2009年3月31日までの間に観測された32Hzサンプリング磁場データ中から探したところ、全8例見つかった。周波数幅は4Hzないし15Hzと広く、これらは月が太陽風中にあるときに検出された。8例中5例は月の昼側で観測され、検出位置は北極と南極に集中していた。なお、かぐやは極軌道衛星のため、限られた時期を除いては、昼夜境界を通るのは極域に限定される。8例中6例は北半球で検出された。

また8例中4例で周波数が時間とともに下がっていた。この4例とも、衛星が極に近づくにつれて周波数が下がっているように見えた。霧状の磁場変動が観測された時の太陽風条件は、速度は平均的だったが、密度は平均よりも高い値であり、太陽風速度と密度の積の大きい時に強度が強い傾向が見られた。

この磁場変動の発生原因は未解明であるが、昼側での検出が多いこと、太陽風のフラックスと関係があること、固有磁場の弱い領域で発生が多いことから、太陽風粒子による月面のスパッタリングとの関係が考えられる。

キーワード：かぐや、ELF磁場変動、昼夜境界、太陽風、月、MAP/LMAG
Keywords: Kaguya, ELF, Terminator, Solar wind, Moon, MAP/LMAG

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

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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.

キーワード：太陽風、アルヴェン波、太陽風プラズマの熱力学的性質
Keywords: solar wind, Alfven 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.

キーワード：ホイッスラー乱流、イオン音波、無衝突衝撃波
Keywords: whistler turbulence, ion acoustic wave, Collisionless shocks

地球フォアショックにおける波動の時空間発展と粒子拡散・加速：１次元PIC計算

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

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我々はこれまで、準線形理論、テスト粒子計算、およびPIC計算を通じて、地球のフォアショック領域における波動生成および粒子加速・拡散において、沿磁力線ビーム(FAB)が果たす役割を系統的に議論してきた。前回の講演で、PIC計算による初期結果を報告し、衝撃波面でのイオン反射によってFABが生成されること、FABがサイクロトロン共鳴によって太陽風中（フォアショック）にアルフヴェン波を励起すること、さらにフォアショックでのイオン分布関数の空間発展の様子、などを報告した。

本講演では、FABによって励起された波動が、その長時間・空間発展を通じて粒子の拡散・加速にどのように寄与するかに着目する。静電および電磁波動のスペクトル解析を行い、その時間・空間発展とFABや太陽風プラズマの分布関数との相関を議論する。また、高エネルギー粒子の軌道解析を通じて、その生成、拡散過程を調べる。

キーワード：地球フォアショック、波動、粒子拡散・加速
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).

キーワード：地球磁気圏衝撃波、衝撃波-衝撃波相互作用、電子加速
Keywords: The Earth's bow shock, Shock-shock interaction, Electron acceleration

銀河宇宙線の太陽圏への侵入過程のテスト粒子計算
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.

キーワード：銀河宇宙線、太陽圏境界、数値実験
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.

キーワード：pickup ion、heliopause、instability
Keywords: pickup ion, heliopause, instability

