R007-01
C 会場 ：9/25　AM1 （9:00-10:30）
9:00〜9:15

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Magnetic field and density fluctuations associated with a CME observed during a radio occultation experiment of the solar corona

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The solar wind is a supersonic plasma flow streamed from the solar corona. Solar wind acceleration mainly occurs in the outer corona at heliocentric distances of about 2–10 solar radii, where the coronal heating by magnetohydrodynamic waves and the wave-induced magnetic pressure are thought to play major roles in the acceleration. The mechanisms have not been fully confirmed because the acceleration occurs in regions where no spacecraft has ever reached to date. Recently, however, an inner heliosphere observation network is getting ready, by such as NASA's Parker Solar Probe and ESA's Solar Orbiter and BepiColombo.

Radio occultation observations cover the acceleration region fully and can obtain information complementary to in-situ observations. Radio occultation observations are conducted during the passage of a spacecraft on the opposite side of the sun as seen from the Earth. Inhomogeneity of coronal plasma density structure traversing the ray path disturbs radio waves' frequency so that we can interpret the received frequency fluctuations as density fluctuations in the coronal plasma. Furthermore, using dual-circular polarization signals transmitted from the spacecraft, we can derive the Faraday rotation (FR) from the phase difference between right-hand circular polarization (RCP) and left-hand circular polarization (LCP). we can obtain the plasma density and magnetic field structure of the solar wind from FR measurements.

Wexler et al. (2017) proposed a method to derive FR from the cross spectrum between the RCP and LCP signals of the spacecraft. Using this method, we have derived the FR from the radio occultation data taken during the solar conjunction of JAXA's Akatsuki spacecraft in 2016. According to SOHO/LASCO C2 images, a coronal mass ejection (CME) crossed the ray path on 9 June 2016 during this campaign. The FR on this day shows larger amplitudes than the other observations at similar solar offset distances, and the time series of the electron column density shows a rapid increase around the time of the CME event. Jensen et al. (2018) reported FR measurements associated with a CME event on 10 May 2013 using the signals transmitted by the Messenger spacecraft. The FR obtained from our analysis has similar amplitudes to the FR which is shown by Jensen et al. (2018). We will report the initial results of the FR analyses.

R007-02
C 会場 ：9/25　AM1 （9:00-10:30）
9:15〜9:30

太陽風擾乱イベントにおいて観測される惑星間空間シンチレーション強度の東西非対称性

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([1] 名大 ISEE,[2] 名大,[3] 名大 ISEE,[4] 名大 ISEE

East-west asymmetry of interplanetary scintillation strength observed for solar wind disturbance events

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Interplanetary scintillation (IPS) observed for a compact radio source is a scattering phenomenon caused by solar wind electron density irregularities Δ Ne, and the strength of IPS is proportional to the integration of Δ Ne along the line of sight (LOS), when the scattering is weak. Using this relation, IPS observations for many sources in a day enable remote sensing of daily changing Δ Ne distribution in the solar wind. Since Δ Ne increases in the compression region associated with solar wind disturbances, the IPS strength increases when the LOS intersects solar wind disturbances propagating toward the Earth. Therefore, the IPS strength acts as a useful tool for detecting solar wind disturbances. IPS observations have been conducted at ISEE for 30 to 60 sources in a day, and the g values which represent the daily variation of IPS strength have been calculated from the IPS observations. The g value is normalized to the level of the quiet solar wind (g=1), and g>1 when the LOS passes across solar wind disturbances. In our previous studies, we calculated the IPS indices which enable quick identification of solar wind disturbances from ISEE g-value data and investigated correlation between the IPS indices and solar wind density/speed measured in situ near the Earth. We also determined the long-term variation in the occurrence rate of solar wind disturbances using the IPS indices. In this study, we investigated response of IPS observations to solar wind disturbances associated with coronal mass ejections (CMEs) and stream interaction region (SIRs) driven by the high-speed solar wind using the IPS indices. We determined Gave indices from ISEE g-value data between 1997 and 2019, and performed the superposed epoch analysis of Gave for CME and SIR events. The Gave index is given as a mean of g values obtained in a day, and the start times of CMEs and SIRs, which were adopted from the lists of Richardson and Cane (2010) and Grandin et al. (2019), respectively, were used as the zero epoch in the analysis. Here, we determined Gave from g values collected on the east and west sides with respect to the Sun-Earth line separately and examined difference between them. As the result, we found distinct difference in time profiles of Gave data between CME and SIR events. Eastern and western Gave for CME events simultaneously increased and peaked at 0 days. This feature is consistent with the analysis for Earth-directed CME events. In contrast, eastern Gave for SIR events was higher (lower) than western one before (after) the start time, and a prominent peak occurred in the western data 2 days after the start time. This east-west asymmetry is ascribed to the spiral-shaped distribution of the SIR, and a consistent result was obtained from calculations of a simple SIR model. Such east-west asymmetry was also observed for correlations between Gave and the solar wind density/speed measured in situ near the Earth, and this is ascribed to the effect of SIR considering the result of superposed epoch analysis. The east-west asymmetry in the correlations for Cycle 24 significantly differed from that for Cycle 23, and this can be explained by the reduced contribution of CMEs due to weakening of the Cycle 24 activity.

見かけの大きさが小さい天体電波源に対して観測される惑星間空間シンチレーション（IPS）は太陽風中の電子密度ゆらぎΔ Ne によって生じる散乱現象であり、散乱が弱い場合、その強度は視線に沿ったΔ Ne の積分量に比例する。この関係を利用すると、1 日に多数の電波源について IPS を観測すれば日々変化する太陽風中のΔ Ne 分布を遠隔測定できる。Δ Ne は太陽風擾乱に伴う圧縮領域で増大するので、地球へ向けて到来する太陽風擾乱が視線を横切った場合、IPS 強度が増加する。よって、IPS 強度は太陽風擾乱を検出する手がかりとなる。ISEE では 1 日に 30〜60 個の電波源について IPS 観測を行い、それぞれの観測データから IPS 強度の日々の増減を表す g 値を計算している。g 値は静穏な太陽風を基準にして規格化 (g=1) していて、太陽風擾乱が視線を横切った場合、g>1 となる。先行研究にて、我々は太陽風擾乱の検出を容易にするため同データから 1 日毎に指数を計算し、その指数と地球近傍で観測された太陽風の速度・密度との相関を調査した。さらに、求めた指数を使って太陽風擾乱の発生率の長期変動を調査している。今回の発表では、IPS 指数を使ってコロナ質量放出現象（CME）および高速風前面の相互作用領域（SIR）に伴う太陽風擾乱に対する IPS 観測の応答を調査した結果について報告する。我々は 1997 年（サイクル 23 初期）〜2019 年（サイクル 24 終了）の期間について ISEE の g 値データから Gave 指数を求め、地球付近の飛翔体観測から同定した CME および SIR イベントの開始時刻の前後 10 日について Gave を重ね合わせる解析（superposed epoch analysis）を行った。ここで、Gave は 1 日に得られた g 値の平均値である。また、CME および SIR の開始時刻はそれぞれ Richardson & Cane (2010) による ICME イベントリストおよび Grandin et al.(2019) による SIR リストを参照した。本研究では、地球から見た太陽の東側と西側で取得した g 値データから別々に Gave を計算し、両者の違いを調べている。その結果、CME イベントと SIR イベントでは東西の Gave の変化に明瞭な違いがあることがわかった。CME イベントでは東西の Gave が開始時刻をピークとして

同時に増加する。これは、地球へ向けて動径方向に伝搬する CME の場合に期待される結果と一致している。一方、SIR イベントでは開始時刻の前（後）は東側の Gave が西側に比べ高く（低く）、Gave のピークは開始時刻より 2 日遅れて西側において顕著にみられた。この東西非対称性は SIR のスパイラル状分布によって生じたものと解釈される。単純なモデル計算からも、このことが裏付けられた。このような東西非対称性は地球付近の飛翔体で観測された太陽風密度・速度と Gave の相関においてもみられ、Superposed epoch analysis の結果を考慮すると、これは SIR による寄与と思われる。相関の東西非対称性はサイクル 23 と 24 で違いが見られ、このことは太陽活動度の低下によって CME の寄与が減少したことで説明できる。

R007-03
C 会場 ：9/25　AM1 （9:00-10:30）
9:30〜9:45

次世代太陽風観測装置に向けた小型アレイの開発

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Development of pathfinder array for Next Generation Solar Wind Observation System

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Interplanetary scintillation (IPS) is a radio scattering phenomenon caused by the disturbances in the solar wind. IPS data obtained by observing radio sources outside the heliosphere with ground-based radio telescopes have been important information for understanding the global structure of the heliosphere. ISEE, Nagoya University has developed unique IPS instruments consisting of a cylindrical parabola antenna with a physical aperture area of about 2000 - 4000 square meters in the 327 MHz band. The instruments have been installed at three locations in Japan to observe solar wind from ground-based radio observations. In addition to contributing to the understanding of the global structure of the heliosphere, the obtained solar wind data can efficiently detect coronal mass ejections propagating in interplanetary space. The IPS data has also contributed the space weather forecasting by improving the predicting accuracy of the arrival of CMEs on the Earth. On the other hand, it has become clear that more IPS observations is necessary to understand the acceleration process of the solar wind and to improve the accuracy of solar wind forecasting.

This project proposes the ”Next Generation Solar Wind Observatory System” to dramatically improve the observational performance of solar wind and to lead the next generation of heliospheric research. In this project, a flat phased array antenna consisting of many antenna elements is constructed. Digital beam forming devices that can simultaneously observe on multiple directions are installed on the array system. This system enables IPS observations 10 times greater than that of existing system. The development of a small array, which accounts for a few percent of the total, is currently underway as a Phase-I project. We have developed a digital backend system that digitizes 64 analog inputs and synthesizes 8 beams simultaneously. For the antenna system, we designed a system that combines multiple antenna elements in an analog stage. Dipole antennas and Yagi antennas were selected as candidates for the antenna elements. Prototypes of both candidate antenna elements have been developed, and experiments are underway to determine the final design for manufacture.

This project has been proposed to the Science Council of Japan’s Future Science Promotion Concept as a part of the ”Study of coupling processes in the solar-terrestrial system” project. This project is also going to be proposed to the Roadmap 2023 by the Ministry of Education, Culture, Sports, Science, and Technology.

太陽風中の擾乱が電波を散乱することで惑星間空間シンチレーション（IPS）現象が発生する。地上の電波望遠鏡を用いて太陽系外の電波天体を観測することで得られる IPS データはグローバルな太陽圏構造を理解する上で重要な情報となってきた。名古屋大学では 327MHz 帯域において、最大約 4000 平方メートルの物理開口面積を持つシリンドリカルパラボラアンテナからなる独自の IPS 観測装置を開発し、国内 3 カ所に設置することで、地上電波観測から太陽風の観測に取り組んできた。得られた太陽風データはグローバルな太陽圏構造の理解に貢献することに加え、惑星間空間を伝搬中のコロナ質量放出現象を効率良く検出し、その地球への到来予測を可能とすることで、宇宙天気予報の高精度化にも貢献してきた。一方、太陽風の加速過程の理解や、太陽風予測の高精度化には IPS 観測の稠密化が必要であることがわかってきた。

本計画では太陽風の観測性能を飛躍的に向上させ、次世代の太陽圏研究をリードするために「次世代太陽風観測装置計画」を提案している。本計画は、多数のアンテナから構成される平面フェーズドアレイアンテナを建設し、そこに独自に開発したデジタルビームフォーム装置を搭載することで、多数の方向を同時に観測できる電波観測装置を開発する。これを用いた太陽風の多方向同時 IPS 観測で、既存装置の 10 倍の太陽風観測を実現する。現在 Phase-I プロジェクトとして全体の数%の小型アレイの開発が進められている。小型アレイでは 64 系統のアナログ入力をデジタル化し 8 ビームを同時に合成するデジタルバックエンドを開発した。アンテナ系は素子アンテナをアナログで複数合成する系を設計した。素子アンテナはダイポールアンテナと八木アンテナを候補とした。両アンテナの試作を開発し、最終形態を決定するための実験をおこなっている。

本計画は「太陽地球系結合過程の研究基盤形成」計画の一部として未来の学術振興構想に提案されるとともに、「学術研究の大型プロジェクトの推進に関する基本構想」（ロードマップ 2023）への提案に向けた準備が進められている。

R007-04
C 会場 ：9/25　AM1 （9:00-10:30）
9:45〜10:00

SUSANOO-CME における初期磁束パラメータによる CME 到達時刻の不定性評価

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Evaluation of Uncertainty in Arrival Time of CME given by initial magnetic flux parameters in the SUSANOO-CME model

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An interplanetary disturbance associated with a transient solar plasma ejection, called Coronal Mass Ejection (CME), sometimes arrives at Earth with a strong southward magnetic field. It is concerned that various communication infrastructure and electrical systems can be damaged through magnetospheric disturbances. To predict the time of arrival (ToA) of the CME accurately in advance of their arrival to the Earth, global heliospheric MHD models have been applied to forecast the ToA. Today, some space weather forecast models have been developed and operated such as WSA-ENLIL (Riley et al., 2018), EUHFORIA (Pomoell & Poedts, 2018) and SUSANOO-CME (Shiota & Kataoka, 2016). In these models, the ToA is known to be sensitive to the initial parameters of the injected CME and some particularly important CME parameters in several models have been investigated (e.g., May et al., 2015; Riley et al, 2018, 2021). In SUSANOO-CME, it is also important to quantitatively estimate the contribution of CME parameters to the ToA in order to achieve a more accurate forecast model. However, it has been suggested that in models that include flux rope structures observed in real ICMEs such as SUSANOO-CME, the additional variables might be causes of further ToA uncertainty (Riley et al., 2021). In addition, some of the SUSANOO-CME parameters, such as the magnetic flux, that their validity of the initial value assumptions has not been fully verified because of difficulties to observe despite their importance. Recently, correlations between the EUV dimming region of the corona associated with CMEs and the photospheric flux contained at their footpoints (Dissauer et al., 2019),. and reconnection flux at flare sites and a lower limit for the flux contained in CMEs (Temmer et al., 2017) have been reported from the solar observations. Based on these studies, the assumption of the amount of magnetic flux contained in the initial CME can be constrained. In this study, then, we aim to quantitatively estimate the contribution of CME parameters such as the magnetic flux in SUSANOO-CME to the ToA and constrain the parameters by comparing them with solar observation data and interplanetary scintillation (IPS) data provided by ISEE, Nagoya University. As a preliminary analysis, we simulated propagation of CME associated with the M1.0 flare on March 28, 2022. Ten CMEs given five different initial velocities (600, 700, 800, 900, and 1000 km/s) and two magnetic fluxes ($2*10^{21}$ Mx and $3*10^{21}$ Mx) were injected. As a result, we found that while the maximum ToA difference with initial speed of CMEs was about 4-5h, it was observed that the ToA changed by about 6h at all initial speeds for CMEs with different magnetic fluxes. However, since ToA variations are known to vary significantly with the order of the magnetic flux. For example, the ToA difference becomes smaller when the input magnetic flux is set to ~10^{20}Mx. The flux parameter characteristics of ToA should be investigated in more detail over a wider parameter range. In addition, this analysis included conditions unsuitable for this study, such as the interaction of the CME structure with the background solar wind, which causes reproduced shock arrival at the earth position to be more complex. Although this interaction is important in terms of actual forecasting, we will remove these effects by methods such as uniformizing the background solar wind to simplify the conditions.

過渡的な太陽プラズマ放出であるコロナ質量放出（CME）に伴う惑星間空間擾乱である ICME が大きな南向き磁場を伴って地球へ到達すると、磁気圏擾乱を通じて通信インフラや電気システムに様々な障害をもたらすことが危惧されている。その到達時刻 (ToA) を地球到達以前に余裕をもって予測するため、グローバルな太陽圏 MHD モデルによる予報が盛んに試みられ、今日では WSA-ENLIL（Pizzo et al. 2011）や EUHFORIA(Pomoell & Poedts, 2018)、SUSANOO-CME（Shiota & Kataoka, 2016）などの宇宙天気予報モデルが開発・運用されている。これらのモデルでは注入する CME の初期パラメータにより ToA が敏感に変化することが知られ、これまでいくつかのモデルで特に重要な CME パラメータが調査されてきた (e.g. May et al., 2015; Riley et al., 2018, 2021)。SUSANOO-CME においても、CME パラメータの ToA への寄与を定量的に見積もることはより正確な予報モデルを実現するために重要である。しかし、SUSANOO-CME のような実際の ICME で観測されるようなフラックスロープ構造を含んだモデルでは、その追加変数がさらなる ToA 不定性の原因となることが示唆されている（Riley et al., 2021）。また、SUSANOO-CME のパラメータのなかには、磁束量のように観測が困難ゆえに、重要でありながらその初期値の仮定が妥当であるか十分に確かめられていないパラメータも存在する。近年では、太陽観測から CME に伴うコロナの EUV 減光領域と、その足元に含まれる光球面磁束との相関（Dissauer et al., 2019）や、フレアサイトでのリコネクションフラックスが CME に含まれる磁束の下限を示唆する報告（Temmer et al., 2017）がなされている。これらに基づき、初期の CME に含まれる磁束量を仮定することで入力する磁束パラメータ範囲に制限を与えられる可能性がある。

そこで、本研究では SUSANOO-CME の磁束量をはじめとした CME パラメータの ToA への寄与を定量的に評価し、さらに太陽観測データや名古屋大学 ISEE の IPS の観測データと比較することでパラメータに制限を与えることを目指す。

2022 年 3 月 28 日に発生した M1.0 フレアに伴う CME に 5 つの異なる初速度（600, 700, 800, 900, 1000 km/s）と 2 つの磁束（2×10^{21} Mx, 3×10^{21} Mx）を与え、計 10 個の CME の伝播をシミュレートした予備的な解析では、初速度による ToA 差が最大で 4 -5h 程度であったのに対し、磁束が異なる CME ではすべての初速度で ToA がおよそ 6 h 変化することが認められた。しかし、入力する磁束を〜10^{20}Mx にすると ToA 差が小さくなるなど、ToA 変動が磁束のオーダーによって有意に変化することが知られるため、ToA の磁束パラメータ特性をさらに広いパラメータ範囲で詳細に調査する必要がある。また、この解析では CME 構造が背景太陽風と相互作用することで地球位置でのショック到達が完全に再現されないなど、本研究に適さない条件が含まれた。実際の予報の観点ではこの相互作用は重要であるが、ToA のパラメータ感度に重点を置いた本研究では、条件の単純化のために背景太陽風を一様化するなどによりこれらの影響を取り除く予定である。

R007-05
C 会場 ：9/25　AM1 （9:00-10:30）
10:00〜10:15

#渡部　温 [1)], 徳丸　宗利 [1)], 岩井　一正 [1)], 藤木　謙一 [1)]
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Optimization of the DCHB Model by using IPS and EUV Coronal Hole Observations

#Haruto Watanabe[1)],Munetoshi Tokumaru[1)],Kazumasa Iwai[1)],Kenichi Fujiki[1)]
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The sources of the solar wind and its acceleration mechanism are not yet fully understood. Several models have been proposed to empirically link the topology of the solar coronal magnetic field to the solar wind velocity. The WS (Wang-Sheeley) model is based on the empirical relation between the solar wind speeds and the expansion rate of the coronal magnetic field. According to the WS model, the solar winds with lower speeds flow out from regions of the coronal magnetic field where the magnetic field expansion rate is larger. The WSA (Wang-Sheeley-Arge) model, which is an evolution of the WS model, has been employed for space weather forecast at NOAA. However, previous studies have shown that the empirical relation between the solar wind speed and the expansion rate doesn't fit in regions with pseudo-streamers, and thus the WSA model gives incorrect predictions there. The DCHB (Distance from Coronal Hole Boundary) model is another model to reproduce the solar wind speed from the coronal magnetic field properties. This model assumes that the solar wind speed is smaller as the source is closer to the boundary of the coronal hole. This model fits in pseudo-streamers; therefore, it is thought to provide a more accurate prediction of solar wind speed than that of the WSA model.

In this study, the parameters of the DHCB model were optimized for the data of solar wind velocity from IPS observations and examined how well the DCHB model reproduces the solar wind velocity. We calculated PCC (Pearson Correlation Coefficient) between the solar wind speeds reproduced by DCHB model and those obtained from the IPS tomographic analysis, and we determined the parameters which maximize the PCC as the optimal parameters. Unlike in-situ observations, IPS observations enable to determine the global distribution of the solar wind speed. Therefore, the DCHB model could be validated more effectively by using IPS observations.

In this analysis, we also used the PFSS (Potential Field Source Surface) model to estimate the structure of the coronal magnetic field and magnetograms from ADAPT (Air Force Data Assimilative Photospheric Flux Transport) as its lower boundary condition. Although the altitudes of the upper and lower boundaries of the PFSS model had been fixed in our previous studies, those altitudes were optimized in each CR so that the coronal hole (CH) shape estimated by the PFSS calculation best matches the EUV observations. Then, we evaluated the solar wind speeds by DCHB rigorously and compared with those obtained from the IPS tomographic analysis.

In consequence, during the solar minimum, the PCC was as high as 0.81. This high correlation is mostly attributed to the excellent reproduction of the bi-modal structure of the solar wind at solar minimum by the DCHB model: it is known that the high- and low-speed winds dominate at high and low latitudes, respectively, at solar minimum. It is also known that, at solar maximum, the high-speed wind almost disappears, and the low-speed wind dominates all latitudes. We found that the DCHB model reproduces the distribution of the low-speed solar wind originating from smaller coronal holes at low latitudes, even during such a maximum period.

R007-06
C 会場 ：9/25　AM2 （10:45-12:30）
10:45〜11:00

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Relationship between coarse-graining scales and Markovian characteristics in the solar wind magnetic fluctuation

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It is known that magnetic fluctuation observed in the solar wind has turbulent spectra [e.g., Bruno+Carbone, 2013; Verscharen et al, 2019]. Since power-law like spectra are usually observed not only at magnetohydrodynamic (MHD) scale but also at ion/electron scales, coarse-graining scales to carry out the scale-separation are not trivial. Recently, the author proposed a method to give a coarse-graining scale in MHD turbulence by using the sub-grid-scale (SGS) model [SGEPSS fall meeting, R007-10, 2019]. In this presentation, we discuss the relationship between coarse-graining scales evaluated by the SGS model and Markovian characteristics of the solar wind magnetic fluctuations, which have been evaluated by using data of several spacecrafts [Sturumik+Macek, NPG, 2008; PRE, 2008; Benella et al, ApJL, 2022; Macek et al, ApJ, 2023]. A Monte-Carlo significance test of the resultant coarse-graining scale is carried out by using the surrogate date method. Physical meaning of an ”ergodic feature” evaluated by the SGS model will be discussed from the point of view of the Markovian characteristics of magnetic fluctuations.

R007-07
C 会場 ：9/25　AM2 （10:45-12:30）
11:00～11:15

#小原　隆博 [1)], 吉川　顕正 [2)]
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Multi-spacecraft observations of widespread solar proton transport in the heliosphere

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We present multi-spacecraft observations of widespread solar energetic protons and discuss on the proton acceleration and transport in the wide spread events.

Based on the list prepared by Dr. Seiji Yashiro for the past PSTEP-SEP-CDAW2 workshop in 2019;

https://sites.google.com/view/pstep-sep-cdaw2/home, we have conducted statistical study with respect to the onset time delay of the solar proton after the solar flare upon the heliographic position of source flares (see Figure) and found following signature; i.e.

1. Delay time seems shorter for the western source cases than that for eastern source cases. The shortest delay time was 15 min. and the location of source flare was 100 deg. west in this case.
2. All of these solar proton events associated CMEs, and the speed of the ejected CME exceeds 900 km/sec for all cases.

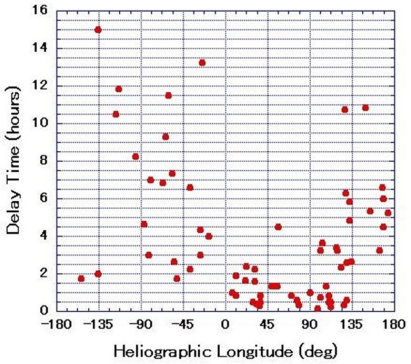
By using multi-spacecraft observation data listed above URL, we have examined the deference of onset times at each spacecraft in detail and found following signature; i.e.

1. Heliographic source of the solar proton distributes in a wide range from -180 degrees to 180 degrees with respect to the central meridian longitude.
2. In some cases, onset times of the arrived solar protons at each spacecraft were quite similar even though the locations of the spacecraft were quite far.
3. Closer inspection revealed that the solar flare occurred around the heliospheric current sheet.

When the energetic solar protons are emitted into the heliospheric neutral sheet structure, these solar protons easily spread widely, resulting in the widespread solar energetic protons.

Figure:

The dependence of the time-delay of the solar proton arrival after the solar flare upon the heliographic position of source flares (from the data in https://sites.google.com/view/pstep-sep-cdaw2/home).



R007-08
C 会場 ：9/25　AM2 （10:45-12:30）
11:15〜11:30

銀河宇宙線の輸送における太陽圏境界の影響および波動によるピッチ角散乱の効果

#吉田　光太郎 [1)], 松清　修一 [1,2)], 鷲見　治一 [2)], 大塚　史子 [1)], 羽田　亨 [2)]
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Effects of the heliospheric boundary and pitch angle scattering by waves on the transport of galactic cosmic rays

#Kotaro Yoshida[1)],Shuichi Matsukiyo[1,2)],Haruichi Washimi[2)],Fumiko Otsuka[1)],Tohru Hada[2)]
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Galactic cosmic rays (GCRs) coming from interstellar space, propagate deep inside the heliosphere and reach the Earth. Their behaviors are very complicated because of solar modulation. Our study aims to understand how the GCRs enter and reach deep inside the heliosphere at the level of particle trajectory and to clarify the role of the heliospheric structure contributing to solar modulation.

We conduct test particle simulations using the electromagnetic field data of the steady heliosphere reproduced by a global MHD simulation. We analyze particle orbits and statistics of GCRs with Lorentz factor γ from 10 (〜10GeV) to 1000 (〜1TeV) that reached the inner boundary at 50 AU. We reported previously that GCRs with γ=10 enter from anywhere in the heliosphere and are more likely to reach high latitude region on the inner boundary, while GCRs with γ=1000 enter the heliosphere from the heliotail and are more likely to reach the inner boundary of low latitude region. In this study, we conducted test particle simulations, increasing the number of particles from 3 million to 10 billion, to gain a comprehensive understanding of the statistical behavior of particles reaching the inner boundary by examining the characteristics of their particle trajectories. Additionally, we plan to report the results of test particle calculations that incorporate the effects of pitch-angle scattering due to waves in the heliosphere.

銀河宇宙線は太陽変調により極めて複雑な運動を経験して地球に飛来する。本研究の目的は、銀河宇宙線が太陽圏へどのように侵入し地球までやってくるのか粒子軌道レベルで理解し、太陽変調における太陽圏構造の役割を明らかにすることである。グローバル MHD 計算で再現された定常太陽圏の電磁場データを用いて、ローレンツ因子 γ=10（〜10GeV）〜1000（〜1TeV）の銀河宇宙線を模したテスト粒子の挙動を調査し、MHD 計算の内側境界 50AU に到達した粒子について解析を行っている。これまでの研究では、γ=10 の粒子が太陽圏のどこからでも侵入し内側境界の高緯度帯に到達すること、γ=1000 の粒子が太陽圏尾部から侵入しやすく内側境界の低緯度帯に到達しやすいことなどが明らかになった。本研究では、粒子数を（300 万個から 100 億個に）大幅に増やした大規模テスト粒子計算を行い、内側境界に到達する粒子の統計的ふるまいをその粒子軌道の特徴にまで踏み込んで理解する。さらに太陽圏内での波動によるピッチ角散乱の効果を考慮したテスト粒子計算の結果についても報告する予定である。

R007-09
C 会場 ：9/25　AM2 （10:45-12:30）
11:30〜11:45

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Numerical study of evaluating the polytropic index in the heliosheath

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The pickup ions (PUIs) generated from the charge exchange between interstellar neutral particles and solar wind plasma are estimated to constitute about 25% of the total plasma and contribute to the majority of the energy density in the heliosheath. Therefore, quantitative verification of the contribution of PUIs is necessary to elucidate the thermodynamic characteristics resulting from the interaction between the solar wind and the interstellar plasma. Accurate evaluation of the polytropic index is particularly significant as it characterizes the energy transport during solar wind propagation. Previous analysis of observational data suggests that the polytropic index is subadiabatic ($<5/3$) within the termination shock, whereas >2 inside the heliosheath. It must be due to the plasma heating by the dissipation of waves generated by PUIs and through the termination shock. We have previously demonstrated through numerical simulations that the energy distribution in the plasma within the heliosheath varies according to the PUI density. In this study, we further advance these analytical results to identify the relationship between the PUI density and the polytropic index. It aims to deepen our understanding of energy transport characteristics between plasmas within the heliosheath.

R007-10
C 会場 ：9/25　AM2 （10:45-12:30）
11:45〜12:00

#大塚　史子 [1)], 松清　修一 [1)], 岡　光夫 [2)]
([1] 九大・総理工,[(2] カリフォルニア大学バークレー校

Electron acceleration at quasi-perpendicular shocks above and below the whistler critical Mach numbers

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([1]IGSES, Kyushu University,[(2]UC Berkeley

Non-thermal electrons with power-law energy spectra are directly observed at the quasi-perpendicular Earth's bow shock. Analysis of Geotail data at the Earth's bow shock showed hard spectra of electrons in the supercritical regime, where the upstream Alfven Mach number, M_A, is above the so-called whistler critical Mach number (Oka et al., 2006). However, the underlying mechanism of the power-law formation remains unclear in the supercritical and subcritical regimes. In this study, we performed several runs of 1D particle-in-cell simulations of quasi-perpendicular shocks with shock angles ranging from 65 to 85 degrees and M_A from 3 to 8. The upstream plasma beta is 0.3 and ion to electron mass ratio is 625. In the subcritical regime, the simulations showed that high-energy electron can penetrate upstream. This behavior is correlated with the presence of whistler wave trains emitted towards the upstream region. On the other hand, in the supercritical regime, the high-energy electrons are generated locally in the narrow region of the overshoot magnetic field. The electrons are accelerated via Landau resonance with the electrostatic field of the phase-standing whistler wave embedded in the overshoot magnetic field. We will compare the statistics of electrons, such as energy spectra, spatial and pitch-angle distributions of high-energy electrons, between the supercritical and subcritical regimes. Furthermore, we will discuss the electron acceleration mechanisms, by analyzing the trajectories of highly accelerated electrons in both regimes.

R007-P01
ポスター 1 ：9/24　PM1/PM2 （13:45-18:15）

Grad-Shafranov 方程式による太陽風磁気ロープ再構築方式に関わる問題

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Resolving a problem in the analysis of flux ropes based on Grad-Shafranov equation

#Katsuhide Marubashi[1)],Daikou Shiota[2)],Yuki Kubo[3)],Hiroshi Hasegawa[4)],Munetoshi Tokumaru[5)]
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The reconstruction method based on Grad-Shafranov equation is widely utilized in analyzing the structures of interplanetary magnetic flux ropes. This method is valid only under the two conditions: (1) that the flux ropes are essentially of 2-dimensional structure, and (2) that the observed magnetic field variations are due to spatial structure with no temporal variations involved. Actually, however, many flux ropes are expanding along their propagation from the Sun, that is, they must be taken as the time-varying structures.

Though this problem has been studied by Hasegawa et al. (JGR, 2014), the method has not been applied to sufficient number of the observed flux ropes. We developed a method to derive the spatial change along the spacecraft orbit for the flux rope expanding in a self-similar fashion, for which it is valid to apply the Grad-Shafranov (GS) method (SGEPSS, 2022; JpGU, 2023). The present study is aimed at making clear the problem in the traditional GS method and the merit of the new GS method. For easy comparison between the two methods, we analyze the theoretically calculated magnetic field variations associated with the flux ropes with various expansion rates by the two methods and examine the results from the two methods. So far, we have found the following:

(1) Two methods yield different results for the direction of the flux rope axis, with larger difference as the strength of the expansion.

(2) The Grad-Shafranov (GS) equation gradually lose the validness as the expansion effect becomes stronger.

(3) For even stronger expansion effects, the conditions for the GS equation collapses.

Though at the present stage, we don't analyze the observed flux ropes sufficiently, the above results suggest that we may need careful examination about the analysis results based on the traditional GS method.

太陽風磁気ロープの内部構造を Grad-Shafranov 方程式から決定する方法（ここでは GS 法と呼ぶ）が広く使われている。この方法が成立するためには、磁気ロープが 2 次元的な構造であり、内部を通過する衛星が観測する磁場変化が空間構造を表している（構造は時間変化を含まない）という 2 条件が必要である。実際は、磁気ロープは膨張していることが多く、時間的に変化する構造と考えなければならない。この問題に対処する理論が考案されているが（Hasegawa et al., JGR, 2014）十分な成果をあげていない。我々は、観測データから膨張の効果をとり除いた上で GS 法を適用する方法を考案し、SGEPSS － 2022 秋、JpGU-2023 で、その有効性を示すことができた。今回は、新方式 GS 法の有用性と、従来方式の GS 法の問題点を考察するために、理論モデルから計算される太陽風磁場の疑似観測データをいろいろに選びながら、２つの方式が与える違いを解析した。これまでに明らかになったことを簡単に書くと、

（１）膨張の効果が強くなるに従って、求められる磁気ロープ軸の方向に差が現れてくる。

（２）膨張の効果が強くなるに従って、Grad-Shafranov 方程式の根拠が失われてくる。

（３）さらに膨張率が大きくなると、従来方式の GS 法では計算が破綻してしまう。

現在はまだ、磁気ロープの観測例の解析には至っていないが、上記の結果は従来方式の GS 法による解析結果については一定程度の吟味が必要になることを示唆している。

R007-P02
ポスター 1 ：9/24　PM1/PM2 （13:45-18:15）

FPGA を用いた太陽観測用電波望遠鏡の開発

#竹原　大智 [1)], 岩井　一正 [1)], 野澤　恵 [2)]
[(1] 名古屋大学　宇宙地球環境研究所,[(2] 茨城大学理工学研究科（理学野） 地球環境科学領域

Development of a Radio Telescope for Solar Observation Using FPGA

#Daichi TAKEHARA[1)],Kazumasa Iwai[1)],Satoshi NOZAWA[2)]
[(1]Nagoya University ISEE,[(2]Ibaraki University Department of Science (Earth Sciences Course)

Flares and coronal mass ejections (CMEs) are the main causes of space weather phenomena. They often emit solar radio bursts that are observed by radio spectroscopic observations in the metric wave band using radio telescopes, and a variety of complex frequency spectral structures are observed at the time of their occurrence. Using observations in the meter wave band, radio telescopes are essential for space weather forecasting, as they can determine the height of the emission region of a burst based on atmospheric models and can estimate the propagation speed of the radiating region based on time variations in frequency. In addition, radio telescopes are useful for studying plasma waves because radio bursts which are associated with various modes of wave phenomena can be observed in the metric waveband even if there is no flare.

We are developing a radio telescope for solar observation that can be easily constructed and operated, with the aim of improving the accuracy of space weather forecasting and contributing to radio astronomy. This telescope is used for spectroscopic observation in the metric waveband.

The details of the telescope under development are as follows: the antenna is a Yagi-Uda antenna, the receiver is a superheterodyne system, the spectrometer is a 1024-point FFT using FPGA, automatic tracking is possible by motor control based on orbit calculation, and the altazimuth is designed using 3DCAD and printed by a 3D printer. The entire telescope is controlled by a Raspberry Pi. The bandwidth of the receiver and the time resolution of the spectrometer are designed so that a typical Type III burst can be detected. However, we found that the quiet Sun cannot be detected as a single antenna and it is necessary to make an array in order to implement it for scientific solar observation. On the other hand, this telescope can be used as a teaching tool for radio astronomy. In this presentation, the progress of the development will be presented.

宇宙天気現象の主な原因として、フレアやコロナ質量放出 (CME) などがあげられる。これらの現象は電波バーストを放射することが知られ、フレアは電波望遠鏡を用いたメートル波帯での電波分光観測によって、その発生時に多彩で複雑な周波数スペクトル構造が観測される。メートル波帯での観測結果を用いることにより、大気モデルと密度の関係からバーストの放射領域の高さを決定したり、周波数の時間変化から放射領域の伝搬速度を推定できたりと、電波望遠鏡は宇宙天気予報にとって必要不可欠な望遠鏡である。さらに、メートル波帯ではフレアがない場合でも、様々なモードの波動現象に関連する電波バーストが観測されるため、電波望遠鏡はプラズマ波動の研究にも役立つ。

本研究では宇宙天気予報の精度向上ひいては電波天文学への貢献を目指し、誰でも簡単に構築と運用ができる太陽観測用電波望遠鏡の開発を行っている。観測内容はメートル波帯での分光観測である。

開発中の望遠鏡の詳細について、アンテナは八木-宇田アンテナ、受信機はスーパーヘテロダイン方式、分光計は FPGA による 1024 点 FFT、自動追尾は軌道計算によるモータ制御で行い、経緯台は 3DCAD で設計したものを 3D プリンタで印刷する。望遠鏡全体の制御は Raspberry Pi を用いている。受信機の帯域幅と分光計の時間分解能は典型的な III 型バーストが検出できるように設計している。しかし、現状として受信テストの段階で単一鏡としては静音時の太陽が受からないことがわかっており、科学研究を対象とした太陽観測用として実装するためにはアレイ化を行う必要がある。そこで、現段階では電波天文学の教材として利用可能な性能の望遠鏡を目指している。本講演では開発の進捗状況について発表する。