

Electron acceleration at high beta low Mach number collisionless shock

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Voyager spacecraft revealed that the solar wind termination shock is a rather weak shock since the upstream plasma beta is high and effective Mach number of the shock is low due to the presence of pickup ions. Nevertheless, the fluxes of non-thermal electrons and ions (the latter are called as termination shock particles) are enhanced when crossing the termination shock. Electron acceleration at a weak shock is also reported in terms of galaxy cluster merger shocks. In this study we perform two-dimensional full particle-in-cell simulation to discuss microstructure of the high beta and low Mach number shock and the associated electron acceleration. Unlike a one-dimensional simulation, electrons are not reflected at the shock when a shock angle is close to 90 deg. due to the effect of rippling. Nevertheless, some electrons are accelerated locally at the transition region. Wave-particle interactions appear to play a role.

Keywords: collisionless shock, numerical simulation, particle acceleration

Acceleration of pickup H^+ , He^+ , and O^+ in the corotating interaction regions

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Pickup ions (PUIs), interstellar neutral particles ionized mainly by the charge exchange with solar wind plasmas, are considered to be the dominant source of anomalous cosmic rays (ACRs). Recent studies suggest that the heliospheric termination shock alone is not capable of accelerating primary PUIs up to the ACR energy range, an order of MeV. Among other mechanisms responsible for the PUI acceleration, we focus on the preacceleration process inside the heliosphere before the encounter with the termination shock. Corotating interaction regions (CIRs) are one of such a particle accelerator because their boundaries form the (forward and reverse) shocks. We perform two-dimensional hybrid simulations to investigate the PUI dynamics in association with CIRs. We have already shown that the hydrogen PUIs can gain energy over 250 keV. A periodic boundary in the present CIR model allows the successive CIRs, where the diffusive shock acceleration for PUIs can be attained between them. In the present study, we will pay additional attention to the behavior of other PUI species, helium and oxygen, which are also main ACR components. Detailed processes as well as efficiency of their acceleration are compared with those of hydrogen case. We will further unify the composite acceleration process during the CIR propagation.

Strahl formation in the solar wind electrons: Particle-in-cell simulation

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The present study puts forth a possible explanation for the outstanding problem of the *strahl* formation in the solar wind electrons. Making use of the fact that in the collisionless limit the electron core-halo relative drift exists in the direction away from the Sun in such a way that the halo usually flow faster than the core, the present study carries out one-dimensional particle-in-cell simulation of whistler instability, assuming anisotropic core and drifting isotropic halo. The enhanced whistler waves driven by anisotropic core lead to the pitch angle scattering of drifting halo in an asymmetric way since the number of the drifting halo participating in the resonant interaction is different between the halos moving the sunward and anti-sunward directions. In this way, pitch angle scattering of the anti-sunward moving halo by the whistler waves propagating sunward is more efficient in phase space and leads to the energy transfer from the drift energy to the thermal energy of halo. During the saturation phase of whistler wave-halo particle resonant interaction, the remaining part of the anti-sunward moving halo, which is out of resonance with the whistler waves propagating sunward, turns out to be a field-aligned *strahl* in the electron velocity distribution.

Keywords: non-thermal solar wind electron velocity distributions, the magnetic-field-aligned strahl, whistler instability

Forward cascade of whistler turbulence at ion scales

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Two-dimensional electromagnetic particle-in-cell simulations in magnetized, homogeneous, collisionless electron-ion plasma demonstrate the forward cascade of whistler turbulence at ion scales. Saito et al. (2015, submitted) emphasized that the modified two-stream instability could contribute the dissipation of kinetic turbulence at ion scales, by demonstrating rapid damping of a monochromatic ion-scale whistler wave in two-dimensional particle-in-cell simulation. The instability is driven by the electric current fluctuation perpendicular to the mean magnetic field. Through the development of the instability, electrons and ions are scattered in the directions parallel and perpendicular to the mean magnetic field, respectively. We expect that the forward cascade of whistler turbulence and the dissipation related to the modified two-stream instability contribute plasma heating and have key role of variability of power-law index of magnetic spectrum at ion scale in solar wind. Solar wind observations show that larger cascade rates of turbulence lead to steeper power-law magnetic spectra. The instability driven dissipation could explain property of the magnetic spectra at ion scales. Discussion will focus on properties of whistler turbulence, such as the power-law index, wavenumber anisotropy, electron and ion heating, through the forward cascade of decaying whistler turbulence.

Keywords: kinetic turbulence, plasma heating, wave-particle interaction

Turbulence analysis using Capon's method

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Multi-point measurements can separate temporal and spatial variations. In case of spacecraft experiments, the number of data points in the time domain can be large, but that in the spatial domain is simply the number of spacecraft, and is only a few at most. Since usual data analysis techniques, such as the Fourier decomposition, cannot be applied to such a dataset, more sophisticated techniques such as Capon's method or the maximum entropy method have been developed and successfully used in various applications.

On the other hand, magnetohydrodynamic (MHD) waves in space plasma often have very large amplitude and thus are subject to rapid nonlinear evolution. As a result, we often encounter MHD turbulence rather than a superposition of a few number of MHD waves in space plasma. The Capon's method cannot be applied to such situations, where the number of waves exceeds the number of data points.

Recently, we have developed a method to analyze the turbulence data making use of the Capon's method, even though the number of waves is much larger than the number of data points. In the presentation, we will introduce the method and discuss how it can be applied to analyze the MHD turbulence in the solar wind.

Keywords: MHD turbulence, Capon's method

Kaguya observations of the lunar wake in the terrestrial foreshock

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There forms a tenuous region behind the Moon in the solar wind, as the lunar dayside surface adsorbs most of the incident solar wind plasma. Entry processes of solar wind plasma into this tenuous region, which is called the lunar wake, have been widely studied. In addition to gradual refilling of the wake by the ambient solar wind, it has been known that a portion of solar wind protons that are scattered at the dayside surface or deflected by crustal magnetic fields can enter the wake (i.e. type-2 entry). However, proton entry into the deepest lunar wake (i.e. anti-subsolar region at low altitude) by the type-2 process needs specific solar wind conditions. Here we report, using data from Kaguya spacecraft in orbit around the Moon, that solar wind ions reflected at the terrestrial bow shock easily access the deepest lunar wake, when the Moon is located in the foreshock. When the spacecraft location is magnetically connected to the lunar night-side surface, the kinetic energy of upward-going field-aligned electron beams decreases or electron beams disappear during the reflected-ion events, which shows that the intrusion of the shock-reflected ions and electrons into the wake changes the electrostatic potential of the lunar night-side surface.

Keywords: Solar wind-Moon interaction, Lunar wake, Plasma refilling, Shock-reflected ions, SELENE (Kaguya)

Classification of ULF waves observed by ARTEMIS around the Moon in the solar wind

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Electromagnetic waves in the ULF band have been observed around the Moon in the solar wind by Explorer 35 [Ness, 1969], WIND [Farrell et al., 1996], Geotail [Nakagawa et al., 2003], Lunar Prospector [Halekas et al., 2006, 2008], Kaguya [Nakagawa et al., 2011, 2012; Tsugawa et al., 2011, 2012], and ARTEMIS [Halekas et al., 2013]. It has been suggested that these waves originate from the solar wind interaction with the Moon, e.g., particle reflections by the lunar magnetic anomalies or surface, temperature anisotropies through the surface absorption, or plasma instabilities at the lunar wake boundary. However, it has been difficult to establish the energy sources and the propagation processes of the waves by a single spacecraft observation. Their phase velocities comparable to or smaller than the solar wind velocity also make it difficult to identify the characteristics of the waves because of large Doppler-shift by the solar wind. We investigate the dataset of ARTEMIS which is a two-spacecraft (P1 and P2) complement in order to reveal natures of the ULF waves.

The two probes are orbiting around the Moon in the ecliptic plane at selenocentric distances~1.1-12 lunar radii since July 2011. We analyze the time series of the magnetic field vectors sampled in 4 Hz by the fluxgate magnetometer (FGM) in the fast survey mode. In consequence of comprehensive analyses, we identify four types of ULF waves: 1) broadband electromagnetic noise, 2) 1 Hz whistlers, 3) 30 s waves, and 4) wake front perturbation <0.01 Hz. The electromagnetic noise is caused by currents or drift driven instabilities in the dayside and wake boundary. 1 Hz whistlers also originate from the instabilities but propagate and group-standing in the Moon frame. 30 s waves of terrestrial ion foreshock are frequently observed around the Moon even 60 R_E upstream from the Earth when the interplanetary magnetic field (IMF) connects to the bow shock. 30 s waves are also occasionally generated by the ions reflected from the Moon when IMF is parallel to the solar wind. The wake front perturbation is observed with right-hand and left-hand polarizations at inbound and outbound the wake, respectively. These features suggest that they are phase-standing whistler perturbation outward the wake edge Doppler-shifted by the spacecraft velocity.

Long-term observation of the solar radio emission by the Nobeyama Radio Polarimeters

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Long-term monitoring observation of the Sun provides the basic data for investigating the variation of the solar activity. However, it is very difficult to consistently observe the solar activity, which has about 11 years cycle, because observational instruments and projects usually have limited durations. The Nobeyama Radio Polarimeters (NoRP) are radio telescopes to monitor the total flux of the Sun at the micrometer range. This frequency range is thought to be a good indicator of the solar activity at the upper chromosphere and corona. In this study, we summarize the 64 years of the NoRP observation and give a perspective of its future observation.

The NoRP was constructed at Toyokawa by Nagoya University on 1951 to observe at 3.75 GHz. Then, the observational frequency has been increased at Toyokawa and Nobeyama. The telescopes in Toyokawa were moved to Nobeyama on 1994. Then, the present 7 frequencies observation which contains 1.0, 2.0, 3.75, 9.4, 17, 35, and 80 GHz was started. The time resolution of this system is 0.1s. This high time resolution data are often used for flare studies. In addition, the calibration method has been kept consistently since the beginning of the observation. Hence, the continuous observation over about 6 solar cycles can also be an important data for the study of the solar activity. Daily operations of the NoRP are fully automated, which is suitable for the long-term monitoring observation. All parts used in the NoRP are listed and spare parts are stored for all parts as possible in order to minimizing the loss of the observation due to the mechanical troubles.

F10.7 index, which is a total radio flux of the Sun at 2.8 GHz (wavelength is 10.7cm), is widely used as an indicator of the solar activity. The observation bands of the NoRP cover around the 2.8GHz. The continuous observation of the NoRP will be a useful data to study the variation of the solar activity and its influence to the upper atmosphere of the Earth.

Keywords: Sun, Radio radiation, Long term variation

Average features of interplanetary shocks observed with the Global Muon Detector Network (GMDN)

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It has been well established that the short term decreases of galactic cosmic ray (GCR) isotropic intensity (or GCR density) at the Earth, called 'Forbush decreases' (Fds), are mostly caused by the interplanetary shocks passing the Earth. The GCR spatial distribution which reflects the magnetic structure and geometry of the shock causing Fd can be deduced from the observation of three dimensional GCR anisotropy associated with Fds, because the first order anisotropy arises from the diffusion and drift of GCRs which are proportional to the spatial gradient of GCR density in the Fd.

Deriving the dynamic variation of GCR anisotropy during the Fd observed with a single detector, however, has been difficult because the traditional analyses based on the diurnal variation of GCR intensity provide only the daily mean equatorial anisotropy. The present GMDN consisting of four multi-directional muon detectors in Nagoya (Japan), Hobart (Australia), São Martinho (Brazil) and Kuwait city (Kuwait) started operation in 2006 and successfully observed dynamic variations of GCR anisotropy associated with major Fd events (Okazaki *et al.*, 2008; Kuwabara *et al.*, 2009; Fushishita *et al.*, 2010; Rockenbach *et al.*, 2014).

In this presentation, we analyze the average features of GCR density gradient associated with interplanetary shocks identified by the Storm Sudden Commencement (SSC) onset recorded at the Earth between 2006 and 2014. About 100 SSC events classified into two groups arising from coronal hole and flare are analyzed. From the first order anisotropy corrected for the solar wind convection and Compton-Getting effect arising from Earth's orbital motion around the Sun, we deduce the three dimensional density gradient on hourly basis for each SSC event. We then derive the average temporal variation by superposing variations at the SSC onset timing. We find clear enhancements of radial and latitudinal density gradients after the SSC implying the geometry of low GCR density region in Fds behind the shock front. We also discuss the difference in average features in events caused by shocks arising from coronal holes and flares.

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A. Fushishita *et al.*, *Advances in Geosciences*, eds. W. H. Ip and M. Duldig (World Scientific Publishing Co., USA), **21**, 199-210, 2010.

M. Rockenbach *et al.*, *Space Sci. Rev.*, **182**, 1-18, 2014.

Keywords: density gradient of galactic cosmic rays, Forbush decrease, solar modulation, interplanetary shock, solar flare, coronal hole

The source region of solar wind in the photosphere

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In this paper, we calculate coronal magnetic field expanding to the interplanetary space by the Radial-Field model (devised by Hakamada) with synoptic maps of photospheric magnetic data observed by the NSO/Kitt Peak, USA. We project solar wind speed distribution on the source surface observed by the STE-Lab of Nagoya University to the photosphere along the line of force in the coronal magnetic field. We found the following results; (1) around the maximum phase of solar activity cycle, slow speed solar winds emanate from very narrow string like areas surrounding closed magnetic regions in the photosphere which have extremely high magnetic expansion rate, (2) in the other phases, besides the maximum, high speed winds emanate from high latitudes of less magnetic expansion rate, except near the poles, and slow speed winds emanate from narrow belts of large magnetic expansion rate in low to middle latitudes extending the solar equator.

Keywords: solar wind, photosphere, source region, solar wind speed

Relationship between coronal hole area and solar wind speed

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We report the relationship between coronal hole areas and average solar wind speeds for Carrington rotations (CR) from 1893 to 2108. The coronal hole is known as a region with low X-ray emissivity, and a source of the high speed solar wind. Nolte et al. (1976) investigated the relationship between equatorial coronal holes, which are located within ± 10 degrees of the ecliptic plane, and the maximum solar wind speed using Skylab data. As the result, they reported a linear correlation between the coronal hole area and the maximum wind speed with a slope of $80 \pm 2 \text{ km s}^{-1} (10^{10} \text{ km}^2)^{-1}$. In this study, we identify coronal holes using synoptic magnetic field data of Kitt-Peak National Solar Observatory (KP/NSO) and the potential field source surface (PFSS) model. The speeds of the solar wind from coronal holes are determined from interplanetary scintillation (IPS) observations of STEL which provide global information of the solar wind. Our analysis reveals a linear relationship between the coronal holes area and the average solar wind speed similarly to Nolte et al. (1976), but with a more gentle slope than the earlier study. We also discuss its dependence on the solar activity.

Keywords: solar wind, coronal hole

North-south asymmetry in global distribution of the solar wind speed during Cycles 22-24

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The north-south (N-S) asymmetry in the solar activity is important from viewpoint of the solar dynamo theory, since the axisymmetric magnetic field cannot be maintained by the dynamo action (Cowling, 1933). The N-S asymmetry in the solar activity has been studied from observations for various kinds of solar surface phenomena. However, the heliospheric consequence caused by the N-S asymmetric solar activity is poorly understood owing to shortage of global observations. The N-S asymmetry in the heliosphere is important information to study the propagation of cosmic rays and influence on the space weather. Therefore, we have studied the N-S asymmetry in global distribution of the solar wind speed using interplanetary scintillation (IPS) observations at the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University. IPS observations enable us to investigate global distribution of the solar wind speed on the source surface for a given Carrington rotation. The period analyzed here is between 1985 and 2013 (except for 2010), corresponding to between Cycles 22 and 24. We divided our IPS data into north and south data, and calculated the fractional areas of fast, slow and intermediate speed winds for those two groups. As result, we find that significant N-S difference in fast and slow wind distributions over the poles exist particularly at solar maxima. This asymmetry results from earlier occurrence of disappearance/reformation of fast winds at the north pole than that at the south pole, and it is closely linked with the time lag of the polarity reversal at both poles. Furthermore, enhanced N-S asymmetry of polar fast wind is also found between Cycle 23 declining phase and 24 maximum. We compared our IPS data with g_{20}/g_{10} , where g_{20} and g_{10} are quadrupole and dipole components of harmonic coefficients derived from the potential field analysis of magnetograph observations at Wilcox Solar Observatory. As result, a weak but significant correlation are found between those quantities, and this fact suggests that higher-order magnetic moments such as quadrupole make an important contribution to the N-S asymmetry in global distribution of the solar wind speed.

Keywords: solar wind, interplanetary scintillation, solar cycle, Sun's magnetic field, heliosphere, space weather

Polarization characteristics of zebra pattern in type IV solar radio bursts observed with AMATERAS

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Type IV bursts are broadband continuum emission observed in metric to decimetric wavelength range that emanate from closed magnetic structures. They often show various spectral fine structures therein. Since most of them are considered to be generated by micro scale physical processes of plasma waves and energetic particles, their spectral characteristics reflect plasma condition of the source regions in the solar corona. In particular, zebra pattern (ZP) has a characteristic spectral pattern with a number of nearly parallel drifting narrowband stripes. Such characteristics of ZP can be used as a tool of the coronal plasma diagnostics, thus the comprehension of ZP has significant meaning for the solar physics. However, generation processes of ZP have been still discussed in spite of a large number of observational and theoretical studies. The purpose of this study is to investigate generation and propagation processes of ZP by evaluating scenarios suggested in previous studies (Zlotnik et al., 2014).

We analyzed an event appeared on June 21, 2011 around 200MHz, in particular on polarization characteristics and their frequency dependences using highly resolved spectra and polarization data obtained from AMATERAS, a solar radio spectropolarimeter developed by Tohoku University. The main observed polarization characteristics are, 1) the ZP emission accommodated right-handed and left-handed polarized components and the degree of circular polarization was about 50-70% in right-handed with almost no frequency dependence. 2) The frequency of right-handed and left-handed polarized components showed a slight difference by tens of kHz and it varied depending on the emission frequency. 3) The left-handed polarized component showed time delay by about 60ms and the delay slightly increased with frequency. In the case of assuming the DPR (Double Plasma Resonance) model as the original generation process of the ZP, the most plausible interpretations for these characteristics are as follows; the emission was generated in O-mode in completely polarized state at the source region and it was partly converted into X-mode near the source due to the scattering by low frequency waves such as ion sound waves or whistler mode waves, which yields the frequency shift, and then difference in group velocities between O-mode and X-mode causes the temporal delay.

Keywords: Solar radio, Zebra pattern, Polarization, AMATERAS

Statistical analysis of spectral fine structures in solar radio type II bursts observed with AMATERAS

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Type II bursts are one of the solar radio bursts associated with flare and coronal mass ejections (CMEs). They are thought to be a plasma emission from non-thermal electrons accelerated by a shock wave. A type II burst appeared as a group of spectral fine structures whose typical duration is within one second is reported recently [e.g. Sato et al., the 26th JpGU meeting]. Such spectral fine structures can be interpreted as the motion of non-thermal electron beams accelerated in the shock region. The spectral fine structures are, therefore, thought to reflect electron acceleration processes by the shock.

In this study, we performed a statistical analysis to investigate generality of spectral fine structures of type II bursts to reveal their generation processes by using the meter wave band solar radio telescope AMATERAS developed by Tohoku University [Iwai et al., 2012]. AMATERAS enables us to observe solar radio bursts in the frequency range between 150 and 500 MHz with the 10 msec accumulation time and 61 kHz bandwidth. Many solar radio bursts have been observed by this system since its construction in 2010.

We identified occurrence of nine type II bursts from the AMATERAS database. Some of them showed fundamental-harmonic band structures and some of them showed band-splitting structures. In addition, it is notable that all of them were accompanied by spectral fine structures. This result implies a possibility that the spectral fine structures are general characteristic of type II bursts. We analyzed drift rates for the spectral fine structures of three events from them. As the result, some of the drift rates indicated more than 100MHz/s. By assuming a general coronal plasma density model, for example the Newkirk model [Newkirk, 1961], the particle speed for the drift rate is estimated to be unrealistic value. The result is similar to the past study [Sato et al., the 26th JpGU meeting] and implies the existence of peculiar plasma structure in the source region of the burst, while the wave generation and particle acceleration processes for the fine structures have not been understood. In this presentation, we will show precise characteristics of drift rates for the spectral fine structures in several type II bursts and also discuss inferred generation processes.

Keywords: corona, particle acceleration, radio burst, spectral fine structures, AMATERAS

Preliminary results of a new solar radio wave observing system in the HF to VHF band

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Tohoku University has developed a new radio receiving system in the HF to VHF band in the Zao observation station. This system enables us to investigate fundamental plasma processes of particle acceleration, heating and plasma environment with the existing solar radio telescope IPRT/AMATERAS in the radial distance of about 1.1Rs - 4Rs from the photosphere. Furthermore, it also potentially contributes to disaster science/space weather research by enabling to obtain early information on occurrence of solar energetic particle events. The new system will consist of wide-band antenna array and high resolution spectro-polarimeter. In the last autumn the first set of antennas was constructed and tentative observations were started with low time and frequency resolutions. Although it is a minimum configuration, some wide-band solar radio bursts have been detected. In the presentation, we will introduce the new radio observing system and also show preliminary results of observed radio bursts.

Keywords: solar, radio, telescope, HF, VHF

On the intensity of the 3-10 Hz magnetic fluctuations observed by Kaguya near the moon

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Possible relationship were examined between the power of the non-monochromatic fluctuations of the magnetic field over the frequency range of 3 - 10 Hz observed by Kaguya at an altitude of 100 km above the lunar surface and the speed of the incident solar wind observed by ACE, but none was found. Instead, control by magnetic connection between the spacecraft and the lunar surface was found. Intense wave activity was observed during the magnetic connection to the magnetic anomaly. The wave activity disappeared when the spacecraft was magnetically disconnected from the lunar surface, even when the detection of protons reflected by the moon persisted. It suggests that the wave was generated below the spacecraft altitude.

Helium distribution in interplanetary space by Hisaki satellite

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The HISAKI (SPRINT-A) satellite has a unique characteristics of the long term planet observation, such as Venus and Jupiter. The interval of planet observational terms, HISAKI has detected the emission from interplanetary space. In this presentation the HISAKI observation of interplanetary emission is shown and its potential on the interplanetary issue is argued.

Keywords: Interplanetary helium, EUV observation

Model simulations of ionizations at the planetary atmosphere induced by energetic particles from a central star

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We are performing monitoring observations of millimeter-waveband spectral lines of carbon monoxide (CO) in the middle atmospheres of Mars and Venus with a 10-m telescope, Solar Planetary Atmosphere Research Telescope (SPART), to understand how the activities of central stars influence the middle and lower atmospheres of terrestrial planets in the solar system and of exoplanets.

For understanding the electron production rate at different altitudes of the planetary middle atmosphere induced by incident energetic particles from planets, we developed an analytical model, using which ionization losses are numerically calculated on the basis of the Bethe-Bloch formula. The ionization of carbon dioxide induced by the energetic particles is considered to increase the production rate of CO. With a basic model under conditions of relatively great solar proton events with incident-proton energies of less than 1 GeV, it was found that the ionization rate reaches its maximum at an altitude of 80-90 km in the Venusian atmosphere and at the ground in the Martian atmosphere. In addition, we also developed a Monte-Carlo simulation model using the Particle and Heavy Ion Transport code System (PHITS). With this model, highly accurate calculation can be achieved by implementing the latest nuclear-reaction database and algorithms for the transport processes including several particles such as electrons, positrons, pions, neutrons, muons, kaons, and photons, in addition to protons, neutrons, and photons. We found that the results of this Monte-Carlo model are in good agreement with those of the above analytical model. The calculated results also suggest that the effect of neutrons produced on the ionization processes is greater than that of protons produced at a low altitude in Venus (<80-km altitude).

In this conference, we will present the results of these models.

Keywords: terrestrial planet, planetary atmosphere, flare and CME, high-energy particle, heterodyne spectroscopy, radio telescope