Propagation characteristics of whistler mode chorus waves deduced from the first-year observations by the Arase satellite

Satoshi Kurita[1]; Yoshizumi Miyoshi[1]; Yoshiya Kasahara[2]; Shoya Matsuda[3]; Ayako Matsuoka[4]; Iku Shinohara[5]
[1] ISEE, Nagoya Univ.; [2] Kanazawa Univ.; [3] ISAS/JAXA; [4] ISAS/JAXA; [5] ISAS/JAXA

Whistler-mode chorus is electromagnetic waves in nature observed in the frequency range from 0.1 to 0.8 times of electron gyrofrequency, fce, and they frequently appear in the dawn and noon side magnetosphere. Chorus waves often have a gap of wave power at 0.5 fce, and the waves below and above 0.5 fce are called lower-band (LBC) and upper-band chorus (UBC), respectively. These waves have been considered as the primary driver of the electron dynamics in the inner magnetosphere since they can resonate with electrons in the wide energy range and cause the acceleration and loss of the electrons. Characteristics of the waves such as the wave normal angle, wave power, and their latitudinal distributions are of interest since these parameters strongly control the time scale for acceleration and loss of electrons. The characteristics of LBC was investigated by using the 11 year Cluster measurements [Santolik et al., 2014], while those of UBC has not been well clarified yet. In this study, we investigate characteristics of both LBC and UBC observed by the Arase satellite using the data processed by Onboard Frequency Analyzer (OFA), which is one of the receivers of the Plasma Wave Experiment (PWE). OFA computes power spectral density of wave electric and magnetic fields in the frequency range from 64 Hz to 20 kHz, and spectral matrices of the electric and magnetic fields are also provided. Applying the singular value decomposition technique [Santolik et al., 2003] to the magnetic spectral matrix computed by OFA, we derive occurrence frequency distributions of wave normal angle and wave magnetic field power as a function of magnetic latitudes. The parameters of LBC and UBC are separately analyzed, and we also classify the magnetic local time of the wave observations into dayside and night side. In the presentation, we will show the latitudinal distributions of wave normal angle of LBC and UBC and discuss the different propagation characteristics between LBC and UBC. We also represent latitudinal wave magnetic field power distributions to discuss the propagation effect on the wave power, that is, convective growth and damping of LBC and UBC. We will also discuss the day/night difference of the parameters between LBC and UBC.

Instantaneous frequency analysis on nonlinear EMIC emissions: Arase observation

Masafumi Shoji[1]; Yoshizumi Miyoshi[1]; Yoshiharu Omura[2]; Lynn M. Kistler[3]; Yasumasa Kasaba[4]; Shoya Matsuda[5]; Yoshiya Kasahara[6]; Ayako Matsuoka[7]; Reiko Nomura[8]; Keigo Ishisaka[9]; Atsushi Kumamoto[10]; Fuminori Tsuchiya[11]; Satoshi Yagitani[6]; Mariko Teramoto[12]; Kazushi Asamura[13]; Takeshi Takashima[14]; Iku Shinohara[15]
[1] ISEE, Nagoya Univ.; [2] RISH, Kyoto Univ.; [3] ISEOS, University of New Hampshire; [4] Tohoku Univ.; [5] ISAS/JAXA; [6] Kanazawa Univ.; [7] ISAS/JAXA; [8] JAXA; [9] Toyama Pref. Univ.; [10] Dept. Geophys, Tohoku Univ.; [11] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [12] ISEE, Nagoya University; [13] ISAS/JAXA; [14] ISAS, JAXA; [15] ISAS/JAXA

In the inner magnetosphere, the Arase spacecraft has observed nonlinear electromagnetic ion cyclotron (EMIC) emissions with both rising and falling frequencies. The instantaneous frequency analyses on the electromagnetic fields of the EMIC rising tone emission have been performed by the Hilbert-Huang transform. The time variation of the instantaneous frequency shows a good agreement with the nonlinear theory for the frequency evolutions. Rapid instantaneous frequency modulation is also found during the rising tone emission. We estimate the peak-to-peak time of the fluctuation in the frequency, and find that the fluctuation is caused around a half of the particle trapping time. Considering the motion of the phase-bunched particle around the resonant velocity, it is expected that the nonlinear resonant current which induces the falling frequency is formed in the half of the trapping time.

あらせ(ERG)で観測されたヘクトメータ線スペクトル

橋本 弘藏 [1]; 熊本 篤志 [2]; 土屋 史紀 [3]; 笠原 禎也 [4]; 長野 勇 [4]; 松岡 彩子 [5]
[1] 京都大学; [2] 東北大・理・地球物理; [3] 東北大・理・惑星プラズマ大気; [4] 金沢大; [5] JAXA 宇宙研

Hectometric Line Spectra found by the Arase (ERG) satellite

Kozo Hashimoto[1]; Atsushi Kumamoto[2]; Fuminori Tsuchiya[3]; Yoshiya Kasahara[4]; Isamu Nagano[4]; Ayako Matsuoka[5]
[1] Kyoto Univ.; [2] Dept. Geophys, Tohoku Univ.; [3] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [4] Kanazawa Univ.; [5] ISAS/JAXA

Hectometric Line Spectra found by the Arase (ERG) satellite are reported. They consist of main constant frequency components and additional frequency changing components. We reported that they were natural waves [1]. Since the main components are expected to be originated from broadcasting waves now, we named them as Hectometric Line Spectra (HLS). They cannot go through the ionosphere like short waves whose frequencies are higher than foF2. We propose the following mechanism.

1. A broadcasting wave is mode converted to the Z mode in a region where its frequency (f) is equal to the local plasma frequency (fp) if ionospheric irregularities like plasma bubbles exist.
2. The Z mode can exist from the L mode cutoff frequency (fL) to the upper hybrid resonance frequency (fUHR). fL is lower than fp.
3. The odd harmonic electrostatic cyclotron instability occurs when fUHR is close to 1.5 fH (cyclotron frequency).
4. A naturally generated emission by the instability is expected to change its frequency like continuum or artificially stimulated VLF emissions. Its frequency is captured to that of a broadcasting wave.
5. The Z mode is mode converted to the L-O mode if ionospheric irregularities like plasma bubbles exist. The L-O mode can propagate widely.

Plasma bubbles are low electron density regions and have steep density gradients which make the mode conversion efficient. The item 4 makes constant frequency components dominant.

[1] K. Hashimoto, et al., JpGU Meeting, PEM16-33, Chiba, Japan, 2018

あらせ (ERG) で観測された波長 100m 台の中波帯の線スペクトルについて報告する。これらは，一定周波数の線スペクトルが主だが，周波数が変動する成分も存在する。foF2 等との比較で，中波の放送波は電離層を抜けられないので，自然電波であるとしてきた [1] が，電離層に浸透した放送波が主体であると考えられる。そのため，名称を Hectometric Line Spectra（HLS）とした。但し，短波帯の電波のように foF2 よりも高い周波数として抜けてきたものではない。以下の機構と考えている。

１．プラズマバブル等の電離層擾乱の存在により，放送波の周波数がプラズマ周波数に等しい領域で，Z モードに変換される。
２．Z モードは，プラズマ周波数よりも低い L モード遮断周波数から高域ハイブリッド共鳴周波数まで存在出来る。
３．高域ハイブリッド共鳴周波数近傍では，サイクロトロン周波数の 1.5 倍のインスタビリティが起こり，放送波の増幅や，自然励起による放射が起こる。
４．自然励起されたものは，continuum や VLF 帯の artificially stimulated emissions のように，周波数が変動するが，放送波が存在する周波数になると，その周波数に引き込まれる。
５．電離層擾乱の存在により，電波の周波数がプラズマ周波数に等しい領域で，Z モードが L-O モードに変換され広い範囲に伝搬する。

電離層擾乱の存在は，低い電子密度の領域であるとともに，急な電子密度勾配のためにモード変換の効率も上昇する。上記 4 の現象のために，一定周波数の線スペクトルが主体となる。これらにより，HLS 特有の性質を説明できる。

[1] K. Hashimoto, et al., JpGU Meeting, PEM16-33, Chiba, Japan, 2018

磁気圏の磁気双極子化に伴い発生する磁場擾乱：あらせ観測結果

松岡 彩子 [1]; 能勢 正仁 [2]; 三好 由純 [3]; 寺本 万里子 [4]; 野村 麗子 [5]; 藤本 晶子 [6]; 田中 良昌 [7]; 篠原 学 [8]; 篠原 育 [9]; 笠原 禎也 [10]; 笠羽 康正 [11]; 石坂 圭吾 [12]; 松田 昇也 [13]; 小路 真史 [3]; 中川 朋子 [14]
[1] JAXA 宇宙研; [2] 名大・宇地研; [3] 名大 ISEE; [4] 名大・宇地研; [5] JAXA; [6] 九工大; [7] 国立極地研究所/総研大; [8] 鹿児島高専; [9] 宇宙研／宇宙機構; [10] 金沢大; [11] 東北大・理; [12] 富山県大・工; [13] ISAS/JAXA; [14] 東北工大・工・情報通信

Magnetic field disturbances associated with the magnetic dipolarization observed by Arase (ERG) in the inner magnetosphere

Ayako Matsuoka[1]; Masahito Nose[2]; Yoshizumi Miyoshi[3]; Mariko Teramoto[4]; Reiko Nomura[5]; Akiko Fujimoto[6]; Yoshimasa Tanaka[7]; Manabu Shinohara[8]; Iku Shinohara[9]; Yoshiya Kasahara[10]; Yasumasa Kasaba[11]; Keigo Ishisaka[12]; Shoya Matsuda[13]; Masafumi Shoji[3]; Tomoko Nakagawa[14]
[1] ISAS/JAXA; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] ISEE, Nagoya University; [5] JAXA; [6] Kyutech; [7] NIPR/SOKENDAI; [8] Kagoshima National College of Technology; [9] ISAS/JAXA; [10] Kanazawa Univ.; [11] Tohoku Univ.; [12] Toyama Pref. Univ.; [13] ISAS/JAXA; [14] Tohoku Inst. Tech.

Magnetic field disturbances often appear in the night-side magnetosphere associated with the magnetic dipolarization. The disturbances carry significant energy which is considered to be released by the global configuration change of the magnetosphere, The energy normally directs to the earth in the inner magnetosphere in the several Re distance from the earth. It suggests that the disturbances are generated in the near-earth magnetosphere, about 10 Re distance from the earth. However, it is not clear how much of the disturbance energy would dissipate on the way to low altitudes and how much would arrive to the ionosphere.

The Arase (ERG) satellite was launched on December 20, 2016, to investigate the physics in the inner magnetosphere. The energy exchange between particles and fields is one of the major subjects of the Arase project. We are studying the magnetic dipolarization and associated disturbances observed by Arase.

In the ARASE orbit magnetic (and electric) disturbances are very often observed when magnetic depolarization occurs. It is consistent with the Van Allen Probes results.

The dipolarization direction of the magnetic disturbances at the plasma sheet boundary layer (PSBL) was aligned with GSM Y direction. In the previous works, magnetic disturbances found at tail PSBL were often linearly polarized and considered to have large perpendicular-k (oblique propagation). Energy is suggested to dissipate by the Landau damping process of kinetic Alfven waves.

Meanwhile, for the magnetic disturbances in the inner magnetosphere associated with the depolarization, the direction of the polarization rotates around the background field. It suggests that the disturbances are torsional mode Alfven wave, in which the polarization direction depends on the location. The torsional mode Alfven waves are considered to propagate in the solar atmosphere and heat the coronal plasma. By studying the Alfven waves in the earth magnetosphere, we anticipate understanding the heating process by Alfven waves in the universe.

サブオーロラ帯でULF/ELF/VLF波動とプラズマ変動を観測するPWINGプロジェクトの現状と2018年9月のキャンペーン観測初期結果

塩川 和夫 [1]; 能勢 正仁 [2]; 土屋 智 [1]; 高木 佑基 [2]; 今城 峻 [3]; 竹下 祐平 [2]; 尾崎 光紀 [4]; 門倉 昭 [5]; 田中 良昌 [6]; 三好 由純 [7]; 片岡 龍峰 [5]; 大山 伸一郎 [7]; 大塚 雄一 [1]
[1] 名大宇地研; [2] 名大・宇地研; [3] 名大・ISEE; [4] 金沢大; [5] 極地研; [6] 国立極地研究所/総研大; [7] 名大 ISEE

Current status and Sept 2018 campaign results of the PWING project for wave and plasma characteristics at subauroral latitudes

Kazuo Shiokawa[1]; Masahito Nose[2]; Satoshi Tsuchiya[1]; Yuki Takagi[2]; Shun Imajo[3]; Yuhei Takeshita[2]; Mitsunori Ozaki[4]; Akira Kadokura[5]; Yoshimasa Tanaka[6]; Yoshizumi Miyoshi[7]; Ryuho Kataoka[5]; Shin-ichiro Oyama[7]; Yuichi Otsuka[1]
[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] Kanazawa Univ.; [5] NIPR; [6] NIPR/SOKENDAI; [7] ISEE, Nagoya Univ.

http://www.isee.nagoya-u.ac.jp/dimr/PWING/

The PWING project (study of dynamical variation of Particles and Waves in the INner magnetosphere using Ground-based network observations) has been carried out since March 2017. All-sky airglow imagers, broadbeam riometers, ELF/VLF receivers, and induction magnetometers are operated at eight stations which are distributed longitudinally around the north geomagnetic pole at subauroral latitudes (magnetic latitudes of ˜60 degree), together with three high-sampling rate (˜100 Hz) EMCCD cameras. Among these eight stations, only the instruments at Nain, Canada, has not been in operation so far due to a difficulty of constructing power lines at the site, though the field instruments has already been installed in September 2017. In September 9-16, 2018 associated with a new moon (Sept. 10) period, we will conduct a campaign observation at Nain using a 900W power generator at the field site, in order to conduct simultaneous conjugate radio and optical measurements with the ERG (Arase) satellite which comes up on the same field line near Nain on September 11, 13, and 15. Associated with this new moon period, we will also conduct field trips to Poker Flat in Alaska to install the fourth EMCCD camera and to Husafell, Iceland, to install a new induction magnetometer. In this presentation, we will show preliminary results obtained from this campaign observation of September 2018. We will also briefly review some recent results obtained by the PWING network observations since March 2017.

Multi-event study of ELF/VLF propagation using Kannuslehto and Arase conjunctions

Claudia Martinez[1]; Yuto Katoh[2]; Jryki Manninen[3]; Ondrej Santolik[4]; Yoshiya Kasahara[5]; Shoya Matsuda[6]; Atsushi Kumamoto[7]; Fuminori Tsuchiya[8]; Ayako Matsuoka[9]; Masafumi Shoji[10]; Mariko Teramoto[11]; Iku Shinohara[12]; Kazuo Shiokawa[13]; Yoshizumi Miyoshi[10]
[1] Science, Tohoku Univ.; [2] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [3] SGO; [4] The Czech Academy of Sciences; [5] Kanazawa Univ.; [6] ISAS/JAXA; [7] Dept. Geophys, Tohoku Univ.; [8] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [9] ISAS/JAXA; [10] ISEE, Nagoya Univ.; [11] ISEE, Nagoya University; [12] ISAS/JAXA; [13] ISEE, Nagoya Univ.

Extremely Low (ELF) and Very Low Frequency (VLF) plasma waves are naturally occurring magnetospheric waves in the frequency range from 3 Hz to 30 kHz. During their propagation away from their source region they accelerate or scatter electrons through wave-particle interactions. As a consequence, they play a fundamental role in radiation belt dynamics. We used a comprehensive data set of simultaneous and conjugated observations between the ground and space to study the propagation characteristics of these waves, in particular for chorus and quasi-periodical (QP) emissions. On the ground, waves were observed at Kannuslehto (MLAT=64.4N, L=5.46, KAN), Finland while Arase (ERG) was used for inner magnetosphere observations. In the 2017-2018 campaign we have 84 days of possible conjugated observations. There are no previous studies that focus on wave propagation properties using such a large number of simultaneous or conjugated events concurrently. During these events, we calculate the observational electric to magnetic field ratio (E/B_{obs}) from ERG data. We also calculate the theoretical E/B ratio (E/B_{th}) from ERG plasma parameters and the cold plasma dispersion relation for a range of wave normal angles. Preliminary results indicate that E/B_{obs} is usually lower than E/B_{th}. Comparing both ratios we can discuss wave propagation and compare results to those obtained separately by the Singular Value Decomposition method. Analyzing cases in which the waves reached KAN and those when they did not, combined with one-to-one conjugate emissions between KAN and ERG we discuss wave propagation properties. We combine these results with ray tracing to quantify the proportion of unducted and ducted waves that successfully reached KAN. We also discuss the conditions facilitating wave propagation to the ground. This study will clarify our understanding on the propagation paths of ELF/VLF waves in the magnetosphere.

サブオーロラ帯緯度における PWING の複数地上観測点を用いた磁気圏 ELF/VLF 波動の経度広がりに関する研究

竹下 祐平 [1]; 塩川 和夫 [2]; 尾崎 光紀 [3]; 大山 伸一郎 [4]; Connors Martin[5]; Manninen Jryki[6]; Oinats Alexey[7]; Kurkin Volodya[7]; Baishev Dmitry[8]
[1] 名大・宇地研; [2] 名大宇地研; [3] 金沢大; [4] 名大 ISEE; [5] Centre for Science, Athabasca Univ.; [6] SGO; [7] ロシア太陽地球系物理学研究所; [8] なし

Study of longitudinal extent of magnetospheric ELF/VLF waves using multipoint PWING ground stations at subauroral latitudes

Yuhei Takeshita[1]; Kazuo Shiokawa[2]; Mitsunori Ozaki[3]; Shin-ichiro Oyama[4]; Martin Connors[5]; Jryki Manninen[6]; Alexey Oinats[7]; Volodya Kurkin[7]; Dmitry Baishev[8]
[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] Kanazawa Univ.; [4] ISEE, Nagoya Univ.; [5] Centre for Science, Athabasca Univ.; [6] SGO; [7] Institute of Solar-Terrestrial Physics, Irkutsk, Russia; [8] IKFIA, SB, RAS

ELF/VLF waves are generated by electron temperature anisotropy in the equatorial plane of the magnetosphere, and propagate to the ground along geomagnetic field lines. The waves interact with electrons which drift longitudinally in the inner magnetosphere, and help to accelerate them to relativistic energies. However the instantaneous longitudinal distribution of these waves has not been well understood. In this study, we investigated the longitudinal extent of magnetospheric ELF/VLF waves by using simultaneous observations at six stations at subauroral latitudes at Athabasca (ATH; 54.7N, 246.4E, MLAT: 61.3N), and Kapuskasing (KAP; 49.4N, 277.8E, MLAT: 58.7N) in Canada, Gakona (GAK; 62.4N, 214.8E, MLAT: 63.6N) in Alaska, Maimaga (MAM: 63.1N, 129.6E, MLAT: 58.0N), and Istok (IST:70.0N, 88.0E, MLAT: 66.1N) in Russia, and Kannuslehto (KAN: 67.7N, 26.3E, MLAT: 64.5N) in Finland. These stations are located encircling the earth at ˜60 MLAT. We conducted simultaneous observation of ELF/VLF waves from Nov. 1, 2017 to Dec. 31, 2017 (a total of 61 days) with a sampling rate of 40 kHz (78.125 kHz at KAN). We counted appearance of magnetospheric ELF/VLF waves every 10 minutes in the wave spectra at 0-10 kHz. The occurrence rates of ELF/VLF waves were KAN (32.4%), MAM (24.3%), IST (23.8%), GAK (18.5%), ATH (15.3%) and KAP (9.7%), showing longitudinal variations though they are located at same subauroral latitudes. We suggest that this longitudinal variation was possibly caused by longitudinal difference of geomagnetic field strength at the ionospheric altitudes where the high-energy electrons that are the energy source of these waves precipitate and lost in the atmosphere. The longitudinal extent of ELF/VLF waves was estimated by using these occurrence rates with an exponential decay function exp(- q/q_0), where q is the longitudes difference. The longitudinal extent q_0 was estimated to be 48.6 degree by fitting this function to the observed occurrence rates. We also divided the occurrence rate to those at geomagnetically active time (SYM-H<=-7.8 nT) and quiet time (SYM-H>-7.8 nT) with equal number of observations, and found that the longitudinal extents become 36.1 degree and 56.6 degree during active and quiet times, respectively.

S001-08 **会場: A** **時間: 11 月 24 日 13:45-14:05**

Density depletions associated with enhancements of ECH emissions observed by ERG

Yoichi Kazama[1]; Hirotsugu Kojima[2]; Yoshizumi Miyoshi[3]; Yoshiya Kasahara[4]; Hideyuki Usui[5]; B.-J. Wang[6]; S.-Y. Wang[7]; Sunny W. Y. Tam[8]; Tzu-Fang Chang[9]; Paul Ho[10]; Kazushi Asamura[11]; Atsushi Kumamoto[12]; Fuminori Tsuchiya[13]; Yasumasa Kasaba[14]; Shoya Matsuda[15]; Masafumi Shoji[3]; Ayako Matsuoka[16]; Mariko Teramoto[17]; Takeshi Takashima[18]; Iku Shinohara[19]
[1] ASIAA; [2] RISH, Kyoto Univ.; [3] ISEE, Nagoya Univ.; [4] Kanazawa Univ.; [5] System informatics, Kobe Univ; [6] ASIAA, Taiwan; [7] ASIAA, Taiwan; [8] ISAPS, NCKU, Taiwan; [9] ISEE, Nagoya Univ.; [10] Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan; [11] ISAS/JAXA; [12] Dept. Geophys, Tohoku Univ.; [13] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [14] Tohoku Univ.; [15] ISAS/JAXA; [16] ISAS/JAXA; [17] ISEE, Nagoya University; [18] ISAS, JAXA; [19] ISAS/JAXA

Small-scale density depletions of cold electrons associated with electrostatic electron cyclotron harmonic (ECH) waves were observed by the ERG spacecraft during a plasmapause crossing near the magnetic equator in the post-midnight. During this event, a hot electron component (several tens eV to ˜1 keV) and an energetic electron component (>1 keV) were measured, and both of the electron components showed pancake-like velocity distributions. The total electron density derived from the local upper-hybrid resonance (UHR) frequency showed roughly two orders of magnitude larger than that of the hot electrons, indicating existence of a cold and dense electron population below ˜20 eV. The cold electron density variation was well anti-correlated to the intensity of the ECH emissions, which means that the ECH emissions were intensified inside a density depletion region (DDR) of the cold and dense electrons. Moreover, a flux enhancement of hot electrons in the perpendicular direction was also associated with the ECH emission intensity. Lower-energy hot electrons (e.g., ˜100 eV) show a better correlation with the ECH emission intensity compared with higher-energy electrons (e.g., ˜1 keV). The relation between the perpendicular electrons and the ECH emission intensity suggests energization of electrons in the perpendicular directions by electric field oscillation of the ECH waves.

Electrostatic electron cyclotron harmonic waves as a candidate to cause pulsating auroras

Mizuki Fukizawa[1]; Takeshi Sakanoi[2]; Yoshizumi Miyoshi[3]; Keisuke Hosokawa[4]; Kazuo Shiokawa[5]; Yuto Katoh[6]; Atsushi Kumamoto[7]; Fuminori Tsuchiya[8]; Yukinaga Miyashita[9]; Yoshimasa Tanaka[10]; Yoshiya Kasahara[11]; Mitsunori Ozaki[11]; Ayako Matsuoka[12]; Shoya Matsuda[13]; Mitsuru Hikishima[14]; Shin-ichiro Oyama[3]; Yasunobu Ogawa[15]; Satoshi Kurita[3]; Ryoichi Fujii[16]
[1] PPARC, Tohoku Univ.; [2] Grad. School of Science, Tohoku Univ.; [3] ISEE, Nagoya Univ.; [4] UEC; [5] ISEE, Nagoya Univ.; [6] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [7] Dept. Geophys, Tohoku Univ.; [8] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [9] KASI; [10] NIPR/SOKENDAI; [11] Kanazawa Univ.; [12] ISAS/JAXA; [13] ISAS/JAXA; [14] ISAS; [15] NIPR; [16] STEL, Nagoya Univ.

Pulsating auroras (PsAs) are classified as diffuse auroras, which show quasi-periodic (2-20 s or longer) temporal fluctuations. They typically appear during the recovery phase of substorms. Observations by sounding rockets and low-altitude satellites have confirmed that pulsating auroras are caused by quasi-periodic precipitation of electrons with energies from a few to tens of keV. The electron energy spectra associated with pulsating auroras are primarily Maxwellian and do not contain signs of acceleration by electrostatic parallel fields. It suggests that electrons are precipitated from the magnetosphere into the ionosphere by pitch angle scattering. Candidate waves to scatter electrons are lower-band chorus (LBC) and electrostatic electron cyclotron harmonic (ECH) waves. They can resonate with more than and less than a few keV electrons through cyclotron resonance, respectively. One-to-one correlation between LBC wave intensity and PsA intensity has been reported in a number of previous studies [Nishimura et al., 2010, 2011]. However, direct correlation between ECH and PsA has not been reported. In this study, using a coordinated satellite and ground-based imager observation, we aim to understand the correlation between the temporal variations of PsA and ECH in addition to LBC.

The Exploration of energization and Radiation in Geospace (ERG, also called Arase) satellite was launched in December 2016. The first campaign observation between the Arase satellite and ground-based optical imager was conducted in March 2017. The optical auroral observation used in this study is from the all-sky imager installed at Sodankyla (67.37 degrees geographic latitude, 26.63 degrees geographic longitude, 64.14 degrees geomagnetic latitude, 106.59 degrees geomagnetic longitude). The sampling rate is 100 Hz and long-pass filter, whose cut-off frequency is 665 nm, is attached to mainly observe N2 1PG emissions, whose life time is very short (~10^{-6} s) and emission height is ~110 km. We calculated cross-correlation coefficients between the wave intensity observed by the Arase satellite and the auroral emission intensity at each pixel on image frame to find the high correlation region between them. Though several pulsating auroral patches were observed within the field of view of the imager, high correlation regions were localized near the footprint of the Arase satellite. We estimated the precipitating electron energy by assuming that the time lag when the cross-correlation coefficient became the highest was travel time of electrons from the modulation region. We found that it was almost consistent with the cyclotron resonance energy of each wave. From a statistical analysis, ECH waves with a similar period of their intensity variations with PsA have been frequently observed by Arase around the magnetic equator. We used data observed by Arase in the 00-06 MLT region from 23 March to 31 May 2017. Combined effect of LBC and ECH waves may be relevant to explain the complex behavior and great diversity in the morphological characteristics of PsA. To confirm whether wave-particle interactions indeed occurred or not, we will compare each wave intensity and loss cone electron flux measured by Low-Energy Particle Experiments - Electron Analyzer (LEP-e) and Medium-Energy Particle Experiments - Electron Analyzer (MEP-e) onboard the Arase satellite.

Strong diffusion of energetic electrons into diffuse aurora

Satoshi Kasahara[1]; Yoshizumi Miyoshi[2]; Shoichiro Yokota[3]; Yoshiya Kasahara[4]; Shoya Matsuda[5]; Atsushi Kumamoto[6]; Ayako Matsuoka[7]; Harald Frey[8]; Vassilis Angelopoulos[9]; Satoshi Kurita[2]; Kunihiro Keika[10]; Tomoaki Hori[2]; Iku Shinohara[11]

[1] The University of Tokyo; [2] ISEE, Nagoya Univ.; [3] Osaka Univ.; [4] Kanazawa Univ.; [5] ISAS/JAXA; [6] Dept. Geophys, Tohoku Univ.; [7] ISAS/JAXA; [8] UCB/SSL; [9] UCLA; [10] University of Tokyo; [11] ISAS/JAXA

Diffuse aurora is believed to be caused by pitch angle scattering of electrons by electrostatic electron cyclotron harmonic (ECH) waves and whistler chorus waves at the magnetospheric equator. However, precipitating electrons have not been identified in the magnetosphere, where the loss cone angle is a few degrees. Here we present a new observation of electrons inside the loss cone in the magnetosphere. During a storm-time auroral event on 17 July 2017, we found two types of diffuse-auroral type precipitating electrons, both of which are in the strong diffusion state. While one type is attributed to the scattering by upper-band chorus waves, the other type could be caused by ECH waves or lower-band chorus waves. The calculated energy flux of 7 – 30 keV is a few ergs/cm2-s, illustrating these hot electrons can substantially contribute to diffuse aurora at lower altitude, while softer electrons would simultaneously generate higher-altitude diffuse aurora.

コーラス放射バンド構造の生成機構と高エネルギー電子の非線形加速

大村 善治 [1]; HSIEH YIKAI[2]
[1] 京大・生存圏; [2] 京大生存研

Generation of lower-band and upper-band chorus emissions and associated acceleration of energetic electrons

Yoshiharu Omura[1]; Yikai Hsieh[2]
[1] RISH, Kyoto Univ.; [2] RISH, Kyoto Univ.

Whistler-mode chorus emissions characteristically occur in two distinct frequency ranges, a lower band and an upper band, separated at half the electron cyclotron frequency. In the source region of chorus emissions near the magnetic equator, a wide-band rising-tone emission is generated without any gap at the half the cyclotron frequency. As the chorus wave packet propagates away from the equator, the wave normal angle gradually deviates from the parallel direction, and there occurs nonlinear trapping of electrons via Landau resonance. Electrons trapped by Landau resonance gain energies from waves. The Landau resonance velocity becomes very close to the group velocity of nearly parallel whistler mode waves at frequencies around half the electron gyrofrequency, resulting in a long time of wave-particle interactions and wave damping.

We perform test particle simulations with parameters at L = 5 and a small wave normal angle to study the wave-particle interactions via the Landau resonance. Analyzing the wave electric fields and the resonant currents formed by electrons undergoing Landau and cyclotron resonances, we find that effective wave damping and resonant electron acceleration occurs near half the electron gyrofrequency. This nonlinear wave damping is contributed by Landau resonance rather than cyclotron resonance.

Furthermore, we confirm that this damping and associated electron acceleration is dominated by perpendicular components of wave electric field and perpendicular resonant currents [Hsieh and Omura, 2018]. The simulation results indicate that nonlinear damping via Landau resonance can divide chorus emissions into the upper band and the lower band. Another mechanism enhancing the separation of the lower and upper bands is a significant difference of propagation characteristics in these bands. The Gendrin angle, at which the oblique waves propagate parallel to the magnetic field, does not exist in the upper band. Therefore, the wave packet of the upper band chorus propagates away from the original magnetic field line, being observed as an independent wave packet entirely separated from the lower band.

Reference:

Hsieh, Y.-K. and Y. Omura, Nonlinear damping of oblique whistler mode waves via Landau resonance, submitted to J. Geophy. Res. Space Physics, 2018.

コロナホール流に伴う放射線帯外帯電子増加：あらせ観測

三好 由純 [1]; 栗田 怜 [1]; 片岡 龍峰 [2]; 篠原 育 [3]; 三谷 烈史 [4]; 高島 健 [5]; 東尾 奈々[6]; 笠原 慧 [7]; 横田 勝一郎 [8]; Wang S.-Y.[9]; 風間 洋一 [10]; 浅村 和史 [4]; 齊藤 慎司 [11]; 寺本 万里子 [12]; 堀 智昭 [1]; 桂華 邦裕 [13]; 笠原 禎也 [14]; 松田 昇也 [15]; 熊本 篤志 [16]; 土屋 史紀 [17]; 小路 真史 [1]; 津川 靖基 [1]; 松岡 彩子 [18]; Chang Tzu-Fang[19]; Park Inchun[20]
[1] 名大 ISEE; [2] 極地研; [3] 宇宙研／宇宙機構; [4] 宇宙研; [5] 宇宙研; [6] JAXA; [7] 東京大学; [8] 阪大; [9] 台湾・中央研究院; [10] 中央研究院天文・宇宙物理学研究所; [11] 名大理; [12] 名大・宇地研; [13] 東大・理; [14] 金沢大; [15] ISAS/JAXA; [16] 東北大・理・地球物理; [17] 東北大・理・惑星プラズマ大気; [18] JAXA 宇宙研; [19] 名大・宇宙地球; [20] 名大 ISEE

Flux enhancements of relativistic electrons of the outer radiation belt associated with coronal hole streams

Yoshizumi Miyoshi[1]; Satoshi Kurita[1]; Ryuho Kataoka[2]; Iku Shinohara[3]; Takefumi Mitani[4]; Takeshi Takashima[5]; Nana Higashio[6]; Satoshi Kasahara[7]; Shoichiro Yokota[8]; S.-Y. Wang[9]; Yoichi Kazama[10]; Kazushi Asamura[4]; Shinji Saito[11]; Mariko Teramoto[12]; Tomoaki Hori[1]; Kunihiro Keika[13]; Yoshiya Kasahara[14]; Shoya Matsuda[15]; Atsushi Kumamoto[16]; Fuminori Tsuchiya[17]; Masafumi Shoji[1]; Yasunori Tsugawa[1]; Ayako Matsuoka[18]; Tzu-Fang Chang[19]; Inchun Park[20]
[1] ISEE, Nagoya Univ.; [2] NIPR; [3] ISAS/JAXA; [4] ISAS/JAXA; [5] ISAS, JAXA; [6] JAXA; [7] The University of Tokyo; [8] Osaka Univ.; [9] ASIAA, Taiwan; [10] Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan; [11] Nagoya Univ.; [12] ISEE, Nagoya University; [13] University of Tokyo; [14] Kanazawa Univ.; [15] ISAS/JAXA; [16] Dept. Geophys, Tohoku Univ.; [17] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [18] ISAS/JAXA; [19] ISEE, Nagoya Univ.; [20] ISEE,Nagoya univ.

The Arase satellite was successfully launched in December 2016 and then started the regular observations from March 2017. Since then, the Arase satellite has observed several flux enhancement events associated with coronal hole streams. Large flux enhancements of relativistic electrons were sometimes observed by Arase/HEP and XEP instruments during the period of coronal-hole high speed streams, and the flux enhancements basically occur associated with the prolonged southward IMF controlled by the Russell-McPherron effect. In this presentation, we will exaimine the relationship between the large-scale solar wind structure and flux enhancements of relativistic electrons in the period for the second half of 2017, especially focusing on the energy dependence of the flux enhancements. Moreover, we will discuss a role of chorus wave activities in the electron flux enhancement, which have been obtained from the Arase/PWE measurements and the low-altitude satellite data.

Study of ULF waves and its effect on radial transport of relativistic electrons based on MHD-Ring current model coupling

Kei Kamiya[1]; Kanako Seki[2]; Shinji Saito[3]; Takanobu Amano[4]; Yoshizumi Miyoshi[5]
[1] none; [2] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [3] Nagoya Univ.; [4] University of Tokyo; [5] ISEE, Nagoya Univ.

Pc5 Ultra-Low Frequency (ULF) waves in the inner magnetosphere are observed as electromagnetic fluctuations with frequencies of 1.67-6.67 mHz and considered as a driver of the radial transport of relativistic electrons in the outer radiation belt. We recently showed that electron interactions with a continuous monochromatic Pc5 wave can produce butterfly pitch angle distributions in the outer radiation belt [Kamiya et al., JGR, 2018]. The mechanism depends on the latitudinal profile of the wave power and spectrum of the Pc5 waves. In order to model more realistic spatial distributions and spectra of ULF waves, we need to improve the outer boundary setup of the global ring current simulation.

In this study, we have developed a one-way model coupling method between two models, i.e., Global MHD-based simulation of the magnetosphere, BATS-R-US+CIMI, and a 5-D drift-kinetic ring current simulation, GEMSIS-RC. The BATS-R-US+CIMI solves the ideal MHD equations for the regions from the sunward boundary to the inner magnetosphere including the ring current pressure gradient. The GEMSIS-RC describes the distribution function of ring current ion together with time evolutions of the electric and magnetic fields self-consistently, which include the ULF waves in the inner magnetosphere. We developed a method to adopt the time-dependent outer boundary condition for GEMSIS-RC based on ion density, temperature, bulk velocity, and magnetic field obtained from BATS-R-US+CIMI simulation to solve the propagation of ULF waves in the inner magnetosphere. The results show that the fast mode waves imposed at the outer boundary propagates in GEMSIS-RC simulation domain as expected from the theoretical fast mode speed. The mode conversion from fast mode to shear Alfven wave along the field line are also seen as the wave propagates inward. We discuss the validity of the model coupling method and the ULF wave interactions with radiation belt electrons using a guiding center test particle simulation: GEMSIS-RB.

GEMSIS-RC モデルに基づいた環電流イオンによる storm-time Pc5 ULF 波動の発生機構の研究

山川 智嗣 [1]; 関 華奈子 [2]; 天野 孝伸 [1]; 高橋 直子 [3]; 三好 由純 [4]
[1] 東大・理; [2] 東大理・地球惑星科学専攻; [3] 東大・理; [4] 名大 ISEE

Study of excitation mechanism of the storm-time Pc5 ULF waves by ring current ions based on the GEMSIS-RC simulation

Tomotsugu Yamakawa[1]; Kanako Seki[2]; Takanobu Amano[1]; Naoko Takahashi[3]; Yoshizumi Miyoshi[4]
[1] University of Tokyo; [2] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [3] Univ. of Tokyo; [4] ISEE, Nagoya Univ.

http://www.sgepss.org/

Storm-time Pc5 waves are electromagnetic fluctuations in the inner magnetosphere with the frequency of 1.67-6.67 mHz, and are considered to be generated by ring current ions associated with plasma injection from the magnetotail during geomagnetic storms. It is observationally known that these waves typically propagate westward with high azimuthal wave number (m = 30-120) [e.g. Takahashi et al., 1985]. Promising candidates of excitation mechanism of the storm-time Pc5 waves are the drift or drift-bounce resonance [Southwood, 1976]. Although there are some satellite observations to suggest the resonant excitation [e.g., Dai et al., 2013; Yeoman and Wright., 2001], there are other possibilities such as periodic pressure inhomogeneity formed by time-dependent injections. The theoretical studies of the drift or drift-bounce resonance assume the simplified situation such as locally homogeneous parameters, and excitation efficiency in more realistic 3D structure is far from understood due to the difficulty of non-linear global simulations of this mechanism.

In order to simulate the excitation mechanism of the storm-time Pc5 waves, we perform a kinetic simulation for ring current particles using GEMSIS-RC model [Amano et al., 2011], in which five-dimensional drift-kinetic equation for the phase space density (PSD) of ring current ions and Maxwell equations are solved self-consistently, and the first adiabatic invariant is assumed to be conserved. In order to simulate consequence of ion injection from the plasma sheet, we set a localized high-pressure region around midnight consisting of H+ ions with a Maxwellian velocity distribution of the isotropic temperature 16 keV with a loss cone as an initial condition. The field perturbation at the inner boundary is set to zero and free boundary condition is used at the outer boundary. For PSD, the mirror reflection at the ionosphere is assumed at the inner boundary.

When we start the simulation, the high-pressure region initially set around midnight expands both dawnward and duskward. The expansion is more toward dusk, since the injected ions undergo duskward magnetic drift depending on their energy. The power spectrum of magnetic field fluctuations show that both poloidal and toroidal mode waves in Pc5 frequency range are excited in the dayside dusk sector.These waves are fundamental mode waves with azimuthal wave number m ˜16 propagating westward. The wave excitation coincides with the arrival of drifting ions of 80-120 keV. Global distribution of the excited Pc5 waves indicates that they are excited where the local growth rate resultant from the positive PSD gradient in energy is positive. We will also report on detailed characteristics of the PSD distribution and its relationship with the Pc5 wave growth rate.

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Concentrically expanding ring-shaped pulsating aurora: simultaneous observations with Arase

Keisuke Hosokawa[1]; Satoshi Kurita[2]; Yoshizumi Miyoshi[2]; Shin-ichiro Oyama[2]; Yasunobu Ogawa[3]; Yoshiya Kasahara[4]; Yasumasa Kasaba[5]; Satoshi Yagitani[4]; Mitsunori Ozaki[4]; Shoya Matsuda[6]; Fuminori Tsuchiya[7]; Atsushi Kumamoto[8]; Ayako Matsuoka[9]; Mariko Teramoto[10]; Ryuho Kataoka[3]; Kazuo Shiokawa[11]; Takeshi Takashima[12]; Iku Shinohara[13]; Ryoichi Fujii[14]
[1] UEC; [2] ISEE, Nagoya Univ.; [3] NIPR; [4] Kanazawa Univ.; [5] Tohoku Univ.; [6] ISAS/JAXA; [7] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [8] Dept. Geophys, Tohoku Univ.; [9] ISAS/JAXA; [10] ISEE, Nagoya University; [11] ISEE, Nagoya Univ.; [12] ISAS, JAXA; [13] ISAS/JAXA; [14] STEL, Nagoya Univ.

During the first coordinated campaign observation of pulsating aurora (PsA) with the Arase/ERG satellite in March 2017, we observed a peculiar PsA which expanded radially and eventually formed a concentric ring-shaped structure. Such a Concentrically Expanding ring-shaped PsA (CoE-PsA) was observed during a 5 min from 00:05 to 00:10 UT on March 29, 2017 by an all-sky camera located in Sodankyla;, Finland. The CoE-PsA started from a small patch of diffuse aurora in a limited region. In the first several minutes, the small patch expanded radially in all the directions. Such a variation in the first stage is very similar to that of expansion type PsA reported in the past literature. Subsequently after the initial expansion, a small dark area appeared in the center of the initial patch and this dark region expanded radially too. Expansions of the first bright area and subsequent dark area formed a ring of diffuse aurora in the final stage. By mapping the traced outer/inner boundaries of CoE-PsA, we estimated the speed of the radial expansion of the corresponding structure in the equatorial plane of the magnetosphere. The speed actually varied, but it ranged from 500 to 3000 km/s in the radial direction. The expansion speed in the longitudinal direction was about an order smaller than that in the radial direction.

The magnetic footprint of the Arase satellite was located within the region of CoE-PsA. PWE/OFA onboard the satellite observed collective bursts of chorus whose intensity variation is very similar to that of CoE-PsA. A cross-correlation analysis indicates that the temporal variation of chorus has a delay of a few seconds from that of the optical intensity at the center of the CoE-PsA. In addition, a map of cross-correlation coefficient implies that the satellite footprint was situated in the southeastern part of the CoE-PsA at the time of expansion. In the presentation, we discuss the temporal variation of CoE-PsA by considering oblique propagation of chorus waves in all the azimuthal direction. In particular, we test the feasibility of the model by comparing the speed of the radial expansion of CoE-PsA with the propagation speed of chorus in the direction perpendicular to the ambient magnetic field.

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Flash aurora as manifestation of the nonlinear resonant interactions between single chorus element and electrons

Mitsunori Ozaki[1]; Yoshizumi Miyoshi[2]; Kazuo Shiokawa[3]; Keisuke Hosokawa[4]; Shin-ichiro Oyama[2]; Ryuho Kataoka[5]; Yusuke Ebihara[6]; Yasunobu Ogawa[5]; Yoshiya Kasahara[1]; Satoshi Yagitani[1]; Yasumasa Kasaba[7]; Atsushi Kumamoto[8]; Fuminori Tsuchiya[9]; Shoya Matsuda[10]; Yuto Katoh[11]; Mitsuru Hikishima[12]; Satoshi Kurita[2]; Yuichi Otsuka[3]; Yoshimasa Tanaka[13]; Masahito Nose[14]; Tsutomu Nagatsuma[15]; Nozomu Nishitani[2]; Akira Kadokura[5]; Martin Connors[16]; Takumi Inoue[1]; Ayako Matsuoka[17]; Iku Shinohara[18]
[1] Kanazawa Univ.; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] UEC; [5] NIPR; [6] RISH, Kyoto Univ.; [7] Tohoku Univ.; [8] Dept. Geophys, Tohoku Univ.; [9] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [10] ISAS/JAXA; [11] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [12] ISAS; [13] NIPR/SOKENDAI; [14] ISEE, Nagoya Univ.; [15] NICT; [16] Centre for Science, Athabasca Univ.; [17] ISAS/JAXA; [18] ISAS/JAXA

Chorus waves have attracted considerable attention because they are a major candidate for rapid local acceleration and/or loss processes of Earth's radiation belts via wave-particle interactions. Rapid (less than 1 s) electron precipitation correlating to chorus element structures is the most important for understanding the elementary physical steps behind the rapid loss of energetic electrons in a wide energy range in the inner magnetosphere. However, the spatiotemporal characteristics of resonant interactions between a single chorus element packet and electrons have not been understood because of the very short duration (a few hundreds of milliseconds) of single chorus element. In order to visualize the resonant interactions between chorus elements and electrons, we have carried out coordinated observations between the Arase satellite and PWING (study of dynamical variation of Particles and Waves in the INner magnetosphere using Ground-based network observations) installing high-speed (100 Hz) EMCCD cameras. In-situ chorus elements at the Arase satellite and transient auroral flashes referred to as 'flash aurora' at the conjugate ground site (Gakona in Alaska) were observed on March 30, 2017. The flash aurora shows not only a temporal evolution correlating with the chorus element structures, but also a spatial variation strongly correlating with the chorus wave amplitude. The ideal conjugate observations suggest that the chorus waves regulate not only time variations of precipitating electron flux in a wide energy range, but also transverse (across the magnetic field line) scales of source size for energetic electron precipitation. Moreover, such rapid spatiotemporal characteristics of flash aurora can be an important signature of nonlinear resonant interactions between a single chorus element packet and energetic electrons.

In this presentation, we will present the spatiotemporal characteristics of flash aurora taken by the high speed EMCCD camera and related chorus element structures by the Arase satellite in detail.

高速EMCCDイメージャーを用いたフラッシュオーロラの時空間解析

井上 拓海 [1]; 尾崎 光紀 [1]; 八木谷 聡 [1]; 今村 幸祐 [1]; 塩川 和夫 [2]; 三好 由純 [3]; 大山 伸一郎 [3]; 片岡 龍峰 [4]; 海老原 祐輔 [5]; 細川 敬祐 [6]
[1] 金沢大; [2] 名大宇地研; [3] 名大 ISEE; [4] 極地研; [5] 京大生存圏; [6] 電通大

Spatio-temporal analysis of flash aurora using a fast EMCCD imager

Takumi Inoue[1]; Mitsunori Ozaki[1]; Satoshi Yagitani[1]; Kosuke Imamura[1]; Kazuo Shiokawa[2]; Yoshizumi Miyoshi[3]; Shin-ichiro Oyama[3]; Ryuho Kataoka[4]; Yusuke Ebihara[5]; Keisuke Hosokawa[6]
[1] Kanazawa Univ.; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] NIPR; [5] RISH, Kyoto Univ.; [6] UEC

High-energy electrons are accelerated and precipitated by resonant interactions with whistler mode waves in the magnetosphere. These electrons travel along the geomagnetic field lines and some of these precipitate into the atmosphere. Then, auroral phenomena are happened. We can investigate indirectly the behavior of electrons in the magnetosphere by observing auroras on the ground. We focus on flash auroras, which illuminate suddenly at less than 1 s, taken by an EMCCD camera (100 Hz sampling). Flash auroras can be a manifestation of resonant interactions with one packet of whistler mode waves and show the spatial evolution of wave-particle interaction regions. Since the luminous time of flash aurora is much shorter than that of discrete auroras, statistical analysis of flash aurora has not been performed. In this study, we have performed statistical analysis of the spatio-temporal variations of flash aurora taken by an EMCCD camera. We used the flash aurora data (about 100 events) taken at Gakona (Alaska) on March 30th, 2017. In order to extract the spatial information on the flash auroras, we used Otsu's method, which is a basic method of contour extraction. Based on the extraction results of spatial shape, we analyzed the spatial size of flash aurora, the total counts in a flash auroral region, luminous time, and spatial extent. The total counts in a flash auroral region is equivalent to the total amount of precipitated electron flux along the geomagnetic field lines connected to each pixel of the image. We found that the spatial size of flash aurora has a strong correlation with the total counts in a flash auroral region. It suggests that precipitating electrons saturate with a certain threshold value at the wave-particle interaction region, and the total amount of precipitating electron flux increases with the spatial size of flash aurora. We also found that the luminous time did not depend on the magnetic longitudes and latitudes in the field-of-view of camera and the average luminous time was 0.17 $\pm$ 0.09 s. By projecting flash auroras onto the magnetic equator, we confirmed that most events (about 80%) expand the earthward at the magnetic equator with an average spatial difference of 0.04 Re. We think that this result can be caused by wave normal angles of whistler mode waves and/or the nonuniformity of spatial distribution of loss cones in the magnetosphere.

In this presentation, we will report on the results of spatio-temporal analysis of flash aurora in detail.

宇宙空間では、プラズマ波動の一種であるホイッスラー波動と電子が相互作用することによって高エネルギー電子が加速・消失している。この高エネルギー電子は地球の磁力線に沿って運動し、一部は地上まで降下する。降下した高エネルギー電子が高層大気と衝突することによってオーロラが発光している。オーロラを地上で観測することで間接的に磁気圏に存在している電子の様相を知ることができる。EMCCD カメラを用いて高速撮像 (100 Hz) されたオーロラの中で、私たちは一秒以下で突発的に発光するフラッシュオーロラに注目している。このフラッシュオーロラは、一つの波群のホイッスラー波動との相互作用によって生じていると考えられ、波動粒子相互作用領域の空間発展を示すものと考えられる。しかし、ディスクリートオーロラなどと比べて発光時間が非常に短く、詳細な解析は行われていない。本研究では、EMCCD カメラで観測されたフラッシュオーロラの時空間変動の統計解析を行った。2017 年 3 月 30 日にガコナ (アラスカ) で撮像されたフラッシュオーロラ (約 100 イベント) の撮像データを用いた。フラッシュオーロラの空間情報を得るために、代表的な二値化手法である大津の二値化を用いて、フラッシュオーロラ領域の抽出を行った。抽出結果をもとに、フラッシュオーロラの面積、フラッシュオーロラ内の輝度値の合計、発光時間、発光分布を調べた。輝度値の合計は、画像の各ピクセルにつながる磁力線に沿った降下電子フラックスの総量と考えることができる。解析の結果、フラッシュオーロラの面積とフラッシュオーロラ内の輝度値の合計には高い相関 (0.9) があることが分かった。これは、フラッシュオーロラ内の各ピクセルにつながる磁力線で生じた波動粒子相互作用により散乱された電子はある閾値で飽和し、降下電子フラックスの総量がフラッシュオーロラの空間サイズとともに増大したことを示唆している。発光時間は EMCCD カメラ視野内の磁気緯度、磁気経度に依存しておらず、平均 0.17 $\pm$ 0.09 秒であることが分かった。また、観測されたフラッシュオーロラを磁気赤道に投影することによって、全イベントのうちの約 80 %が磁気赤道で内側に向けて平均 0.04 Re より大きく拡大していることが確認された。この結果は、波動の伝搬角や磁気圏におけるロスコーンの空間分布の不均一性が関係していると考えられる。

本発表では、フラッシュオーロラの時空間解析結果について詳細に報告する予定である。

VLF/LF 帯標準電波を用いた ULF 波動と関連するサブストーム中の高エネルギー降下電子の観測

宮下 拓也 [1]; 大矢 浩代 [2]; 土屋 史紀 [3]; 中田 裕之 [4]; 鷹野 敏明 [5]; 塩川 和夫 [6]; 三好 由純 [7]
[1] 千葉大・工・電気電子; [2] 千葉大・工・電気; [3] 東北大・理・惑星プラズマ大気; [4] 千葉大・工・電気; [5] 千葉大・工; [6] 名大宇地研; [7] 名大 ISEE

Energetic electron precipitations observed through VLF/LF standard radio waves during substorms-associated ULF waves

Takuya Miyashita[1]; Hiroyo Ohya[2]; Fuminori Tsuchiya[3]; Hiroyuki Nakata[4]; Toshiaki Takano[5]; Kazuo Shiokawa[6]; Yoshizumi Miyoshi[7]
[1] Electrical and Electronic, Chiba Univ; [2] Engineering, Chiba Univ.; [3] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [4] Grad. School of Eng., Chiba Univ.; [5] Chiba Univ.; [6] ISEE, Nagoya Univ.; [7] ISEE, Nagoya Univ.

During geomagnetic storms, a lot of studies have been reported that energetic electrons precipitate into atmosphere at the high latitudes. It is known that the low latitude limit of the particle precipitations is L-4.0 (Berkey et al., 1974). However, several studies reported that the particle precipitations occurred at the mid and low latitudes (L-1.3-2.8) (Kikuchi and Evans, 1989: Clilverd et al., 2008). In this study, we investigate the precipitations of energetic electrons into the atmospheres during substorms of 27 April, 2017 and 7-8 September, 2017, using a network of very low frequency (VLF)/low frequency (LF) subionospheric radio propagation from the low and high latitudes. As for the substorm of 27 April, 2017, the transmitters are NAA (USA, 24.0 kHz, L = 2.88), NLK (USA, 24.8 kHz, L = 2.88), NDK (USA, 25.2 kHz, L = 2.98) and WWVB (USA, 60.0 kHz, L = 2.26), while the receivers are ATH (Athabasca, L=4.31) and PKR (Poker Flat, L=5.95). As for the substorm of 7-8 September, 2017, the transmitters are NRK (Iceland, 37.5kHz, L = 4.05) and NPM (Hawaii, 21.4kHz, L = 1.15), while the receivers are NYA (Ny-Alesund, L=17.2) and PKR. The substorm occurred at 05:35 UT, 27 April, 2017. Based on the wavelet analysis, we found that the radio intensities for the NDK-ATH, WWVB-ATH, and NLK-ATH paths show oscillations with a period of 4-6 minutes during the substorm growth phase (05:00-06:00 UT). Magnetic field variations at ATH also show the same period, indicating that the radio intensity variations with the period of 4-6 minutes were caused by Pc5 modulations. We also analyzed the substorm occurred at 19:40 UT on 7 September, 2017. Variations in the radio intensities (3-4 dB) for NRK-NYA, NRK-PKR and NPM-NYA paths due to precipitations were seen during 23:20 UT, 7 September – 01:00 UT, 8 September, 2017. Based on the wavelet analysis, the radio intensities for above 3 paths show oscillations with periods of 30-40 minutes. Magnetic field variations along the subionospheric propagationpaths, the IMF Bz, and AE index also showed the same periods of 30-40 minutes. In the presentation, we will discuss the cause of these radio variations in detail.

磁気嵐の発生に伴い、高緯度帯において下部電離圏に高エネルギー粒子の降り込みがあることについては広く研究されている。そして、高エネルギー粒子の降り込みが発生する低緯度の限界は、L 値～4.0 という報告がある（Berkey, 1974）。しかし、いくつかの研究が中低緯度（L=1.3～2.8）においても粒子の降り込みが観測されたことを報告している（Kikuchi and Evans, 1989: Clilverd et al., 2008）。本研究では高緯度から低緯度まで VLF/LF 帯標準電波の伝搬ネットワークを用いて 2017 年 4 月 27 日および 2017 年 9 月 7-8 日に発生したサブストーム中の下部電離圏への高エネルギー電子の降り込みを解析する。2017 年 4 月 27 日の磁気嵐において、VLF/LF 波の送信局は NAA(USA, 24.0kHz, L = 2.88)、NLK(USA, 24.8kHz, L = 2.88)、NDK(USA, 25.2kHz, L = 2.98) および WWVB(USA, 60.0kHz, L = 2.26) であり、受信局は ATH(Athabasca, L=4.31) および PKR(Poker Flat, L=5.95) である。また、2017 年 9 月 7-8 日の磁気嵐において、送信局は NRK(Iceland, 37.5kHz, L = 4.05)、NPM(Hawaii, 21.4kHz, L = 1.15) であり、受信局は NYA(Ny-Alesund, L=17.2) と PKR である。2017 年 4 月 27 日 5:35 UT にサブストームのオンセットがあり、ウェーブレット変換の結果、VLF/LF 波の振幅の NDK-ATH パス、NLK-ATH パスおよび WWVB-ATH パスでサブストームの成長相 (05:00-06:00 UT) の間 4-6 分周期の変動がみられた。ATH の地磁気にもまた同様な 4-6 分周期の変動がみられた。これらは Pc5 modulations によるものである。また、2017 年 9 月 7 日 19:40 UT にオンセットがあったサブストームの解析も行った。NRK-NYA パス、NRK-PKR パスおよび NPM-NYA パスで 9 月 7 日 23:20 UT - 8 日 1:00 UT に VLF/LF 波の振幅高エネルギー電子の降り込みによる 3～4 dB の変動が見られた。ウェーブレット変換より、この 3 つのパスで VLF/LF 波の振幅に 30-40 分の周期性があった。これらの伝搬パス上の地磁気や IMF B ｚ、AE 指数にも同じ 30-40 分の周期性があった。この発表で我々はこれらの電波の変動の原因を議論する。

One-to-one correspondence between relativistic electron precipitation and pulsating aurora obsrved on 27 March 2017

Fuminori Tsuchiya[1]; Asuka Hirai[2]; Takahiro Obara[3]; Hiroaki Misawa[4]; Satoshi Kurita[5]; Yoshizumi Miyoshi[5]; Kazuo Shiokawa[6]; Martin Connors[7]; Mitsunori Ozaki[8]; Yoshiya Kasahara[8]; Atsushi Kumamoto[9]; Yasumasa Kasaba[10]; Ayako Matsuoka[11]; Masafumi Shoji[5]; Iku Shinohara[12]
[1] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [2] PPARC, Tohoku Univ.; [3] PPARC, Tohoku University; [4] PPARC, Tohoku Univ.; [5] ISEE, Nagoya Univ.; [6] ISEE, Nagoya Univ.; [7] Centre for Science, Athabasca Univ.; [8] Kanazawa Univ.; [9] Dept. Geophys, Tohoku Univ.; [10] Tohoku Univ.; [11] ISAS/JAXA; [12] ISAS/JAXA

http://pparc.gp.tohoku.ac.jp/

Recent studies of pulsating auroras (PsA) suggest that energetic electrons with energies up to several hundred keV precipitate into the atmosphere as a result of pitch angle scattering by whistler mode chorus waves. In this paper, we report correlation between PsA and EEP for the first time during recovery phase of substorms on 27 March 2017. EEPs were detected by subionospheric propagation of VLF radio waves. PsA was observed by the THEMIS all-sky imagers. We found one-to-one correspondence between pulsations of auroral intensity above the radio propagation path and perturbation of the received radio signal when PsA occurred on the path. The VLF perturbation showed short recovery time of 2 seconds. The recovery time reflects relaxation time of the ionization and strongly depends on the stopping altitude of the precipitating electrons. The short recovery time required the stopping altitude of 50-60km and indicates that PsA accompanied relativistic electron precipitation.

Energetic Electron Precipitation and its relation to IPDP type EMIC waves

Asuka Hirai[1]; Fuminori Tsuchiya[2]; Takahiro Obara[3]; Yasumasa Kasaba[4]; Yuto Katoh[5]; Hiroaki Misawa[6]; Kazuo Shiokawa[7]; Yoshizumi Miyoshi[8]; Satoshi Kurita[8]; Martin Connors[9]
[1] PPARC, Tohoku Univ.; [2] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [3] PPARC, Tohoku University; [4] Tohoku Univ.; [5] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [6] PPARC, Tohoku Univ.; [7] ISEE, Nagoya Univ.; [8] ISEE, Nagoya Univ.; [9] Centre for Science, Athabasca Univ.

Electromagnetic ion cyclotron (EMIC) waves are excited by the ion cyclotron instability in the equatorial region of the magnetosphere. EMIC waves propagate along the magnetic field line to the ground and are observed as the Pc1- Pc2 pulsations. Pitch angle scattering due to EMIC waves is considered to be an important loss mechanism of relativistic electrons. As evidence of its contribution to the loss of radiation belt electrons, we previously reported a good correspondence between the time variation of energetic electron precipitation (EEP) and the intensity of EMIC waves during the main phase of a geomagnetic storm on 27 March, 2017 (Hirai et al., AOGS2018).

In this paper, we enhanced this result with more temporal and spatial correspondences of EMIC waves with EEP, through their statistical analyses from 1 November 2016 to 30 June 2018. We used induction magnetometers at Athabasca (latitude: 54.7 deg, longitude: 246.7 deg, L: 4.45) for the detection of EMIC waves. The artificial radio waves received at Athabasca were also used for the detection of the ionization caused by EEP with typical energies higher than 100 keV, which propagated in the subionospheric waveguide from the transmitters located at NDK (latitude: 46.4, longitude: 261.5, L: 2.98, 25.2 kHz) and NLK (latitude: 48.2, Longitude: 238.1, L: 2.85, 24.79 kHz).

Simultaneous data of the magnetometer and the radio wave receiver were obtained on 289 days. This data set included 395 EMIC wave events, and 55 had the IPDP (Interval of Pulsations of Diminishing Period) type (14%). In this data set, we investigated 20 clear EEP events with simultaneous EMIC wave events. Among them, 16 EMIC wave events were IPDP type. 19 events occurred in duskside and only one event in post-midnight. The IPDP type EMIC event is characterized by an increase in wave frequency over 30-60 min and is observed in the evening sector accompanied by a substorm. When energetic protons are injected into the inner magnetosphere and drift westward during the expansion phase of substorm, IPDP waves are generated. The local time dependence of IPDP found in this study is consistent with this picture. The result suggests that the IPDP type EMIC wave event is closely related with the precipitation of energetic electrons into the atmosphere, a different mechanism than those causing other types of EMIC waves.

無人システムを利用したオーロラ現象の南極広域ネットワーク観測：共役点イベント解析

門倉 昭 [1]; 山岸 久雄 [2]; 岡田 雅樹 [1]; 小川 泰信 [1]; 田中 良昌 [3]; 片岡 龍峰 [1]; 内田 ヘルベルト陽仁 [4]; 大塚 雄一 [5]
[1] 極地研; [2] 極地研; [3] 国立極地研究所/総研大; [4] 総研大; [5] 名大宇地研

Antarctic large area network observation of auroral phenomena using unmanned system: Conjugate auroral event studies

Akira Kadokura[1]; Hisao Yamagishi[2]; Masaki Okada[1]; Yasunobu Ogawa[1]; Yoshimasa Tanaka[3]; Ryuho Kataoka[1]; Herbert Akihito Uchida[4]; Yuichi Otsuka[5]
[1] NIPR; [2] National Inst. Polar Res.; [3] NIPR/SOKENDAI; [4] SOKENDAI; [5] ISEE, Nagoya Univ.

Conjugate auroral events observed at Syowa Station, Antarctica and observatories in Iceland on September 28 and 29 in 2017 are analyzed. During this period, auroral data obtained by the all-sky auroral imager of the Unmanned Auroral Observation system (UAO) at Amundsen Bay, which is located about 500 km eastward from Syowa Station, are also available. We will discuss development of the conjugate auroral activities in a broader longitudinal area than before.

2017 年 9 月 28 日と 29 日に、南極昭和基地とアイスランドとの間で同時観測された共役点オーロライベントの初期解析結果について紹介する。この時、南極側では、昭和基地から東に約 500km 離れた沿岸域のアムンゼン湾に設置されている「無人オーロラ観測装置（UAO：Unmanned Auroral Observation system）」によっても、全天オーロライメージャのデータが取得されており、従来よりもより広い経度範囲でのオーロラ活動の共役性の議論が期待出来る。

あらせとRBSP衛星による経度方向に局所的に発生するULF波動による高エネルギーfluxの周期的な変動

寺本 万里子 [1]; 堀 智昭 [2]; 齊藤 慎司 [3]; 三好 由純 [2]; 栗田 怜 [2]; 東尾 奈々[4]; 三谷 烈史 [5]; 松岡 彩子 [6]; 高島 健 [7]; Park Inchun[8]; 野村 麗子 [4]; 能勢 正仁 [9]; 藤本 晶子 [10]; 田中 良昌 [11]; 篠原 学 [12]; 篠原 育 [13]
[1] 名大・宇地研; [2] 名大 ISEE; [3] 名大理; [4] JAXA; [5] 宇宙研; [6] JAXA 宇宙研; [7] 宇宙研; [8] 名大 ISEE; [9] 名大・宇地研; [10] 九工大; [11] 国立極地研究所/総研大; [12] 鹿児島高専; [13] 宇宙研／宇宙機構

Periodic energetic electron flux modulations interacted by the azimuthally-confined ULF waves observed by Arase and RBSP

Mariko Teramoto[1]; Tomoaki Hori[2]; Shinji Saito[3]; Yoshizumi Miyoshi[2]; Satoshi Kurita[2]; Nana Higashio[4]; Takefumi Mitani[5]; Ayako Matsuoka[6]; Takeshi Takashima[7]; Inchun Park[8]; Reiko Nomura[4]; Masahito Nose[9]; Akiko Fujimoto[10]; Yoshimasa Tanaka[11]; Manabu Shinohara[12]; Iku Shinohara[13]
[1] ISEE, Nagoya University; [2] ISEE, Nagoya Univ.; [3] Nagoya Univ.; [4] JAXA; [5] ISAS/JAXA; [6] ISAS/JAXA; [7] ISAS, JAXA; [8] ISEE,Nagoya univ.; [9] ISEE, Nagoya Univ.; [10] Kyutech; [11] NIPR/SOKENDAI; [12] Kagoshima National College of Technology; [13] ISAS/JAXA

We report a drift resonance using data simultaneously observed by the Arase (ERG) and Radiation Belt Storm Probes (RBSP)-B satellites around 06:30 UT on March 30, 2017, when both satellites observed radiation belts at different MLTs but the same L-shell. The Extremely High-Energy Electron Experiment (XEP) carried by Arase observed periodic fluctuations in the energetic electron flux with energies ranging from 500 keV to 2 MeV with an energy dispersion when the satellite was located in the morning local time sector. Significant fluctuations in the ambient magnetic field were not observed by the Magnetic Field Experiment (MGF) on the ERG satellite. We estimated the modulation region using a time-of-fight analysis with the dispersion signature of the energetic electron fluctuations and found that the source regions extended from the post-noon to dusk sector (14–18 Magnetic Local Time (MLT)). The Magnetic Electron Ion Spectrometers (MagEIS) and Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) onborard the RBSP-B, which was located at ˜18 MLT, observed Pc5 pulsations in the compressional component and electron flux modulations with energies from 500 keV to 2 MeV with the almost same period. The energy dependence of the amplitude and phase difference relative to the compressional Pc5 pulsations suggests that the drift resonance was excited near 1 MeV. Ground magnetometers with longitudinal extension at 14–03 MLT observed eastward-propagating Pc5 pulsations with a small m number of ˜4. These Pc5 pulsations were confined to the afternoon–dusk sector of 14–18 MLT. These results indicate that azimuthally-confined Pc5 pulsations interact with drifting electrons via drift resonance.

We also visually surveyed such periodic energetic electron modulations without ULF waves from the energetic electron flux and magnetic field data observed by Arase from March 21, 2017 through December 31, 2017. We found that energetic electron modulations without ULF waves frequently appear in the dawn side.

In this study, we will show the event on March 30, 2017 and statistical results of periodic energetic electron modulations without ULF waves.

High-energy electron observations with the HEP instruments onboard Arase and its calibration status

Takefumi Mitani[1]; Takeshi Takashima[2]; Tomoaki Hori[3]; Inchun Park[4]; Yoshizumi Miyoshi[3]; Satoshi Kasahara[5]; Satoshi Kurita[3]; Mariko Teramoto[6]; Nana Higashio[7]; Iku Shinohara[8]
[1] ISAS/JAXA; [2] ISAS, JAXA; [3] ISEE, Nagoya Univ.; [4] ISEE,Nagoya univ.; [5] The University of Tokyo; [6] ISEE, Nagoya University; [7] JAXA; [8] ISAS/JAXA

The high-energy electron experiments (HEP) onboard the Arase satellite detects 70 keV-2 MeV electrons and generates a three-dimensional velocity distribution for these electrons in every period of the satellite's rotation. Electrons are detected by two instruments, namely, HEP-L and HEP-H, which differ in their geometric factor (G-factor) and range of energies they detect. HEP-L detects 70 keV-1 MeV electrons and its G-factor is 9.3 x 10^{-4} cm^2 sr at maximum, while HEP-H observes 0.7 MeV-2 MeV electrons and its G-factor is 9.3 x 10^{-3} cm^2 sr at maximum. The instruments utilize silicon strip detectors and application specific integrated circuits to readout the incident charge signal from each strip.

In order to deduce the distribution of incident electrons from the direction and energy detections in orbit, we are developing a detector simulator using the Geant4 toolkit. Especially contamination from high energy particles must be considered. We are working on comparisons between the simulation results and observation. We are also planning electron beam experiments using HEP detector modules which are almost same as the flight model in order to compare detailed simulations and experimental data.

Since HEP started its normal observations in late March 2017, it has observed several cycles of sudden depletion and recovery of electron fluxes in the outer radiation belt in response to geomagnetic storms. When the geomagnetic activity was low for about a month, the electron fluxes slowly decrease in the outer radiation belt.

We will present calibration status using the simulator and also highlights of the HEP 1.5-year observations.

S001-24 **会場: A** **時間: 11 月 25 日 9:35-9:50**

Substorm injection like signatures observed at the plasma sheet boundary

Iku Shinohara[1]; Tsugunobu Nagai[2]; Takefumi Mitani[3]; Satoshi Kasahara[4]; Yoichi Kazama[5]; S.-Y. Wang[6]; Sunny W. Y. Tam[7]; Nana Higashio[8]; Ayako Matsuoka[9]; Kazushi Asamura[3]; Shoichiro Yokota[10]; Takeshi Takashima[11]; Yoshizumi Miyoshi[12]
[1] ISAS/JAXA; [2] ISAS/JAXA; [3] ISAS/JAXA; [4] The University of Tokyo; [5] ASIAA; [6] ASIAA, Taiwan; [7] ISAPS, NCKU, Taiwan; [8] JAXA; [9] ISAS/JAXA; [10] Osaka Univ.; [11] ISAS, JAXA; [12] ISEE, Nagoya Univ.

The Arase (ERG) satellite is possible to observe higher L-value plasma sheet close to the plasma sheet boundary because of its characteristic orbit, and, actually, Arase has observed several lobe entry events just outside of the outer radiation belt. In some of these events, we found that energetic electron bursts up to 500 keV appear at the plasma sheet boundary. Since the GOES satellites also observed rapid increases of energetic electrons at the same timing, the observed energetic electron bursts look quite similar to typical dispersionless substorm injection events. If the observed electron busts are due to the substorm injection, the observation cannot be explained by the standard understanding of the injection since the injection is thought to occur associated with local magnetic field dipolarizations in downstream of the magnetotail reconnection jets in deep inside of the plasma sheet. In this paper, we will discuss the observed electrons are really the same phenomena as the substorm injections. The discussion is important to address the relationship between magnetotail reconnection and injections.

Simulation of the substorm injection of high-energy electrons observed by ERG and GOES

Tzu-Fang Chang[1]; Chio-Zong Cheng[2]; Sunny W. Y. Tam[2]; Chih-Yu Chiang[2]; Yoshizumi Miyoshi[3]; Tomoaki Hori[3]; Takefumi Mitani[4]; Takeshi Takashima[5]; Ayako Matsuoka[6]; Mariko Teramoto[7]; Iku Shinohara[8]
[1] ISEE, Nagoya Univ.; [2] ISAPS, NCKU, Taiwan; [3] ISEE, Nagoya Univ.; [4] ISAS/JAXA; [5] ISAS, JAXA; [6] ISAS/JAXA; [7] ISEE, Nagoya University; [8] ISAS/JAXA

One of the indicators of magnetospheric substorms is the injection of high-energy particles. The ERG and GOES spacecraft observe the injection of high-energy electrons associated with the substorm, initiating on Apr. 5, 2017. The ERG satellite observes the nearly-dispersionless injection and the subsequent drift echoes while the GOES spacecraft observe the dispersion features of the drift echoes. Assuming that a substorm-associated electromagnetic pulse propagates earthward, motions of the high-energy electrons are analyzed in the combined electric and magnetic fields. We proposed a particle motion model including the relativistic effect to simulate the observed features. Considering the relativistic effect, the particle drift motion, the adiabatic invariant and particle magnetic moment differ from the non-relativistic ones. Our simulations successfully reproduce the features of the nearly-dispersionless injection and the subsequent drift echoes observed by the three satellites. We discuss the differences among the results of spacecraft observations and the relativistic /non-relativistic computations.

Electron flux variations of the outer radiation belt during magnetic storms observed by Arase/HEP and Van Allen Probes/MagEIS

Inchun Park[1]; Yoshizumi Miyoshi[2]; Takefumi Mitani[3]; Tomoaki Hori[2]; Takeshi Takashima[4]; Satoshi Kurita[2]; Mariko Teramoto[5]; Nana Higashio[6]; Ayako Matsuoka[7]; Satoshi Kasahara[8]; Shoichiro Yokota[9]; Iku Shinohara[10]
[1] ISEE,Nagoya univ.; [2] ISEE, Nagoya Univ.; [3] ISAS/JAXA; [4] ISAS, JAXA; [5] ISEE, Nagoya University; [6] JAXA; [7] ISAS/JAXA; [8] The University of Tokyo; [9] Osaka Univ.; [10] ISAS/JAXA

The Arase satellite has been regularly observing high-energy electrons of the outer radiation-belt since March 2017 with the HEP (High-energy electron experiments) instrument that measures electrons with energies from 70 keV to 2 MeV. In addition to calibrations with laboratory accelerators, simulations for HEP were carried out to establish the performance of this instrument. Also, we use the calibrated data for our analysis. Since the beginning of the HEP observations, the Arase has observed more than 15 magnetic storms with Dst values under -30 nT. For these storm events, we investigate variations of energetic electron flux, primarily focusing on the dropout of the outer radiation belt during the storm main phases. Using the superposed epoch analysis, we derived average variations of the energy spectrum as a function of L and time. With this, we found the energy dependency of the flux dropout, which was identified by fitting a power-law function to energy spectra, and subsequent recovery and enhancements of the outer belt electrons. The energy spectrum tends to become hard between L ˜3 to 7 during the storm recovery phase, indicating the acceleration of energetic electrons. We also examined simultaneous observations of electrons made by Van Allen Probes to compare them with the Arase data for the same magnetic storms.

磁気圏MHDシミュレーションとテスト粒子シミュレーションの連成計算にもとづく太陽風動圧変化に伴う放射線帯外帯電子の消失

伊藤 大輝 [1]; 三好 由純 [2]; 齊藤 慎司 [3]; 松本 洋介 [4]; 天野 孝伸 [5]
[1] 名大・ISEE; [2] 名大 ISEE; [3] 名大理; [4] 千葉大理; [5] 東大・理

Flux decrease of outer radiation belt electrons associated with solar wind pressure pulse: A Code coupling simulation

Hiroki Ito[1]; Yoshizumi Miyoshi[2]; Shinji Saito[3]; Yosuke Matsumoto[4]; Takanobu Amano[5]
[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] Nagoya Univ.; [4] Chiba University; [5] University of Tokyo

Relativistic electron flux of the outer radiation belt dynamically changes in response to solar wind variations. There exist several conditions to cause the flux drop-out of the outer belt electrons. The magnetopause shadowing (MPS) is one of the processes to cause the rapid loss of outer belt electrons (e.g.,Kim et al.,2008). In this study, we have done a code-coupling simulation using GEMSIS-RB test particle simulation code (Saito et al., 2010) and GEMSIS-GM global MHD magnetosphere simulation code (Matsumoto et al., 2010) to demonstrate how radiation belt electrons are lost through the MPS process, by focusing pm the equatorial pitch angle and local time dependence. We calculate trajectories of electrons in electromagnetic fields calculated from GEMSIS-GM with initial L-shells from 9 to 11, initial energies from 100 keV to 10 MeV, and initial pitch angles between 85 degrees and 90 degrees, using the guiding-center equation. The simulation consists of the following three phases associated with variations of the solar wind dynamic pressure; [1] The standoff distance of magnetopause at the subsolar point is 12 Re with the initial dynamic pressure of 1.0 nPa. [2] The solar wind dynamic pressure becomes 2.5 nPa, and the magnetopause moves to 9 Re. [3] The solar wind dynamic pressure decreases, so that the inflation of the magnetopause takes place and the standoff distance of the magnetopause is 10 Re. The simulation shows that electrons move to the open field line due to the earthward movement of the magnetopause and then electrons escape to the interplanetary along the field line at the dayside in the phase [2]. On the other hand, electrons are lost at the night side along the open field lines when the dynamic pressure decreases in phase [3] due to the outward motion of trapped electrons caused by dusk-to-dawn electric fields associated with the expansion of the magnetosphere. Almost all lost electrons (~90%) have strong pitch angle scattering by the drift shell bifurcation which breaks the second adiabatic invariant.

Meridional distribution of proton plasma and pressure-driven currents in the nightside inner magnetosphere: Arase observation

Shun Imajo[1]; Masahito Nose[2]; Satoshi Kasahara[3]; Ayako Matsuoka[4]; Shoichiro Yokota[5]; Kunihiro Keika[6]; Tomoaki Hori[7]; Mariko Teramoto[8]; Kazuhiro Yamamoto[9]; Satoshi Oimatsu[10]; Reiko Nomura[11]; Akiko Fujimoto[12]; Iku Shinohara[13]; Yoshizumi Miyoshi[7]
[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] The University of Tokyo; [4] ISAS/JAXA; [5] Osaka Univ.; [6] University of Tokyo; [7] ISEE, Nagoya Univ.; [8] ISEE, Nagoya University; [9] Geophysics, Kyoto Univ.; [10] Geophysics, Kyoto Univ; [11] JAXA; [12] Kyutech; [13] ISAS/JAXA

Plasma pressure, anisotropy, and beta value in the inner magnetosphere have been well examined in terms of L value and magnetic-local time distributions, but their the meridional distribution has not yet been revealed by observations. The present study examines the averaged meridional distributions of proton plasma parameters and pressure-driven currents in the nightside (20-04 h MLT) ring current region during disturbed time (SYM-H from -50 to -20 nT) using the long-term data set of the Arase satellite. Since the Arase satellite has a large inclination orbit (31^o inclination), it covers the magnetic latitude (MLAT) range of 0-40^o and the radial distance greater than 6 Re. The plasma pressure was calculated based on proton fluxes for the energy range of 10-180 keV observed by the Medium-energy particle experiments - ion mass analyzer (MEP-i) instrument onboard Arase. We find that the perpendicular and parallel plasma pressures significantly decrease with the absolute value of the magnetic latitude (|MLAT|) at L less than 5 (L is defined by the Tsyganenko 96 model). The plasma pressure on the same L shell at 30-40^o |MLAT|is about 20-50% of that at 0-10^o. On the other hand, at L greater than 5.5, the plasma pressure does not monotonically decrease with |MLAT|. The pressure anisotropy which is defined by the perpendicular pressure divided by the parallel pressure decreases with radial distance, and shows no clear dependence on |MLAT|. The perpendicular plasma beta drastically decreases with |MLAT|. We compare the observed plasma pressure distribution with the theory of field-aligned particle distribution proposed by Parker [1957]. The relative plasma pressure distribution predicted from the magnetic strength and anisotropy is almost consistent with the observed plasma pressure for L = 4-5. We then calculated the azimuthal current distribution based on the proton plasma pressure distribution in the $(X_{SM}{}^2+X_{SM}{}^2)^{1/2}$ - Z_{SM} plane. The resultant pressure-gradient current spreads over ~0-20^o in |MLAT|, while the curvature current is limited within ~0-10^o. These results indicate that the latitudinal variations of plasma parameters and pressure-driven currents are not negligible, and the magnetic latitude of satellites should be considered in addition to L value and magnetic local time of satellites.

Longitudinal Structure of Oxygen Torus in the Inner Magnetosphere: Simultaneous Observations by Arase and Van Allen Probe A

Masahito Nose[1]; Ayako Matsuoka[2]; Atsushi Kumamoto[3]; Yoshiya Kasahara[4]; Jerry Goldstein[5]; Mariko Teramoto[6]; Fuminori Tsuchiya[7]; Shoya Matsuda[8]; Masafumi Shoji[9]; Shun Imajo[10]; Satoshi Oimatsu[11]; Kazuhiro Yamamoto[12]; Yuki Obana[13]; Reiko Nomura[14]; Akiko Fujimoto[15]; Iku Shinohara[16]; Yoshizumi Miyoshi[9]; William S. Kurth[17]; Craig A. Kletzing[18]; Charles W. Smith[19]; Robert J. Macdowall[20]
[1] ISEE, Nagoya Univ.; [2] ISAS/JAXA; [3] Dept. Geophys, Tohoku Univ.; [4] Kanazawa Univ.; [5] Space Science and Engineering Div., SwRI; [6] ISEE, Nagoya University; [7] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [8] ISAS/JAXA; [9] ISEE, Nagoya Univ.; [10] ISEE, Nagoya Univ.; [11] Geophysics, Kyoto Univ; [12] Geophysics, Kyoto Univ.; [13] Engineering Science, Osaka Electro-Communication Univ.; [14] JAXA; [15] Kyutech; [16] ISAS/JAXA; [17] Dept. of Physics and Astronomy, Univ. of Iowa; [18] Department of Physics and Astronomy, UoI; [19] Department of Physics, UNH; [20] NASA/GSFC

Simultaneous observations of the magnetic field and plasma waves made by the Arase and Van Allen Probe A satellites at different MLT enable us to deduce the longitudinal structure of an oxygen torus for the first time. During 04:00-07:10 UT on 24 April 2017, Arase flew from L=6.2 to 2.0 in the morning sector and detected an enhancement of the average plasma mass up to ~3.5 amu around L=4.9-5.2 and MLT=5.0 hr, implying that the plasma consists of approximately 15% O^+ ions. Probe A moved outbound from L=2.0 to 6.2 in the afternoon sector during 04:10-07:30 UT and observed no clear enhancements in the average plasma mass. For this event, the O^+ density enhancement in the inner magnetosphere (i.e., oxygen torus) does not extend over all MLT but is skewed toward the dawn, being described more precisely as a crescent-shaped torus or a pinched torus.

Statistical properties of molecular ions in the ring current observed by the Arase (ERG) satellite

Kanako Seki[1]; Masayoshi Takada[2]; Kunihiro Keika[3]; Satoshi Kasahara[4]; Shoichiro Yokota[5]; Ayako Matsuoka[6]; Mariko Teramoto[7]; Yasunobu Ogawa[8]; Kazushi Asamura[9]; Yoshizumi Miyoshi[10]; Iku Shinohara[11]
[1] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [2] Earth and Planetary Science, Tokyo Univ.; [3] University of Tokyo; [4] The University of Tokyo; [5] Osaka Univ.; [6] ISAS/JAXA; [7] ISEE, Nagoya University; [8] NIPR; [9] ISAS/JAXA; [10] ISEE, Nagoya Univ.; [11] ISAS/JAXA

It is observationally known that the terrestrial heavy ion contribution to the magnetospheric plasma increases with increasing geomagnetic activities, while the mechanisms of the enhanced ionospheric supply are far from understood. O+ ions are the main species of the terrestrial heavy ions. The heavier molecular ions such as NO+ and O2+ have been also observed in the various regions of the magnetosphere during geomagnetically active periods [e.g., Klecker et al, 1986; Peterson et al., 1994; Christon et al, 1994]. In order to get the molecular ion outflows from the deep ionosphere, they need to be transported upward within a short time scale (˜order of minutes) to overcome the dissociative recombination lifetime at the source altitudes typically less than 300 km altitude. Thus the existence of molecular ions in the magnetosphere can be a tracer of the rapid ion outflow from the deep ionosphere. However, previous observations based on event studies, and how frequently the molecular ions exist in the magnetosphere remains to be investigated.

In this paper, we report on statistical properties of molecular ions (O2+/NO+/N2+) in the ring current observed by the Arase (ERG) satellite and their relations to the solar wind and geomagnetic conditions. The ion composition data of the Arase satellite obtained by MEPi and LEPi instruments, which detects the ions less than 180 keV/q, were analyzed in details. The investigated period from late March to December 2017 includes 11 geomagnetic storms with the minimum Dst index less than -40 nT. The molecular ions are observed in the region of L=2.5-6.6 and clearly identified at energies above ˜12 keV during most of the magnetic storms. The lowest ion energy of detected molecular ions is consistent between two instruments (LEPi and MEPi). During quiet times, molecular ions are not observed. The average energy density and number density ratios of the molecular ions to O+ are 2.8 and 2.3 percent, respectively. The peak molecular ion ratio tends to increase with the size of the magnetic storms measured with the minimum Dst. The results show that the existence of molecular ions in the ring current is rather common even during small magnetic storms, and suggest that the rapid ion outflow from the deep ionosphere occurs frequently during geomagnetically active periods.

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Molecular ion outflow mechanism from the deep ionosphere observed by EISCAT radar in conjunction with the Arase (ERG) satellite.

Masayoshi Takada[1]; Kanako Seki[2]; Yasunobu Ogawa[3]; Kunihiro Keika[4]; Satoshi Kasahara[5]; Shoichiro Yokota[6]; Kazushi Asamura[7]; Yoshizumi Miyoshi[8]
[1] Earth and Planetary Science, Tokyo Univ.; [2] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [3] NIPR; [4] University of Tokyo; [5] The University of Tokyo; [6] Osaka Univ.; [7] ISAS/JAXA; [8] ISEE, Nagoya Univ.

Abstruct:

Molecular ions (N_2^+,O_2^+,NO^+) in the inner magnetosphere were first observed by AMPTE/IRM [Klecker et al., 1986] and also recently observed by Arase during geomagnetically active periods. It is considered that these molecular ions have been transported upward by some heating processes in the ionosphere [e.g., Kosch et al., 2010]. However, in order to achieve heavy molecular ions outflow from the deep ionosphere around the altitude of ˜300 km by the heating process, the rapid upward transport is required. In this study, we aim at quantitative assessment of the outflow process of the molecular ions from the deep ionosphere by using data of EISCAT ultra high frequency radar in conjunction with the Arase (ERG) satellite.

We here focus on the magnetic storm event started on the September 7, 2017. During the storm, the Arase satellite and EISCAT radar have simultaneous observations from 16:00 to 20:00 UT on September 8, 2017. The minimum Dst index of the magnetic storm was -125 nT. During the period, the MEPi instrument onboard the Arase satellite detected high-energy (>20 keV) molecular ions (N_2^+,O_2^+,NO^+) in the ring current and EISCAT radar observed strong upward flow of ˜100 m/s and ion heating which made the ion temperature higher than 2000 K. The EISCAT data and models of the ionosphere (IRI) and neutral upper atmosphere (MSISE-90) enabled us to discuss the heating and outflow mechanisms. We evaluated each term of the equation of motion about molecular ions quantitatively. The results suggest that the most important part of these processes is the acceleration mechanism driven by pressure gradient of ions itself. We also estimated the electric field strength at ˜110 km based on the statistical study by EISCAT radar [Davies and Robinson, 1997], and found that there was enhancement of the electric field by a factor of 2 in the deep ionosphere during the period.

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Investigation of small-scale electron density perturbations observed by the ARASE satellite near the plasmapause: Initial Results

Neethal Thomas[1]; Kazuo Shiokawa[2]; Yoshizumi Miyoshi[3]; Yoshiya Kasahara[4]; Iku Shinohara[5]; Atsushi Kumamoto[6]; Ayako Matsuoka[7]
[1] ISEE; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] Kanazawa Univ.; [5] ISAS/JAXA; [6] Dept. Geophys, Tohoku Univ.; [7] ISAS/JAXA

The region of the Earth's inner magnetosphere, which constitutes a torus of the cold (low energy ˜1-10 electron volt (eV)), dense (10-10^4 cm^{-3}) plasma, trapped to the Earth's magnetic and gravitational field is called plasmasphere. The outer boundary of the plasmasphere termed, plasmapause, separates this dense, cold plasma population in the inner magnetosphere from highly energized, low density plasma of the outer region. Plasmapause is often complicated by the presence of various density structures and can affect the propagation characteristics of different plasma waves such as electromagnetic ion cyclotron waves (EMIC), Extreme/Very Low frequency (ELF/VLF) chorus waves etc. The observations from recently deployed Japanese satellite mission ERG (Exploration of energization and Radiation in Geospace, also known as ARASE) have revealed the occurrence of several small scale density perturbations near the plasmapause location. These density variations often observed in the ARASE observations were less investigated and therefore have not been addressed yet. The present study investigates these small scale density perturbations in detail by probing the electron density data with 1-minute resolution together with 8-sec vector magnetic field measurements from ARASE satellite. The electron density data is obtained from the High Frequency Analyzer (HFA) onboard ARASE, which measures the upper hybrid resonance (UHR) frequency of the plasma in the frequency range between 10 kHz to 10 MHz together with Onboard Frequency Analyzer (OFA), for UHR frequency less than 20 kHz. We have investigated three months of data from April - June 2017 to understand the characteristics of these density perturbations, i.e., their occurrence rate, scale size, location with respect to plasmapause, and dependence on geomagnetic conditions. A preliminary analysis indicates that the occurrence of these density perturbations increases with increasing radial distances from L=3 to 6. In the presentation we will show several case studies together with the statistical results and will discuss the results in the light of possible source mechanisms responsible for their origin.

あらせ衛星と GNSS-TEC 観測データを用いた磁気嵐時のプラズマ圏・電離圏の時空間変動について

新堀 淳樹 [1]; 大塚 雄一 [2]; 津川 卓也 [3]; 西岡 未知 [3]; 熊本 篤志 [4]; 土屋 史紀 [5]; 松田 昇也 [6]; 笠原 禎也 [7]; 松岡 彩子 [8]

[1] 名大・宇地研; [2] 名大宇地研; [3] 情報通信研究機構; [4] 東北大・理・地球物理; [5] 東北大・理・惑星プラズマ大気; [6] ISAS/JAXA; [7] 金沢大; [8] JAXA 宇宙研

Temporal and spatial variations of storm-time plasmasphere and ionosphere using Arase satellite and GNSS-TEC observation data

Atsuki Shinbori[1]; Yuichi Otsuka[2]; Takuya Tsugawa[3]; Michi Nishioka[3]; Atsushi Kumamoto[4]; Fuminori Tsuchiya[5]; Shoya Matsuda[6]; Yoshiya Kasahara[7]; Ayako Matsuoka[8]

[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] NICT; [4] Dept. Geophys, Tohoku Univ.; [5] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [6] ISAS/JAXA; [7] Kanazawa Univ.; [8] ISAS/JAXA

In order to investigate characteristics of temporal and spatial variations of the plasmasphere and ionosphere during a geomagnetic storm, we analyze the 5-min average Global Navigation Satellite System (GNSS)-TEC data together with solar wind, interplanetary magnetic field, geomagnetic field, and electron density in the inner magnetosphere and ionosphere obtained from Arase High Frequency Analyzer (HFA) (subcomponent of Plasma Wave Experiment (PWE)) observation data. The electron density along the Arase satellite orbit is determined with high time resolution of 1 or 8 seconds from the upper limit frequency of the upper hybrid resonance (UHR) waves. In calculating the electron density, we use 8-sec spin-average total magnetic field intensity data obtained from the Magnetic Field Experiment (MGF) instrument. On the other hand, to identify the location of the mid-latitude trough minimum during a geomagnetic storm, we first subtract an average TEC data of 10 geomagnetically quiet days in April from the storm-time TEC data. As a next step, we identify a minimum value of the subtracted TEC in the mid-latitudes as a trough minimum in a TEC keogram. As a result, the location of the mid-latitude trough minimum moves equatorward from 60 to 48 degrees in geomagnetic latitude (GMLAT) within 4 hours after the onset of the main phase of the geomagnetic storm. The movement speed increases from 1.3 to 3.5 degrees of geomagnetic latitude per hour after the onset of a storm-time high-latitude geomagnetic disturbance. The enhancement of the speed means an abrupt shrink of the plasmasphere due to a sudden enhancement of convection electric field in the inner magnetosphere associated with the geomagnetic disturbance. The location of the nighttime mid-latitude trough is in good agreement with that of an abrupt drop of electron density in the inner magnetosphere detected by the Arase satellite. In this case, the electron density profile along the Arase orbit shows an irregular variation near the plasmapause. The geomagnetic longitude distribution of the location of the mid-latitude trough minimum shows a significant variation with a scale of 1000 – 2500 km. The feature can be found during a quiet time, but the pattern of the longitudinal variation is different between the storm and quiet times. This phenomenon has not yet been reported by previous studies due to limitations in the coverage density of GNSS receiver networks. After the start of the recovery phase of the geomagnetic storm, the location of the mid-latitude trough minimum rapidly moves poleward back to the quiet-time location within 4 hours in a geomagnetic longitude range of 310 – 360 degrees in geomagnetic longitude. The average speed of the poleward movement is 2.3 degrees of geomagnetic latitude per hour.

Plasma Density Distributions along the Magnetic Fields: The Coordinated Observation of Arase and Van Allen Probes

Yuki Obana[1]; Naomi Maruyama[2]; Atsuki Shinbori[3]; Yukinaga Miyashita[4]; Masahito Nose[3]; Ayako Matsuoka[5]; Mariko Teramoto[6]; Reiko Nomura[7]; Akiko Fujimoto[8]; Yoshimasa Tanaka[9]; Manabu Shinohara[10]; Yoshizumi Miyoshi[11]; Iku Shinohara[12]; Atsushi Kumamoto[13]; Fuminori Tsuchiya[14]; Shoya Matsuda[15]; Yoshiya Kasahara[16]
[1] Engineering Science, Osaka Electro-Communication Univ.; [2] CU/CIRES, NOAA/SWPC; [3] ISEE, Nagoya Univ.; [4] KASI; [5] ISAS/JAXA; [6] ISEE, Nagoya University; [7] JAXA; [8] Kyutech; [9] NIPR/SOKENDAI; [10] Kagoshima National College of Technology; [11] ISEE, Nagoya Univ.; [12] ISAS/JAXA; [13] Dept. Geophys, Tohoku Univ.; [14] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [15] ISAS/JAXA; [16] Kanazawa Univ.

Plasma density distributions along the magnetic fields are studied using coordinated observation of Arase and Van Allen Probes.

From radio and plasma waves observed by the PWE onboard Arase and the EMFISIS onboard Van Allen Probes we identify upper hybrid resonance frequencies and determine in-situ electron number densities. Due to the difference of inclination of orbits of Arase and Van Allen Probes, we can measure electron number densities at different magnetic latitudes on the same field line by utilizing data obtained by both Arase and Van Allen Probes. Such data sets provide information of field aligned density distributions.

On the other hand, The MGF onboard Arase measures the static magnetic field and low-frequency magnetic field variations. From the MGF data, we obtained field line resonance (FLR) frequency and estimated equatorial plasma mass densities. Solving the FLR wave equation, we assumed power-low density distribution with value of power low index which is estimated from the above-mentioned electron density measurements. Furthermore, we derived average ion mass from mass density and electron density with the assumption of quasi-neutrality of plasma.

We will report plasma density distribution in the inner magnetosphere including the plasmasphere, plasma trough and plume.

Wire Probe Antenna and Electric Field Detector of Plasma Wave Experiment aboard ARASE: Evaluation results – II

Yasumasa Kasaba[1]; Keigo Ishisaka[2]; Yoshiya Kasahara[3]; Tomohiko Imachi[3]; Satoshi Yagitani[3]; Hirotsugu Kojima[4]; Shoya Matsuda[5]; Masafumi Shoji[6]; Satoshi Kurita[6]; Tomoaki Hori[6]; Atsuki Shinbori[7]; Mariko Teramoto[8]; Yoshizumi Miyoshi[6]; Tomoko Nakagawa[9]; Naoko Takahashi[10]; Yukitoshi Nishimura[11]; Ayako Matsuoka[12]; Atsushi Kumamoto[13]; Fuminori Tsuchiya[14]; Reiko Nomura[15]
[1] Tohoku Univ.; [2] Toyama Pref. Univ.; [3] Kanazawa Univ.; [4] RISH, Kyoto Univ.; [5] ISAS/JAXA; [6] ISEE, Nagoya Univ.; [7] ISEE, Nagoya Univ.; [8] ISEE, Nagoya University; [9] Tohoku Inst. Tech.; [10] Univ. of Tokyo; [11] UCLA; [12] ISAS/JAXA; [13] Dept. Geophys, Tohoku Univ.; [14] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [15] JAXA

This paper shows the evaluation results of Wire Probe Antenna (WPT) and Electric Field Detector (EFD), which are one of the key parts of Plasma Wave Experiment (PWE) aboard the Arase (ERG) Satellite. The data qualifications and cautions revised from the first-year observations are shown for the scientists who expect to utilize this data sets.

It is well known that the potential and electric field measured by WPT and EFD has the tricky characteristics, which is common in the similar instruments aboard the MMS, Themis, and many previous spacecraft. Even though the Level-2 calibrated data are distributed, we need to summarize the potential problems for the data analyses of electric field in low frequency range caused by the effects of surrounding electron plasma characteristics on the spacecraft potential, wake effect caused by the spacecraft motions, and possible artificial contaminations, in order to support the fruitful scientific results from this valuable data sets with careful treatments. Possible comparisons with electron density and temperature with magnetic field data are newly added.

あらせ衛星を用いた内部磁気圏 Pc3-5 の統計解析

寺本 万里子 [1]; 松岡 彩子 [2]; 野村 麗子 [3]; 笠原 禎也 [4]; 笠羽 康正 [5]; 松田 昇也 [6]; 堀 智昭 [7]; 小路 真史 [7]; 津川 靖基 [7]; 能勢 正仁 [8]; 藤本 晶子 [9]; 田中 良昌 [10]; 篠原 学 [11]; 篠原 育 [12]; 三好 由純 [7]
[1] 名大・宇地研; [2] JAXA 宇宙研; [3] JAXA; [4] 金沢大; [5] 東北大・理; [6] ISAS/JAXA; [7] 名大 ISEE; [8] 名大・宇地研; [9] 九工大; [10] 国立極地研究所/総研大; [11] 鹿児島高専; [12] 宇宙研／宇宙機構

Statistical analysis of Pc3-5 pulsations observed in the inner magnetosphere by the Arase satellite

Mariko Teramoto[1]; Ayako Matsuoka[2]; Reiko Nomura[3]; Yoshiya Kasahara[4]; Yasumasa Kasaba[5]; Shoya Matsuda[6]; Tomoaki Hori[7]; Masafumi Shoji[7]; Yasunori Tsugawa[7]; Masahito Nose[8]; Akiko Fujimoto[9]; Yoshimasa Tanaka[10]; Manabu Shinohara[11]; Iku Shinohara[12]; Yoshizumi Miyoshi[7]
[1] ISEE, Nagoya University; [2] ISAS/JAXA; [3] JAXA; [4] Kanazawa Univ.; [5] Tohoku Univ.; [6] ISAS/JAXA; [7] ISEE, Nagoya Univ.; [8] ISEE, Nagoya Univ.; [9] Kyutech; [10] NIPR/SOKENDAI; [11] Kagoshima National College of Technology; [12] ISAS/JAXA

To investigate latitudinal structure of Pc3-5 waves, we have performed statistical analysis on the magnetic field data observed by the the Magnetic Field Experiment (MGF) on the Arase (ERG) satellite from March 21, 2017 to April 30, 2018. We identified 202 Pc3, 3037 Pc4, and 346 Pc5 events using a method for automatically detecting ULF waves. The compressional component is dominant for the identified Pc3-5. We investigate the spatial occurrence rate distribution. There are distinct differences of the occurrence rate between Pc3 pulsations and Pc4-5 pulsations. The occurrence rate of Pc3 pulsations is high in the day side at L $<$6 near the magnetic equator while the occurrence rate of Pc4-5 waves is high in the flunk side at L $>$6 off the magnetic equator. We also found that the Pc4-5 waves frequently appear at $|$Mlat$|>$30 degrees at L $>$6, which might indicate that Arase can observe a fundamental odd mode resonance far from the magnetic equator.

In this study, we will also report the spatial distributions of ULF waves in the electric field, using the Electric Field Detector (EFD) of Plasma Wave Experiment (PWE) aboard the Arase satellite.

Contribution of ULF and chorus waves to the radiation belt dynamics based on Arase observations and BATSRUS+CRCM simulation

Naoko Takahashi[1]; Kanako Seki[2]; Mariko Teramoto[3]; Mei-Ching Fok[4]; Yihua Zheng[5]; Kazuo Shiokawa[6]; Dmitry Baishev[7]; Akimasa Yoshikawa[8]; Tsutomu Nagatsuma[9]; Ayako Matsuoka[10]; Yoshiya Kasahara[11]; Nana Higashio[12]; David Hartley[13]

[1] Univ. of Tokyo; [2] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [3] ISEE, Nagoya University; [4] NASA/GSFC; [5] NASA GSFC; [6] ISEE, Nagoya Univ.; [7] IKFIA, SB, RAS; [8] ICSWSE/Kyushu Univ.; [9] NICT; [10] ISAS/JAXA; [11] Kanazawa Univ.; [12] JAXA; [13] Univ. of Iowa

The Earth's radiation belt exhibits a dramatic variation, especially during the active condition of the magnetosphere such as magnetic storms. Two candidate mechanisms that are known to cause variations of relativistic electrons include: (1) the radial diffusion of the electrons driven by ultra-low-frequency (ULF) waves in Pc5 frequency ranges (1.6-6.7 mHz) and (2) the local acceleration caused by wave-particle interactions between whistler-mode chorus waves and radiation belt particles. Over the past decade, multi-point observations enable us to discuss the contribution of each wave to the acceleration of relativistic electrons. However, it is debatable how much these waves affect to the global variation of the radiation belt. In addition, it is known that the radiation belt variation depends on the solar wind type, i.e., coronal mass ejections (CME) and co-rotating interaction regions (CIR), but the difference of ULF and chorus wave activities between different solar wind-type storms is still an open issue. In this study, we compare the temporal variation of ULF and chorus wave activities between CME-and CIR-type storms, and then discuss the relationship to the acceleration of relativistic electrons in the radiation belt.

We focus on two CME-type storms (28 May 2017 and 8 September 2017) and two CIR-type storms (27 March 2017 and 27 September 2017). During these storms, Arase satellite observed the enhancement of relativistic electron flux and activities of ULF and chorus waves. To understand the global extent of ULF waves, we calculate the total wave power from Arase-related ground observations. The ULF wave activity on the ground depends on both AE index and solar wind dynamic pressure, which consistent with magnetic field data detected by the Arase satellite. We also investigate the characteristics of ULF and chorus activity in the magnetosphere using both Arase satellite and Van Allen Probes. During CME-type storms, the ULF wave activity is large in the main phase and the end of the recovery phase, while the chorus wave activity is large in the beginning of the recovery phase. On the other hand, during CIR-type storms, both ULF and chorus wave activities are constantly large. In this presentation, we will also show the global distribution of ULF and chorus waves in the magnetosphere based on numerical simulations.

Pc4-5帯トロイダルモードULF波動とホイッスラーモード・コーラス放射の強度変調との対応に関する研究

大野 敦裕[1]; 加藤 雄人[1]; 熊本 篤志[2]; 土屋 史紀[3]; 寺本 万里子[4]; 笠原 禎也[5]; 松田 昇也[6]; 松岡 彩子[7]
[1] 東北大・理・地球物理; [2] 東北大・理・地球物理; [3] 東北大・理・惑星プラズマ大気; [4] 名大・宇地研; [5] 金沢大; [6] ISAS/JAXA; [7] JAXA宇宙研

Study of the relationship between whistler-mode chorus emissions and toroidal mode Pc4-5 ULF waves

Atsuhiro Ono[1]; Yuto Katoh[1]; Atsushi Kumamoto[2]; Fuminori Tsuchiya[3]; Mariko Teramoto[4]; Yoshiya Kasahara[5]; Shoya Matsuda[6]; Ayako Matsuoka[7]
[1] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [2] Dept. Geophys, Tohoku Univ.; [3] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [4] ISEE, Nagoya University; [5] Kanazawa Univ.; [6] ISAS/JAXA; [7] ISAS/JAXA

Whistler-mode chorus emissions are electromagnetic plasma waves generated in the equatorial region of the terrestrial magnetosphere. Previous studies suggested that chorus emissions play an important role in the precipitation of energetic electrons into the atmosphere through wave-particle interaction. Since the amplitude modulation of chorus emissions should controls the variation of the electron precipitation, the investigation of the generation mechanism of chorus emissions is essentially important in understanding the energetic electron precipitation. One of the important factors which modulate the amplitude of chorus emissions is ULF (Ultra Low Frequency) waves, which are low frequency plasma waves occurring in the terrestrial magnetosphere. Previous studies reported the relationship between chorus emissions and Pc4-5 ULF waves, whose wave period is about 1-10 minutes. Li et al. (2011) reported that the periodic intensity variations of chorus emissions associated with compressional Pc4-5 ULF waves, in which chorus emissions are enhanced at the timing of the Pc4-5 ULF waves oscillate southward, corresponding to the intensity minimum of the ambient magnetic field. Jaynes et al. (2015) reported that the periodic variations of chorus emissions associated with toroidal and poloidal mode Pc4-5 ULF waves, while chorus emissions enhanced twice during one wave period of the ULF waves.

In the present study, we investigate the relationship between the amplitude modulation of chorus emissions and ULF waves using observation results of the Arase satellite. We use the data observed by the Onboard Frequency Analyzer (OFA) of the Plasma Wave Experiment (PWE) and the Magnetic Field Experiment (MGF). We analyze the data during the campaign observation of the Arase satellite with stations on the ground, from March to June 2017, and identified 4 events of the enhancement of chorus emissions simultaneously with ULF waves. In this paper, we focus on Pc4-5 waves observed from 2130UT to 2230UT on March 27, 2017 when Arase satellite was located in the magnetic local time from 04:00 to 04:30, the magnetic latitude from -12.7 to -7.4 degrees, and the L-value from 6.3 to 5.9. These Pc4-5 waves appear with the periods of about 2-3 minutes and are dominated by the toroidal component. We also find the periodic enhancements of chorus emissions with the periodicity of about 2-3 minutes, where chorus emissions enhanced at the timing of the toroidal component of ULF wave directing westward. The identified phase relationship between chorus emissions and the toroidal mode ULF waves is different from those reported in Jaynes et al. (2015).

地球磁気圏の磁気赤道領域で発生するホイッスラーモード・コーラス放射は、波動粒子相互作用を通して、磁気赤道面に存在する高エネルギー電子を地球電離圏に降り込ませる役割を果たしていると考えられている。そのため、地球電離圏に降り込む電子のフラックスの変動には、コーラス放射の強度変化が深く関わっていると考えられており、これらの現象について考察する上でコーラス放射の発生機構を理解することは本質的に重要である。コーラス放射の発生機構に関係すると考えられている現象の1つとして、地球の磁気圏で発生する低周波のプラズマ波動であるULF波動が挙げられる。過去の研究では、周期が約1-10分のPc4-5帯のULF波動とコーラス放射の強度変化の間に対応関係があるということが指摘されている。Li et al. (2011)では、コーラス放射の周期的強度変化はcompressionalモードのPc4-5帯ULF波動と対応関係があり、磁気赤道面でULF波動が南向きに振動するとき、すなわち背景磁場強度が最小になるときにコーラス放射の強度が増大するという対応関係が報告されている。一方で、Jaynes et al. (2015)では、コーラス放射の周期的強度変化はトロイダルモード・ポロイダルモードのPc4-5帯ULF波動と対応関係があり、ULF波動の1振動周期の間にコーラス放射の強度が2回極大値を取ることが指摘されている。このように過去の研究では、コーラス放射の強度変化とULF波動の間に、ULF波動のモードごとに異なった対応関係が存在することが指摘されている。

本研究では、コーラス放射の強度変化とULF波動の対応関係について理解することを目的として、あらせ衛星の観測結果を解析する。2017年3月から4月にかけて実施 されたあらせ衛星と地上観測局とのキャンペーン観測期間中に得られた結果に着目して、プラズマ波動・電場観測器(PWE)のOnboard Frequency Analyzer(OFA)と磁場観測器(MGF)の観測データの解析を行った結果、ULF波動とコーラス放射が同時に計測されているイベントを4例同定した。本発表では特に2017年3月27日UT21:30-22:30に計測されたイベントに着目して解析を行った結果について報告する。解析対象とする時間帯には、あらせ衛星は磁気地方時04:00から04:30、磁気緯度-12.7°から-7.4°、L値6.3から5.9程度の地点、すなわち地球磁気圏の磁気赤道面付近の朝側領域に位置していた。解析の結果、MGFにより観測された磁場波形に周期2-3分程度のPc4-5帯に対応する周期的な変動成分が見出された。このPc4-5帯の周期的な磁場変動はポロイダル成分、トロイダル成分とcompressional成分の全ての成分に見いだされたが、特にトロイダル成分の振幅が卓越しているこ

とが示された。また、OFA により観測された波動電磁場成分のスペクトル解析結果から、kHz 帯に 2-3 分程度の周期でコーラス放射が周期的に発生していることが確認された。これらの MGF ならびに OFA の観測結果を比較した結果、トロイダルモードの Pc4-5 帯 ULF 波動の磁場成分が西向きに卓越する位相においてコーラス放射の波動強度が増大する対応関係が確認された。コーラス放射の発生周期は ULF 波動の周期と同程度であり、Jaynes et al. (2015) と異なる対応関係であることが示された。本発表では、ULF 波動の位相とコーラス放射の発生との対応関係について詳細に解析した結果を報告する。

プラズマポーズ近傍でのプラズマ密度変動とホイッスラーモード・コーラス放射との対応

竹中 達 [1]; 加藤 雄人 [2]; 熊本 篤志 [3]; 土屋 史紀 [4]; 木村 智樹 [5]; 笠原 禎也 [6]; 八木谷 聡 [6]; 尾崎 光紀 [6]; 松田 昇也 [7]; 松岡 彩子 [8]; Wang Shiang-Yu[9]; 風間 洋一 [10]; Tam Sunny W. Y.[11]
[1] 東北大・理・地物; [2] 東北大・理・地球物理; [3] 東北大・理・地球物理; [4] 東北大・理・惑星プラズマ大気; [5] Tohoku University; [6] 金沢大; [7] ISAS/JAXA; [8] JAXA 宇宙研; [9] 中央研究院天文及天文物理研究所; [10] 中央研究院天文・宇宙物理学研究所; [11] 台湾・成大・宇宙プラズマ

Study of the plasma density variation with the enhancement of chorus emissions in the vicinity of plasmapause

Toru Takenaka[1]; Yuto Katoh[2]; Atsushi Kumamoto[3]; Fuminori Tsuchiya[4]; Tomoki Kimura[5]; Yoshiya Kasahara[6]; Satoshi Yagitani[6]; Mitsunori Ozaki[6]; Shoya Matsuda[7]; Ayako Matsuoka[8]; Shiang-Yu Wang[9]; Yoichi Kazama[10]; Sunny W. Y. Tam[11]
[1] Geophysics, Tohoku Univ.; [2] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [3] Dept. Geophys, Tohoku Univ.; [4] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [5] Tohoku University; [6] Kanazawa Univ.; [7] ISAS/JAXA; [8] ISAS/JAXA; [9] Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan; [10] Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan; [11] ISAPS, NCKU, Taiwan

Whistler-mode waves satisfy the cyclotron resonance condition with energetic electrons in the wide kinetic energy range from keV to MeV in the inner magnetosphere. Previous studies suggested that whistler-mode chorus emissions play significant roles in the pitch angle scattering of energetic electrons contributing the enhancement of diffuse/pulsating aurora. The periodicity of pulsating aurora is closely related to the repetition period of chorus emissions, but the mechanism controlling the repetition period has not been fully understood.

In the present study, we discuss the enhancement of chorus emissions observed in association with the plasma density variation around the plasmapause, based on the Arase satellite observation. The event was appeared in the spectra measured by Onboard Frequency Analyzer (OFA) of Plasma Wave Experiment (PWE) on board the Arase satellite from 02:05 to 02:45 UT in 5 May 2017. During the event, Arase moved from L = 5.4 to 5.8, MLT from 01:00 to 01:30, and the magnetic latitude from 2.7 to 7.2 degree, respectively. The enhancement of the spectra was identified from 02:05 UT in the frequency range from 1.3 kHz to 2.3 kHz with a distinct gap at 1.85 kHz, indicating upper and lower band whistler-mode chorus emissions. The frequency range of the waves decreased with increasing the radial distance of Arase from the Earth, closely associated with the decrease of the local background magnetic field intensity. The history of the upper-hybrid resonance (UHR) frequency identified in the spectra measured by High Frequency Analyzer (HFA) of PWE showed that Arase measured the enhancement soon after the crossing of the plasmapause around 02:03 UT. The number density of the background plasma estimated from the UHR frequency varies from 24 to 77 cm-3 during a few minutes. We estimate the resonance energy for whistler-mode waves of frequency of 0.5 fce to 762 and 222 eV for the plasma density of 24 and 77 cm-3, respectively, where fce is the electron cyclotron frequency.

In this study, we focus on the correspondence among the enhancement of chorus emissions, plasma density variation, and the flux variation of energetic electrons measured by LEP-e. We found that the amplitude of chorus emission enhanced in the high plasma density region in the first half of the event but the correspondence becomes opposite in the latter half of the event. The results of the propagation angle analysis of OFA data suggested that observed chorus emissions propagated from the geomagnetic equator, but the planarity fluctuates largely. The fluctuation of the planarity may suggest that the reflection and overlap of waves occur due to a steep change of the plasma density during their propagation. Furthermore, we found that the plasma density variation inversely correlated with the number of the counts of energetic electrons measured by LEP-e. These results suggest that the plasma density structure identified by this study was formed by the intrusion of energetic electrons in the vicinity of plasmapause. The interchange instability should be suggested as one of the candidates for the formation process of the density structure. We present results of the detailed analysis of wave and particle data measured by Arase during the event in order to understand the generation process of the observed chorus emissions.

地球内部磁気圏に存在する keV から MeV に至る高エネルギー電子のピッチ角散乱には、ホイッスラーモード・コーラス放射が重要な役割を果たすと考えられている。磁気赤道面付近で発生するコーラス放射とサイクロトロン型の共鳴条件を満たす高エネルギー電子はピッチ角散乱を受け、ロスコーン角よりも小さいピッチ角を持つに至った一部の高エネルギー電子は極域電離圏高度まで降り込むこととなり、脈動オーロラを含むディフューズオーロラの発光を引き起こすと考えられている。特に脈動オーロラの特徴である周期的な発光については、コーラス放射が周期的に発生することが脈動オーロラの周期性に深く関連していることが過去の研究により指摘されている。しかしながら、コーラス放射発生過程の周期性の要因については未解明の点が多く残されている。

本研究はあらせ衛星による観測結果に基づいて、プラズマポーズ外縁部で観測されたコーラス放射の発生過程と、発生時に同時に観測されたプラズマ密度の変動との関連に着目した解析を行った。解析には、あらせ衛星に搭載されたプ

ラズマ波動・電場観測器 (PWE: Plasma Wave Experiment) の High Frequency Analyzer (HFA) ならびに Onboard Frequency Analyzer (OFA)、磁場観測器 (MGF: Magnetic Field Experiment)、低エネルギー電子分析器 LEP-e のデータを用いる。対象とするイベントは、2017 年 5 月 5 日 UT2:05-2:45、磁気赤道面付近の磁気地方時 01:00 から 01:30、磁気緯度 2.7-7.2、L = 5.4 - 5.8 の地点で観測されたものである。OFA の観測結果から 1.3-2.3kHz の周波数帯域にコーラス放射の発生が認められている。HFA により観測された波動電場成分のスペクトルから高域混成共鳴（UHR）周波数を読み取り、プラズマ密度を推定すると、対象とするイベントはあらせ衛星がプラズマポーズを横切ったタイミングで観測され、プラズマ密度が数分の時間スケールで変動しており、その範囲は 24 cm-3 から 77 cm-3 であることが示されている。観測されたコーラス放射と共鳴条件を満たす電子のエネルギーについて見積もると、0.5 fce（fce は電子サイクロトロン周波数）の周波数をもつホイッスラーモード波動との共鳴エネルギーは、プラズマ密度が 24 cm-3 の場合は 762eV、77 cm-3 の場合は 222 eV となる。

本研究ではコーラス放射の発生タイミングとプラズマ密度ならびに LEP-e による観測結果との対応関係について着目して解析を行なった。その結果、イベントの前半ではプラズマ密度が高い領域でコーラス放射の強度増大が認められる一方で、イベントの後半では異なる対応関係が確認された。コーラス放射の伝播角解析の結果からは、磁気赤道方向から伝搬してきたことが示唆されるが、planarity が大きく変動しており、プラズマ密度の急峻な変化による波動の反射と重畳が生じている可能性が指摘される。さらに、今回着目したイベントでは、数百 eV から数 keV のエネルギー帯の電子のカウント数とプラズマ密度の変化が逆相関の関係にあることが示された。この結果は、本研究により同定されたプラズマ密度構造が、プラズマポーズに高エネルギー電子が侵入することによって形成されたものであることを示唆しており、形成過程としては交換型不安定が候補の一つとして挙げられる。本発表では、観測されたコーラス放射の発生過程とプラズマ密度変動、keV 帯エネルギー電子のカウント数との対応について詳細に解析した結果を報告する。

Arase 衛星 S-WPIA 解析におけるプラズマ波動電界較正に関する評価

三木 淳平 [1]; 小嶋 浩嗣 [2]; 加藤 雄人 [3]; 松田 昇也 [4]; 笠原 禎也 [5]; 疋島 充 [6]; 栗田 怜 [7]; 北原 理弘 [3]; 笠原 慧 [8]; 三好 由純 [7]; 熊本 篤志 [9]
[1] 京大・工・電気; [2] 京大・生存圏; [3] 東北大・理・地球物理; [4] ISAS/JAXA; [5] 金沢大; [6] 宇宙研; [7] 名大 ISEE; [8] 東京大学; [9] 東北大・理・地球物理

Calibration of electric fields dedicated to the measurement of the S-WPIA of the Arase Satellite

Jumpei Miki[1]; Hirotsugu Kojima[2]; Yuto Katoh[3]; Shoya Matsuda[4]; Yoshiya Kasahara[5]; Mitsuru Hikishima[6]; Satoshi Kurita[7]; Masahiro Kitahara[3]; Satoshi Kasahara[8]; Yoshizumi Miyoshi[7]; Atsushi Kumamoto[9]
[1] Electrical Engineering, Kyoto Univ.; [2] RISH, Kyoto Univ.; [3] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [4] ISAS/JAXA; [5] Kanazawa Univ.; [6] ISAS; [7] ISEE, Nagoya Univ.; [8] The University of Tokyo; [9] Dept. Geophys, Tohoku Univ.

The outer radiation belt consists of high-energy electrons. They are strongly affected by geomagnetic activities in the relation to solar wind disturbances. One of the science targets in the ERG mission is to clarify the generation mechanism of relativistic electrons in the outer radiation belt. It is thought that the wave-particle interaction is a plausible mechanism for the generation/extinction processes of relativistic electrons. For the purpose of quantitatively understanding the interaction between plasma waves and electrons, S-WPIA (Software-type Wave-Particle Interaction Analyzer) is installed in the Arase satellite. In the S-WPIA, it is possible to identify a relative phase angle of a plasma wave electric field vector and a velocity vector of each detected particle. The relative phase angle is essential in understanding energy exchange processes between plasma waves and particles; however, it was missing in conventional observations.

In order to accurately capture the relative phase angle between the electric field vector of the plasma wave and the particle velocity vector, it is significant to correctly calibrate the electric field vector of the plasma wave. The amplitude and phase of the electric field data obtained from the plasma wave receiver are influenced by sensors and various filters and amplifiers of the receiver. In particular, since the preamplifier of the electric field sensors has high input impedance, the influence of cable between the preamplifier and the sensor and the input capacitance of the preamplifier are not negligible. In addition, the complex impedance of the electric field sensor strongly depends on parameters of ambient plasmas and dynamically changes along the orbit of the satellite. In the calculation of the S-WPIA, it is necessary to accurately calibrate this electric field observation data considering characteristics of the receiver and the electric field sensor. In the presentation, we will discuss the preamplifier input equivalent circuit and the influence of the antenna impedance on the calibration of this electric field observation data and aim to improve the accuracy of the S-WPIA observation.

地球近傍の内部磁気圏では相対論的エネルギー粒子が大量に蓄積されている放射線帯が存在する。放射線帯外帯は高エネルギー電子から成っており、太陽風の擾乱に起因する宇宙嵐に伴って生成と消滅を繰り返している。放射線帯における相対論的高エネルギー粒子の生成、及び宇宙嵐の発達のメカニズムを明らかにするべく、2016 年 12 月に ERG 衛星が打ち上げられた。相対論的エネルギー電子の生成・消失プロセスには、プラズマ波動との相互作用が重要な役割を果たしていると考えられている。このプラズマ波動と電子の相互作用を定量的に捉えることを目的として、ERG 衛星ではソフトウエア型波動粒子相互作用解析装置 S-WPIA(Software-type Wave-Particle Interaction Analyzer) が搭載された。S-WPIA では、波動粒子相互作用の本質であるにもかかわらず、従来の観測では欠落していた、プラズマ波動電界ベクトルと粒子の速度ベクトルの位相角情報を捉えることができる。

このプラズマ波動電界ベクトルと粒子速度ベクトルの位相角を正確に捉えるためには、プラズマ波動電界ベクトルの較正が正確に行われている必要がある。プラズマ波動観測器から得られる電界データは、センサー、および、観測器の各種フィルタやアンプにより、振幅、位相に影響を受けている。特に、プリアンプは入力インピーダンスが高いため、アンテナからプリアンプのケーブルの影響や入力容量の影響が避けられない。また、電界センサーの複素インピーダンスは、周囲のプラズマ環境に強く依存しており衛星の軌道によってダイナミックに変化する。S-WPIA の計算では、この電界観測データを観測器や電界センサーの特性から正確に較正する必要がある。運動エネルギーの時間変化を算出する上で、電界の振幅・位相の精度は重要である。講演ではこの電界観測データの較正についてプリアンプ入力等価回路の検討とアンテナインピーダンスの影響について評価を行い、S-WPIA 観測の精度向上を目指す。

あらせ衛星プラズマ波動観測データにおける波動伝搬方向推定

五十嵐 智 [1]; 笠原 禎也 [1]; 松田 昇也 [2]; 太田 守 [3]; 松岡 彩子 [4]
[1] 金沢大; [2] ISAS/JAXA; [3] 富山県立大; [4] JAXA 宇宙研

Study on direction finding of plasma waves measured by the PWE on board the Arase

Satoshi Ikarashi[1]; Yoshiya Kasahara[1]; Shoya Matsuda[2]; Mamoru Ota[3]; Ayako Matsuoka[4]
[1] Kanazawa Univ.; [2] ISAS/JAXA; [3] Toyama Prefectural Univ.; [4] ISAS/JAXA

The Arase satellite was launched in December, 2016 to study the acceleration and loss mechanism of relativistic electrons in the radiation belt. In order to achieve this purpose, the Arase measures electric and magnetic wave fields and plasma particles in the inner magnetosphere. The PWE (Plasma Wave Experiment) on board the Arase covers wide frequency range from DC to 10 MHz for electric field and from a few Hz to 100 kHz for magnetic field. The PWE measures two types of data: ”continuous data” and ”burst data”. The continuous data mainly consists of spectrum data generated 24 hours per day for surveying the entire observation region, while the burst data is intended for detailed scientific analysis. Because of the limitation of the telemetry resource, we intermittently measure the burst data, but we can obtain raw waveform data which consists of two components of electric field and three components of magnetic field.

In the present study, we introduce the direction finding results derived from the PWE burst data. In the direction finding analysis, we calculate spectral matrix which consists of variance-covariance of the observed electric and magnetic field signals. We need covariance between electric and magnetic components to determine the absolute direction of the wave, otherwise ambiguity of direction polarity remains. In the case of continuous data, however, covariance between electric and magnetic field components are not available due to limitation of the PWE specification. On the other hand, we have five components of waveforms which enable us to calculate covariance between electric and magnetic components in the burst data, and we expect precise direction of the wave. Furthermore, elements of the chorus and lighting whistler can be analyzed by deriving the spectrum from the waveform data of the burst data with a fine time resolution.

In the presentation, we introduce evaluation results of propagation directions and Poynting vectors of chorus and lightning whistlers with a fine time resolution from the burst data.

2016 年に打ち上げられたジオスペース探査衛星あらせは，内部磁気圏におけるプラズマ波動・粒子の総合観測によって，放射線帯電子の加速・消失のメカニズムを明らかにすることを目的としている. あらせ衛星に搭載されている PWE は，DC から 10 MHz までの周波数帯の電界成分と，数 Hz から 100 kHz までの周波数帯の磁界成分を測定する．観測されるデータは,「常時観測データ」と「バースト観測データ」の 2 つに分けられる．常時観測データは，スペクトルなど，観測データ全体を俯瞰するためのデータであり，PWE が観測状態であれば常に生成される．バースト観測データは，電磁界波形など，詳細な科学解析を目的としたデータであり，電界 2 成分, 磁界 3 成分の電磁界生波形を取得し, 特定時間・領域の観測データを常時データを元に選択して，地上に伝送する.

本研究では，あらせ衛星に搭載されているプラズマ波動電場観測機 PWE (Plasma Wave Experiment) のバースト観測データからプラズマ波動の伝搬方向を推定した．伝搬ベクトル解析には, 観測された電磁界各成分の解析信号の複素相関行列であるスペクトルマトリクスを用いる. 伝搬方向の絶対方向の推定には電磁界間の位相情報を相互相関値から求める必要があるが, 常時観測データは PWE のハードウェア上の制約から電磁界間の位相差を求めることができない. 一方, バースト観測データは, 伝送容量の制限によって間欠的ではあるが, 電磁界 5 成分の生波形が地上伝送されるため, これらを用いて波動伝搬方向の絶対方向を求めることができる. また，連続波形を取得できるバースト観測データからスペクトルを計算することで, コーラスや雷ホイッスラの個々のエレメントの詳細解析が可能である.

発表では, バースト観測データから高時間・周波数分解能のスペクトルマトリクスを計算し, コーラスや雷ホイッスラ等の様々な波動の伝搬ベクトルやポインティングベクトルを推定した結果について報告する予定である.

探査衛星あらせのデータを用いた突発性電子サイクロトロン高調波の解析

新城 藍里 [1]; 小嶋 浩嗣 [2]; 笠原 禎也 [3]; 風間 洋一 [4]; 臼井 英之 [5]; 三好 由純 [6]; 笠羽 康正 [7]; 松田 昇也 [8]; Wang S.-Y.[9]; Tam Sunny W. Y.[10]; 熊本 篤志 [11]
[1] 京大・工・電気; [2] 京大・生存圏; [3] 金沢大; [4] ASIAA; [5] 神戸大・システム情報; [6] 名大 ISEE; [7] 東北大・理; [8] ISAS/JAXA; [9] 台湾・中央研究院; [10] 台湾・成大・宇宙プラズマ; [11] 東北大・理・地球物理

Sudden enhancements of electron cyclotron harmonic waves observed by the Arase satellite

Airi Shinjo[1]; Hirotsugu Kojima[2]; Yoshiya Kasahara[3]; Yoichi Kazama[4]; Hideyuki Usui[5]; Yoshizumi Miyoshi[6]; Yasumasa Kasaba[7]; Shoya Matsuda[8]; S.-Y. Wang[9]; Sunny W. Y. Tam[10]; Atsushi Kumamoto[11]
[1] Engineering, Kyoto Univ.; [2] RISH, Kyoto Univ.; [3] Kanazawa Univ.; [4] ASIAA; [5] System informatics, Kobe Univ; [6] ISEE, Nagoya Univ.; [7] Tohoku Univ.; [8] ISAS/JAXA; [9] ASIAA, Taiwan; [10] ISAPS, NCKU, Taiwan; [11] Dept. Geophys, Tohoku Univ.

Electron cyclotron harmonic waves are frequently observed in the low latitude region just outside the terrestrial plasmapause. They are electrostatic waves and their frequency spectra have harmonic structures which are believed to depend on composition of cold and hot components of electrons. The Plasma Wave Experiment (PWE) on board the Arase satellite have observed the ECH, since the start of the operation. The observed ECH are mainly classified into two types. They are the diffuse ECH and the enhanced ECH. The diffuse ECH are weak and they appear as continuous emissions which last for more than a few minutes. The enhanced ECH are the sudden enhancements of the diffuse ECH in shorter time periods. In the present paper, we focus on the enhanced ECH observed by the Arase satellite. Similar ECH are also observed by Geotail just inside the dayside magnetopause. The spectrum feature is similar to that of the enhanced ECH observed by the Arase satellite, but the mechanism of the enhancement is still not clear. The Arase PWE has the advantage of being able to acquire continuous waveforms up to 20 kHz for a longer duration than Geotail. In this study, we clarify the feature of the enhanced ECH based on the Arase waveform data by focusing on their temporal change with high temporal resolution and detailed structures of their frequency spectra by high frequency resolution spectrum. We also analyze the correlation between the parameter variations of the surrounding plasma and the enhanced ECH and discuss mechanisms of their sudden enhancements.

本研究では、ジオスペース探査衛星あらせ（ERG）により観測された突発性電子サイクロトロン高調波（ECH: Electron Cyclotron Harmonic waves）の解析を行う。ECH は、低緯度のマグネトポーズ外側で頻繁に観測される静電波である。あらせ衛星のプラズマ波動観測器 (PWE: Plasma Wave Experiment) も、この ECH を多く観測しているが、そのタイプはスペクトルが diffuse で長時間継続するタイプと、突発的にエンハンスされるタイプとにわけられる。本研究は後者の突発的にエンハンスされる ECH についてその発生メカニズムの解明を目的としている。

突発性 ECH は、磁気圏尾部観測衛星 GEOTAIL でも観測されていたが、その明確な発生メカニズムは解明されていない。GEOTAIL では、昼間側のマグネトポーズ付近で観測されており、あらせ衛星が観測しているものと同じ発生メカニズムであるかどうかはわからないが、あらせ衛星では、GEOTAIL よりも高い周波数 (上限 20kHz) で、かつ、より長時間の連続波形データ (burst mode data) を取得することができているため、詳細な解析が可能である。

本研究では、あらせ衛星 PWE の burst mode で観測された突発性 ECH の波形データをもとに、高い時間分解能による突発性 ECH の時間変化、高周波数分解能スペクトルによる突発性 ECH 周波数スペクトルの構造などに着目して、突発性 ECH の特徴についてまず明らかにする。また、周辺プラズマのパラメータ変動と突発性 ECH との相関解析を行い、ECH が突発的にエンハンスされるそのメカニズムについて解析していく。

Characteristics of temporal variation of AKR and Pi 2 observed by ARASE and MAGDAS/CPMN: Initial results

Teiji Uozumi[1]; Akimasa Yoshikawa[2]; Shinichi Ohtani[3]; Atsushi Kumamoto[4]; Fuminori Tsuchiya[5]; Yoshiya Kasahara[6]
[1] ICSWSE, Kyushu Univ.; [2] ICSWSE/Kyushu Univ.; [3] The Johns Hopkins University Applied Physics Laboratory; [4] Dept. Geophys, Tohoku Univ.; [5] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [6] Kanazawa Univ.

Auroral breakup occurs at the onset of substorm [*Akasofu*, 1964], and it represents the development of the auroral acceleration region above the auroral ionosphere. Auroral kilometric radiation (AKR) can remotely detect the development of the auroral acceleration region [e.g., *Gurnett et al.*, 1981]. Three-dimensional current system of the substorm, so called substorm current wedge (SCW) [*McPherron et al.*, 1973], is also formed at the onset of the substorm. Duskward part of the SCW corresponds to an intense upward field-aligned current (FAC) [e.g., *Samson and Rostoker*, 1983], and it is collocated with the auroral acceleration region [e.g., *Kamide and Rostoker*, 1977]. It has been widely accepted that Pi 2 occurs at the onset of substorm and each auroral breakup [*Sakurai and Saito*, 1979], and global high-correlation Pi 2 pulsation manifests the fluctuation of the FACs of the SCW [*Uozumi et al.*, 2009, 2016]. AKR and Pi 2 are recognized as elementary components of the substorm [*Morioka et al.*, 2005], and there exist many conjunctional studies between the two phenomena [e.g., *Liou et al.*, 2000; *Morioka et al.*, 2008]. Past studies presented the timing relation between the occurrence of AKR breakup and Pi 2 onsets. However, few studies investigated the relation between the temporal variation of AKR and Pi 2, except *Uozumi et al.* [2011]. In this study, we made a comparative study concerning temporal variation between AKR modulation and ground Pi 2 pulsation with data sets obtained by the High Frequency Analyzer (HFA) of the Plasma Wave Experiment (PWE) on board the Arase (ERG) satellite [*Kasahara et al.*, 2018; *Kumamoto et al.*, 2018] and the MAGDAS/CPMN equatorial ground magnetometer [*Yumoto et al.*, 2006]. We will report some initial results of the present study in our talk.

AKR events were searched for during the interval from April to October 2017, and 40 AKR events were selected. Time series data of AKR power were derived by integrating the power spectrum data of the PWE/HFA with respect to frequency of AKR (mostly 50-300kHz, but depended on each event) at every time step of 8s. It is found that the dominant period of the modulation of AKR power was distributed within the Pi 2 period range (40-150s) for 35 out of 40 events. The temporal variation of the AKR modulation was compared to the waveform of the equatorial ground Pi 2 pulsations that were observed at Huancayo in Peru. It is found that 34 out of 40 events exhibited high correlation coefficient of $|R| >= 0.70$ ($|R| >= 0.85$ for 15 out of 40 events). Those results are consistent with the results reported by *Uozumi et al.* [2011]. It implies that the modulation of AKR power is closely related to global Pi 2 oscillations. It suggests that the modulation of AKR power could be controlled by global Pi 2 pulsation through a wave-wave interaction. It also suggests that the temporal variation of the auroral acceleration could be connected to the global Pi 2 as well.

Correlation analysis of plasma waves simultaneously observed by Arase and Van Allen Probes

Yuta Ogawa[1]; Yoshiya Kasahara[1]; Yuhei Hayashi[1]; Shoya Matsuda[2]; Yoshizumi Miyoshi[3]; Mamoru Ota[4]; Mitsuru Hikishima[5]; Yuto Katoh[6]; Ondrej Santolik[7]; Ivana Kolmasova[8]; George Hospodarsky[9]; Craig A. Kletzing[10]; Chris Colpitts[11]; John Wygant[12]
[1] Kanazawa Univ.; [2] ISAS/JAXA; [3] ISEE, Nagoya Univ.; [4] Toyama Prefectural Univ.; [5] ISAS; [6] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [7] The Czech Academy of Sciences; [8] The Czech Academy of Sciences; [9] Dept. of Physics and Astronomy, Univ. of Iowa; [10] Department of Physics and Astronomy, UoI; [11] Univ. of Minnesota; [12] Univ. of Minnesota

The Arase satellite was a Japanese scientific satellite launched in December, 2016 to explore the plasma environment in the inner magnetosphere. On the other hand, Van Allen Probes (RBSP-A, RBSP-B) have been in operation since 2012 mainly in the equatorial region in the inner magnetosphere. Because the inclination of the Arase is larger than the ones of Van Allen Probes, we expect to clarify global characteristics of the inner magnetosphere by comparing the simultaneous observation data. So far we conducted collaborative observation during more than 200 conjunction periods from June 2017 to July 2018 and obtained huge amount of waveform data.

We could identify correlated wave spectra such as chorus and lightning whistlers among some portion of the waveform data during the conjunction periods, and quantitative correlation analysis is necessary to study the propagation characteristics of these waves. In this research, therefore, we aim to develop an environment for correlation analysis of the waveform data simultaneously observed by the Arase and the Van Allen Probes.

In the correlation analyses, we first convert the waveform data into spectrum by performing FFT. As a next step, we interpolate the spectrum data of the Van Allen Probes in order to match up the time and frequency resolution to the ones of the data of the Arase. Finally we calculated the cross-correlation to estimate the time difference of the wave spectra as a function of frequency.

In the present study, we analyzed result of the data measured around 20:54 UT on September 3, 2017, when similar chorus elements were simultaneously observed by Arase and RBSP-A. At this time, both satellites were located around L-value of ˜4 and magnetic local time of ˜16, and the Arase was located at higher magnetic latitude (18.6 degree for the RBSP-A and 28.8 degree for Arase). We found the chorus elements detected by the Arase were about 0.6s delayed from the ones detected by the RBSP-A, that suggests the chorus elements were propagating from equatorial region toward higher latitude region. In the presentation, we will also show the variations of delay times depending on the frequency and observation time to clarify the propagation characteristics of the chorus.

A Machine Learning Approach for the Determination of Upper Hybrid Resonance Frequencies Observed by Arase

Shoya Matsuda[1]; Tatsuhito Hasegawa[2]; Atsushi Kumamoto[3]; Fuminori Tsuchiya[4]; Yoshiya Kasahara[5]; Yoshizumi Miyoshi[6]; Yasumasa Kasaba[7]; Ayako Matsuoka[8]
[1] ISAS/JAXA; [2] University of Fukui; [3] Dept. Geophys, Tohoku Univ.; [4] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [5] Kanazawa Univ.; [6] ISEE, Nagoya Univ.; [7] Tohoku Univ.; [8] ISAS/JAXA

Electron number density is a key parameter for discussions of plasma wave generation/propagation, and wave-particle interaction in the inner magnetosphere. The High Frequency Analyzer (HFA) is a subsystem of Plasma Wave Experiment (PWE) aboard Arase [Kasahara et al. (2018), Kumamoto et al. (2018), Miyoshi et al. (2018)]. The HFA measures electric field spectra in a frequency range from 10 kHz to 10 MHz, which covers a typical frequency range of Upper Hybrid Resonance (UHR) frequency in the inner magnetosphere. Kumamoto et al. (2018) proposed the semiautomatic method for the identification of UHR frequency by computer and a human operator. However, it takes a enormous effort of a human operator.

We propose an automatic determination system of UHR frequency by machine learning. Machine learning is a technique in the field of artificial intelligence to give computers the ability to learn with data. In this study, we defined the task of UHR frequency determination as supervised regression that a computer estimates UHR frequencies using the dataset composed of electric field dynamic spectra with correct UHR frequency labels. We adopted the random forest regressor [Breiman (2001)] as a machine learning algorithm. Our method calculates the maximum and standard deviation of observed spectrum intensities for each frequency as a feature vector of machine learning inputs. In this study, we introduce our machine learning approach and initial results for determining UHR frequency from electric field spectra observed by PWE/HFA.

Compressional Pc5 waves associated with the modulation of lower-band chorus wave intensity in the deep inner magnetosphere

Satoshi Oimatsu[1]; Masahito Nose[2]; Mariko Teramoto[3]; Craig A. Kletzing[4]; Charles W. Smith[5]; Robert J. Macdowall[6]; Donald Mitchell[7]
[1] Geophysics, Kyoto Univ; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya University; [4] Department of Physics and Astronomy, UoI; [5] Department of Physics, UNH; [6] NASA/GSFC; [7] JHU/APL

We examined a compressional Pc5 wave observed by the Van Allen Probes satellites in the deep inner magnetosphere (L ˜4.4-6.0) around noon near the magnetic equator during the storm recovery phase on 21 December 2015. The Pc5 wave with a wave period of ˜250 s was excited by an arrival of a solar wind structure like a flux rope at the magnetopause at ˜21:20 UT. The amplitudes were similar in the radial, azimuthal, and compressional components. When the solar wind dynamic pressure enhanced at ˜22:40 UT, the Pc5 wave properties changed and the amplitude in the compressional component became dominant. Electron fluxes at 20-200 keV also oscillated in-phase with the magnetic field oscillation in the compressional component. Simultaneously, lower-band chorus waves were observed, and the wave intensity was modulated with the same period of the compressional Pc5 wave. In presentation, we show the detail results and discuss the Pc5 wave properties, the excitation mechanism of the waves, and the chorus wave modulations.

The temporal characteristics of PsA internal modulation

Yuki Kawamura[1]; Keisuke Hosokawa[1]; Shin-ichiro Oyama[2]; Yoshizumi Miyoshi[2]; Yasunobu Ogawa[3]; Satoshi Kurita[2]; Mitsunori Ozaki[4]; Kazuo Shiokawa[5]; Ryoichi Fujii[6]
[1] UEC; [2] ISEE, Nagoya Univ.; [3] NIPR; [4] Kanazawa Univ.; [5] ISEE, Nagoya Univ.; [6] STEL, Nagoya Univ.

Pulsating aurora (PsA) is a kind of diffuse aurora which almost always appears in the morning side during the recovery phase of auroral substorm. PsA typically has two characteristic temporal variations. One is so-called main pulsation whose period ranges from a few seconds to a few tens of seconds. The other is a few Hz modulation (internal modulation), which is often seen during the ON time of main pulsation. Previous study has suggested that the temporal variation of PsA is characterized by wave-particle interaction between whistler-mode chorus waves and high energy electrons in the magnetosphere. Especially, it has been indicated that there is a one-to-one correspondence between the amplitude variation of chorus waves and the luminosity modulation of PsA. Recent studies revealed the frequency distribution of the main pulsation. However, there has been almost no statistical study which analyzed the periodicity of the internal modulation; thus we still do not know the average/peak frequency and the frequency distribution of the internal modulation of PsA.

To reveal the temporal characteristics of the internal modulation, we need to perform a frequency analysis using data from high speed optical instruments. For this purpose, we make use of highly sensitive EMCCD cameras which have been operative in Sodankyla, Finland and Gakona, Alaska. All-sky aurora images are taken with a temporal resolution of 100 Hz. The temporal resolution of these cameras is sufficient to identify the temporal variation of the internal modulation. In the frequency analysis, we have employed all-sky images obtained on March 30, 2017 (13:00 - 13:30 UT) in Gakona. We derived the frequency distribution of the internal modulation using 109 examples of internal modulation each of which has 30 sec duration. We also computed the average frequency of the internal modulation and it was estimated to be 3.81 Hz. This result is consistent with Samara and Michell [2010].

We will identify the dependence of the internal modulation on latitude and longitude (L-value and MLT, respectively). In the presentation, we discuss what factors control the periodicity of PsA internal modulation by taking into account their dependence on L-value and MLT.

脈動オーロラは、磁気圏から高エネルギーの電子が準周期的に降り込むことによって、高度 100 km 付近の超高層大気が数秒から数十秒の周期で明滅する現象である。この脈動オーロラには、数秒から数十秒の周期の変動 (主脈動) の上に、数 Hz 周期の短い変動 (内部変調) が重畳する階層的周期構造が存在する。このような脈動オーロラの明滅が、磁気圏に存在するコーラス波動と電子の間の波動粒子相互作用によって作り出されていることは古くから示唆されてきた。特に、近年、脈動オーロラの主脈動とコーラス波動の集団的発生の間に 1 対 1 対応がある事例が報告されている。また、脈動オーロラの主脈動の周期性については、近年の研究により、その明滅の平均/ピーク周波数や周波数分布が明らかとなっている。しかしながら、地上光学観測において内部変調を同定できるほどの高時間分解能の観測が行われてこなかったことにより、内部変調の周期性に関する研究は統計的に行われことがなかった。そこで、本研究では、高い時間分解能を有する地上光学観測を用いることで、脈動オーロラ内部変調の周期性に関する基礎的な情報を得ることを目的とする。

本研究で用いる観測機器は、フィンランド・ソダンキラ及びアラスカ・ガコナに設置されている電子倍増型 CCD (EMCCD) 全天カメラである。EMCCD 全天カメラは 100 Hz という非常に高い時間分解能でオーロラ発光を観測しているため、数 Hz 周期の内部変調を十分に同定することが可能である。本研究では、初期解析として、2017 年 3 月 30 日 13:00 - 13:30 UT にガコナの全天 EMCCD カメラによって、取得された撮像データを用いて、脈動オーロラ内部変調の周期性に関する解析を行った。解析ウインドウを 30 秒として、目視により内部変調を確認し、計 109 例のイベントを抽出した。これらの事例について、脈動オーロラの輝度値に対する周波数解析を行うことで、脈動オーロラ内部変調の周波数分布を導出した。その結果、脈動オーロラ内部変調の平均周波数は 3.81 Hz であり、3 Hz 付近にピークを持つことが分かった。この結果は、Samara and Michell [2010] で示された内部変調の周期性と良い一致を示している。

今後は、解析期間を拡大し、ガコナの 2017 年 3 月 30 日 12:00 - 13:00UT 及びソダンキラの 2017 年 3 月 29 日 00:00 - 02:00 UT のデータに対しても同様の解析を行い、統計的に有意な周波数分布を導出する予定である。また、それに加えて、脈動オーロラ内部変調の発生頻度の導出や、周期の緯度や MLT に対する依存性の検証を行う予定である。統計結果に基づいて、発生率や依存性を考慮した上で、脈動オーロラ内部変調の周期性を決定している要因について議論する。

脈動オーロラ消光時に見られる発光強度の極端減少の原因

岸山 泰輝 [1]; 細川 敬祐 [2]; 野澤 悟徳 [3]; 小川 泰信 [4]; 大山 伸一郎 [5]; 三好 由純 [5]; 藤井 良一 [6]; 笠原 禎也 [7]; 尾崎 光紀 [7]; 松田 昇也 [8]; 篠原 育 [9]
[1] 電通大・情報理工; [2] 電通大; [3] 名大・宇地研; [4] 極地研; [5] 名大 ISEE; [6] 情報・システム研究機構; [7] 金沢大; [8] ISAS/JAXA; [9] 宇宙研／宇宙機構

Origin of over-darkening pulsating aurora

Taiki Kishiyama[1]; Keisuke Hosokawa[2]; Satonori Nozawa[3]; Yasunobu Ogawa[4]; Shin-ichiro Oyama[5]; Yoshizumi Miyoshi[5]; Ryoichi Fujii[6]; Yoshiya Kasahara[7]; Mitsunori Ozaki[7]; Shoya Matsuda[8]; Iku Shinohara[9]
[1] Information Science, UEC; [2] UEC; [3] ISEE, Nagoya Univ.; [4] NIPR; [5] ISEE, Nagoya Univ.; [6] ROIS; [7] Kanazawa Univ.; [8] ISAS/JAXA; [9] ISAS/JAXA

Pulsating aurora is a luminous phenomenon during which the upper atmosphere at ~100 km altitude pulsates with a period ranging from a few to a few tens of second by quasi-periodic precipitation of high energy electrons from the magnetosphere. It has been suggested that the interaction between the chorus waves and energetic electrons near the equatorial plane of the magnetosphere has a potential to cause of luminosity modulation of pulsating aurora. This hypothesis is supported by the existence of one-to-one correspondence between quasi-periodic variations in the luminosity of pulsating aurora and intensity of chorus waves. Recent analyses of high time resolution ground-based optical observations have reported that the brightness of pulsating aurora decreases below the diffuse background level either immediately before/after the ON phase of the main optical pulsation (e.g., Kataoka et al. [2012], Dahlgren et al. [2017]). To date, however, the generation mechanism of such 'over-darkening pulsating aurora' has not been investigated in detail; thus, the origin of this phenomenon is still unclarified.

In this paper, we investigate the characteristics and the origin of the over-darkening pulsating aurora by performing both statistical and case studies using several ground-based/satellite observations. The optical instruments employed in this study are the 5-channel photometer in Tromso, Norway (69N, 19E, 66MLAT) and an EMCCD all-sky camera in Sodankyla, Finland (67N, 26E, 64MLAT). The field-of-view of the 5-channel photometer is directed along the local magnetic field line and it measures the emission intensity of aurora/airglow with a temporal resolution of 20 Hz. The EMCCD all-sky camera captures auroral emissions with a temporal resolution of 100 Hz. In addition to these instruments, the wave instruments onboard the THEMIS and Arase spacecrafts are used for detecting the intensity variation of chorus waves with a temporal resolution of 1 Hz.

In the statistical analysis, we made simple time-series plots of data from the 5-channel photometer, and computed the occurrence frequency of the over-darkening pulsating aurora. The statistical result using data from one winter season in 2017 indicates that ~15% of all the ON/OFF pairs of pulsating aurora show over-darkening characteristics immediately after their ON phase. An additional analysis using the THEMIS satellites indicates that similar characteristics are not seen in the time-series of the chorus wave amplitude.

In the case study using the EMCCD data from March 29, 2017, we found that over-darkening area appeared in the outer boundary of pulsating aurora patches and moved in tandem with the poleward propagating patches. As seen in the analysis using the THEMIS satellites, over-darkening feature was not seen in the intensity of chorus waves observed by the Arase satellite. These results indicate that over-darkening pulsating aurora is not caused by the temporal variation of chorus wave, but produced by propagation of over-darkening area with patches of pulsating aurora. To evaluate this scenario, now we confirm if all the over-darkening pulsating aurora show similar spatio-temporal variation. In the presentation, we will discuss two patterns of over-darkening area (over-darkening before the ON phase and after the ON phase) based on the results, and suggest a model explaining their generation mechanism.

脈動オーロラは、磁気圏から電子が準周期的に降り込むことによって、高度 100 km 付近の大気が数秒から数十秒の周期で明滅する現象である。脈動オーロラの明滅を作り出す電子の降下は、準周期的に強度が変動する磁気圏コーラス波動と電子との相互作用によって生じると考えられている。これまでに、脈動オーロラの準周期的な輝度変化とコーラス波動の強度変化の間に高い相関関係があることが示されている。近年の高時間分解能光学観測データの解析から、脈動オーロラの主脈動が ON から OFF に切り替わった後、または OFF から ON に切り替わる前の消光時に、発光強度が背景の発光強度のレベルよりも低くなる事例が報告されている（e.g., Kataoka et al. [2012], Dahlgren et al. [2017]）。しかし、コーラス波動と脈動オーロラの対応関係を研究する際に、このような脈動オーロラの発光強度に極端減少が見られる傾向に着目してデータが解析されたことは無く、その発生頻度及び発生メカニズムについて未だに明らかにされていない。

本研究では、高時間分解能の地上光学観測及び衛星電磁界波動観測から得られた脈動オーロラの発光強度及びコーラス波動の電磁界波動強度データを解析することで、脈動オーロラに見られる「発光強度の極端減少」事例について、発生頻度及び発生メカニズムを明らかにすることを目的とする。本研究で用いる地上光学観測機器は、ノルウェー・トロムソ (地理緯度: 69.6 度 , 経度: 19.2 度 , 磁気緯度: 66.7 度) に設置された 5 チャンネルフォトメーター、及びフィンランド・ソダンキュラ (地理緯度: 67.3 度 , 経度: 26.4 度 , 磁気緯度: 63.9 度) に設置された電子倍増型 CCD (EMCCD) 全天カメラである。5 チャンネルフォトメーターは 20 Hz の時間分解能で磁力線方向の観測を行っている。また、EMCCD 全天カメラは、100 Hz という高い時間分解能で脈動オーロラを観測している。これらに加えて、磁気圏における電磁界波動観測については、NASA の THEMIS 衛星、及び日本のあらせ (Arase) 衛星を用いた。THEMIS 衛星及びあらせ衛星は 1

秒の時間分解能で電磁界波動の計測を行なっており、脈動オーロラと同様の周期性を持つコーラス波動の強度変化を同定することが可能である。

まず、5 チャンネルフォトメーターにより 2017 年 2 - 3 月に取得された発光強度の時系列データから、全 19 晩分 (総観測時間 95 時間) の脈動オーロラの事例について極端減少の検出を行い、その発生頻度について解析を行った。 その結果、確認した全ての ON/OFF ペアのうちの約 15 %において、発光強度の極端減少が見られることが分かった。これらに加えて、THEMIS 衛星によって得られたコーラス波動強度の時系列データを解析したところ、同期間に観測されたコーラス波動については、脈動オーロラの極端減少に対応するものは見られなかった。

続いて、EMCCD カメラ及びあらせ衛星による脈動オーロラとコーラス波動の同時観測事例 (2017 年 3 月 29 日) において、EMCCD カメラにより取得された撮像データを用い、極端減少領域の時空間変動の解析を行った。その結果、極端減少は脈動オーロラ領域の外縁部に存在し、脈動オーロラパッチの極方向伝搬に追随する形で移動していることが確認された。また、この同時観測事例についても、コーラス波動の強度変動に極端減少は見られなかった。以上のことから、脈動オーロラの極端減少はコーラス波動に起因するものではなく、オーロラパッチの外縁部に存在する極端減少領域の伝搬を定点で観測することによって形作られる現象であることが示唆された。現状では、脈動オーロラにおける極端減少が、「発光強度が極端に現象した領域が伝搬することにより発生する」という特徴を捉えた例はこの 1 例しかない。今後は、同様の事例を複数探すことにより、極端減少の発生メカニズムの普遍性を明らかにする。発表では、脈動オーロラに追随して伝搬する発光強度の極端減少領域についてのパターンを示し、その発現メカニズムに関するモデルを提案する。

Long-lasting high correlation between pulsating aurora and chorus

Suguru Kawamura[1]; Keisuke Hosokawa[1]; Satoshi Kurita[2]; Shin-ichiro Oyama[2]; Yoshizumi Miyoshi[2]; Yoshiya Kasahara[3]; Mitsunori Ozaki[3]; Shoya Matsuda[4]; Ayako Matsuoka[5]; Yuki Kawamura[1]; Iku Shinohara[6]
[1] UEC; [2] ISEE, Nagoya Univ.; [3] Kanazawa Univ.; [4] ISAS/JAXA; [5] ISAS/JAXA; [6] ISAS/JAXA

Pulsating Aurora (PsA), which consists of diffuse patches/arcs blinking with various periodicities ranging from a few to a few tens of second, is known to occur very frequently in a local time sector from the magnetic midnight to dawn. It has been suggested that the luminosity variation of PsA is controlled by the intensity modulation of chorus wave often appearing near the equatorial plane of the magnetosphere. Chorus waves typically occur in two distinct frequency ranges, lower-frequency and upper-frequency bands, respectively below and above half the gyro frequency. In particular, lower-band chorus (LBC) waves can resonate with PsA electrons whose energy typically ranges from a few to a few tens keV, which is one of the reasons why the modulation of LBC has been considered as an agent causing luminosity variation of PsA.

However, most of previous studies analyzed intervals whose duration is 5 min or less; thus, the direct association between PsA and chorus has not yet fully confirmed. In this study, we perform a continuous cross correlation analysis between the chorus intensity observed by the Arase satellite and the luminosity of PsA captured by an all-sky imager (ASI) in Apatity(Kola Peninsula, Russia) during 1.0 h interval of simultaneous observations from 0000 to 0100 UT on March 31, 2017. Then, we tracked the motion of the high correlation region within the field-of-view. The result showed that the high correlation region moved in tandem with the magnetic footprint of the satellite estimated by the empirical model which strongly confirmed the modulation of chorus dominated the temporal variation of PsA. However, During the interval, the motion of the high correlation region showed sudden jumps in both the latitudinal and longitudinal directions. We will discuss the reasons for such abrupt jumps in terms of motion of the satellite through discrete spatial structure of plasma in the region of wave particle interaction.

アラスカ・ガコナにおける全天カメラとあらせ衛星による SAR arc detachment の同時観測

高木 佑基 [1]; 塩川 和夫 [2]; 大塚 雄一 [2]; 大山 伸一郎 [3]; Wang S.-Y.[4]; 浅村 和史 [5]; 笠原 慧 [6]; 横田 勝一郎 [7]; 松岡 彩子 [8]; 笠原 禎也 [9]; 三好 由純 [3]; 篠原 育 [10]; 風間 洋一 [11]; 熊本 篤志 [12]; 土屋 史紀 [13]
[1] 名大・宇地研; [2] 名大宇地研; [3] 名大 ISEE; [4] 台湾・中央研究院; [5] 宇宙研; [6] 東京大学; [7] 阪大; [8] JAXA 宇宙研; [9] 金沢大; [10] 宇宙研／宇宙機構; [11] ASIAA; [12] 東北大・理・地球物理; [13] 東北大・理・惑星プラズマ大気

Conjugate observation of SAR arc detachment at Gakona, Alaska, and the Arase satellite on March 30, 2017

Yuki Takagi[1]; Kazuo Shiokawa[2]; Yuichi Otsuka[2]; Shin-ichiro Oyama[3]; S.-Y. Wang[4]; Kazushi Asamura[5]; Satoshi Kasahara[6]; Shoichiro Yokota[7]; Ayako Matsuoka[8]; Yoshiya Kasahara[9]; Yoshizumi Miyoshi[3]; Iku Shinohara[10]; Yoichi Kazama[11]; Atsushi Kumamoto[12]; Fuminori Tsuchiya[13]
[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] ASIAA, Taiwan; [5] ISAS/JAXA; [6] The University of Tokyo; [7] Osaka Univ.; [8] ISAS/JAXA; [9] Kanazawa Univ.; [10] ISAS/JAXA; [11] ASIAA; [12] Dept. Geophys, Tohoku Univ.; [13] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.

SAR arcs are the optical phenomenon caused by low-energy electron precipitation into the ionospheric F layer from the interaction region between the ring current and the plasmasphere. During the recovery phase of geomagnetic storms, low-energy electrons in the plasmasphere are heated by high-energy plasma in the ring current, and these electrons precipitate into the F layer at subauroral latitude where oxygen atoms are excited at altitudes about 400 km. Thus, SAR arcs have been observed at subauroral latitudes during geomagnetic storms. Shiokawa et al. (2009) reported an event of SAR arcs detached from the main oval after substorms, based on observation at Athabasca, Canada (54.7N, 246.7E, magnetic latitude = 61.7N). However, conjugate observation of such SAR arcs detachment with magnetospheric satellites has not been done yet. In this study, we investigate SAR arcs detachment observed at Gakona, Alaska, using all-sky images at a wavelength of 630.0 nm and the Arase satellite at ˜12:00 UT on March 30th, 2017. We investigated the SAR arc detachment using the SAR arc images taken through a 630.0 nm wavelength filter and using data from LEPe, MEPi, MEPe, MGF, and PWE onboard the Arase satellite. The PWE wave spectra show that the SAR arc detachment was occurred inside the plasmapause. In LEPe electron spectra, the electron energy decreases with decreasing latitudes. In MEPi ion spectra, the ion energy flux increases with decreasing latitudes. In the presentation, we will report these results and discuss their characteristics and possible causes of SAR arcs detached from the main oval.

SAR アークは、磁気嵐の回復相に収縮したプラズマ圏にリングカレントのエネルギーが入り込むことによって加熱されたプラズマ圏電子が、磁力線に沿って電離圏 F 層に降り込むことにより、酸素原子が励起し発光する現象として知られている。近年、Shiokawa et al. (2009) によって、サブストームに伴ってオーロラオーバルから分離する SAR arc detachment が報告されている。Takagi et al. (JpGU, 2018) では、この SAR arc detachment に関する長期統計解析の結果を報告した。しかし、SAR arc detachment に関する磁気圏衛星との同時観測はこれまでなされていなかった。そこで本研究では、アラスカのガコナでの高感度全天カメラによる観測とあらせ衛星の同時観測に基づき、SAR arc detachment 発生の原因を調べた。

ガコナでは、超高層大気イメージングシステム (OMTIs) により、2017 年 3 月 3 日から観測を行っている。本研究では、2017 年 3 月 30 日 12:00UT 付近に観測されたあらせ衛星との同時観測イベントについて解析を行った。ガコナに設置された高感度全天カメラにより撮像された波長 630.0 nm フィルターを通した画像より SAR arc の輝度とあらせ衛星に搭載された LEPe、MEPi、MEPe、MGF、PWE を用いて SAR arc detachment を調べた。その結果、PWE の UHR 周波数より、このイベントがプラズマポーズの内側で発生していることがわかった。さらに LEPe のスペクトルより低緯度ほど低エネルギー電子のフラックスが高いこと、MEPi より低緯度ほど高エネルギーイオンのフラックスが高いこと、どちらのエネルギー範囲も、プラズマシート粒子の低緯度側境界付近で現象が発生していることが分かった。講演では、これらの観測結果を報告し、SAR arc detachment の特性とその発生原因を議論する。

Contribution from oxygen ions to plasma pressure in the inner magnetosphere: Spatial distributions and contributing energies

Kunihiro Keika[1]; Satoshi Kasahara[2]; Shoichiro Yokota[3]; Masahiro Hoshino[1]; Kanako Seki[4]; Masahito Nose[5]; Takanobu Amano[1]; Yoshizumi Miyoshi[6]; Iku Shinohara[7]
[1] University of Tokyo; [2] The University of Tokyo; [3] Osaka Univ.; [4] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [5] ISEE, Nagoya Univ.; [6] ISEE, Nagoya Univ.; [7] ISAS/JAXA

The ring current is mainly controlled by the ion pressure and its spatial gradient. The ion pressure is dominated by ions with energies of a few to a few 100s keV. Oxygen ions of ionospheric origin, O+, can be energized in the plasma sheet and/or the inner magnetosphere up to a few tens to a few hundreds of keV. O+ can make a significant contribution to the ion pressure during geomagnetically active periods. This study is focused on spatial distributions of the O+ contribution and O+ contributing energies which we term an energy range that makes the dominant contribution to the total plasma pressure.

Since the launch on 20 December 2016, the Arase spacecraft have explored the inner magnetosphere and measured plasma with a wide energy range. We primarily use data from the MEP-i (Medium-Energy Particle experiments - ion mass analyzer) which measures ions with energies of ˜10 to 180 keV/q and distinguishes between different ion species. We analyze the MEP-i data during six magnetic storms in Year 2017 with the Dst minimum smaller than -50 nT. The results show that the inner part (L lower than ˜5) is dominated by relatively low-energy protons adiabatically transported from the plasma sheet by enhanced convection. At higher L shells (L higher than ˜5), the contributing energies are higher for O+ than for H+, suggesting a significance contribution from mass-dependent acceleration processes such as O+ effective/selective acceleration during substorm activity to the buildup of the outer part the ring current. We will also discuss about high oxygen-to-proton pressure ratios (greater than 1) that have been observed both in the deep inner magnetosphere (L lower than 3) and near the Arase apogee (L higher than 6).

Penetration depth of multi-energy ions and evolution of the plasmasphere during magnetic storms: Arase observations

Ryosuke Fujii[1]; Yoshizumi Miyoshi[2]; Masafumi Shoji[2]; Kazushi Asamura[3]; Lynn M. Kistler[4]; Vania Jordanova[5]; Tomoaki Hori[2]; Satoshi Kurita[2]; Mariko Teramoto[6]; Yasunori Tsugawa[2]; Yoshiya Kasahara[7]; Yasumasa Kasaba[8]; Atsushi Kumamoto[9]; Fuminori Tsuchiya[10]; Shoichiro Yokota[11]; Satoshi Kasahara[12]; Kunihiro Keika[13]; Ayako Matsuoka[14]; Iku Shinohara[15]
[1] ISEE, Nagoya Univ.; [2] ISEE, Nagoya Univ.; [3] ISAS/JAXA; [4] ISEOS, University of New Hampshire; [5] LANL; [6] ISEE, Nagoya University; [7] Kanazawa Univ.; [8] Tohoku Univ.; [9] Dept. Geophys, Tohoku Univ.; [10] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [11] Osaka Univ.; [12] The University of Tokyo; [13] University of Tokyo; [14] ISAS/JAXA; [15] ISAS/JAXA

During geomagnetic storms, enhanced convection electric field causes the earthward transport of ions from the plasma sheet, and the enhanced ion pressure drives the ring current. According to the Dessler-Parker-Sckopke formula, variation of the Dst (Sym-H) index can be approximately expressed as a function of the total kinetic energy of ring current ions. However, the relationship between the penetration depth of ring current ions and the Dst (Sym-H) index, and ion energy dependence of the penetration depth have not well been investigated. We examine temporal and spatial evolution of multi-energy protons using the Low-energy particle experiments-ion mass analyzer (LEP-i) and the Medium-energy particle experiments-ion mass analyzer (MEP-i) instruments onboard the Arase satellite. We also investigate the storm-time variations of the plasmasphere using the in-situ plasma density derived from the upper hybrid resonance (UHR) waves emissions observed by the Plasma wave experiment (PWE)/High frequency analyzer (HFA) and the ambient electric field observed by PWE/electric field detector (EFD). We study 19 magnetic storms in 2017 after the Arase launch. During the storm main phase, the plasma sheet ions penetrate into the inner magnetosphere and the plasmapause moves earthward due to the enhanced convection electric field. The penetration depth of ions depends on the minimum amplitude of the Dst (Sym-H) index. The correlation coefficient between the minimum L-shell of 25 keV protons and the minimum Sym-H index is 0.744. Lower energy ions penetrate closer toward the earth than high-energy ions due to energy dependence of magnetic drifts (grad-B and curvature drifts). We also discuss the relationship between the temporal and spatial variations of the protons and evolution of the ambient electric field.

Initial calibration of the LEPe instrument onboard the ERG spacecraft

Yoichi Kazama[1]; Tomoaki Hori[2]; Tzu-Fang Chang[3]; Chih-Yu Chiang[4]; B.-J. Wang[5]; S.-Y. Wang[6]; Sunny W. Y. Tam[4]; Paul Ho[7]; Kazushi Asamura[8]; Atsushi Kumamoto[9]; Fuminori Tsuchiya[10]; Masafumi Shoji[2]; Ayako Matsuoka[11]; Mariko Teramoto[12]
[1] ASIAA; [2] ISEE, Nagoya Univ.; [3] ISEE, Nagoya Univ.; [4] ISAPS, NCKU, Taiwan; [5] ASIAA, Taiwan; [6] ASIAA, Taiwan; [7] Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan; [8] ISAS/JAXA; [9] Dept. Geophys, Tohoku Univ.; [10] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [11] ISAS/JAXA; [12] ISEE, Nagoya University

It is known that a quantum efficiency of a micro-channel plate (MCP) highly depends on its surface properties, and thus the efficiency can differ by each individual MCP and even by the position of the MCP. However, absolute efficiency measurement is difficult because a beam intensity for the test cannot be absolutely calibrated or evaluated. Therefore, in-flight calibration is needed to obtain physical quantities such as electron fluxes from MCP's electron signals. For the initial calibration of the low-energy electron instrument LEPe onboard the ERG spacecraft, we made 1) relative count correction between MCP anode channels, and 2) estimation of efficiency's energy profile. The calibration results have been applied to LEPe measurement data, and calibrated LEPe Level2 data are available on the ERG Science Center's web pages.

あらせ衛星搭載低エネルギーイオン質量分析器 (LEPi) における TOF(time of flight) 型質量分析の較正

長谷川 達也 [1]; 浅村 和史 [2]; 三好 由純 [3]; 齋藤 義文 [4]
[1] 東大・理・地惑; [2] 宇宙研; [3] 名大 ISEE; [4] 宇宙研

Calibration of ion species discrimination by LEPi onboard the Arase satellite

Tatsuya Hasegawa[1]; Kazushi Asamura[2]; Yoshizumi Miyoshi[3]; Yoshifumi Saito[4]
[1] Earth and Planetary Science,Tokyo Univ.; [2] ISAS/JAXA; [3] ISEE, Nagoya Univ.; [4] ISAS

https://sprg.isas.jaxa.jp/researchTeam/spacePlasma/member_master.html

LEPi (Low-Energy Particle experiments - Ion mass analyzer) is one of the particle instruments onboard the Arase satellite. LEPi is an ion energy-mass spectrometer which covers the energy range from 0.01 keV/q to 25 keV/q. In order to resolve the species of incoming ions, LEPi uses a combination of an electrostatic energy-per-charge analysis and a TOF (time-of-flight) technique. In the TOF analysis, the velocity of the incoming ion is identified by measuring the elapsed time between two signals (START and STOP signals). For the START signals, secondary electrons released at the passage of incoming particles through the ultra-thin carbon foil are used. The incoming particles that pass though the carbon foil are detected as STOP signals. Because of the usage of the foil, the measured TOF time contains several uncertain factors, such as energy loss and angular struggling of the incoming ions at the passage of the foil, flight time of the secondary electrons, etc. Therefore it is expected that the measured TOF profiles overlapped between different species. In order to discriminate the species, we have determined an analytical function which reproduces the observed TOF profile for each species at the energy range from 0.01 keV/q to 25 keV/q by a fitting analysis. Using this result, it has become possible to calculate the energy flux of the each ion species.

あらせ衛星搭載観測器の 1 つである LEPi (Low-Energy Particle experiments - Ion mass analyzer) は、0.01keV/q~25keV/q の範囲のエネルギーのイオンを測定するよう設計されたイオンエネルギー質量分析器である。現在、定常観測が行われており、得られたデータの較正が行われているを行っている 。本研究では、LEPi の観測データに対し、質量分析についての較正を行った。

LEPi は静電型エネルギー分析に加え、飛行時間計測 (TOF: Time-Of-Flight) 法を用いて質量弁別を行う。TOF 法では、粒子が特定距離を飛行するまでにかかった時間を計測してその速さを計算する求める。この粒子の速さ v は静電分析部で分析したエネルギー・電荷比 E/q を用いて,

$E/q=1/2(m/q)\ v^2$ と表すことができる。ここで速さは飛行時間 T_{TOF} と飛行距離 L から、

$v=L/T_{TOF}$ と計算することができるため、粒子の質量電荷比 m/q の同定が可能となる。しかし、計測される T_{TOF} には、粒子の超薄膜カーボン通過時のエネルギーロス、角度分散、荷電状態の変化、二次電子の飛行時間など、採用した TOF 法のを用いることによる原理的問題に起因するよるばらつきがあり、マイナーな粒子種などを抽出するためには詳細な較正が必要となる。

そこで本研究では H^+,He^{++},He^+,O^{++},N^+&O^+ について、T_{TOF} に対するカウント数の関数を推定し、各粒子種毎の分布を決定した。この分布を用いてれにより、観測された TOF 分布を各粒子の分布の足し合わせとしてで表現することが可能となるった。また、でき、この操作を各エネルギー帯の観測データについて行うことで、粒子種毎のフラックスを正確に計算することができるようになった。

Inter-channel calibration of the high-energy electron experiments (HEP) instrument onboard the Arase satellite

Tomoaki Hori[1]; Takefumi Mitani[2]; Takeshi Takashima[3]; Inchun Park[4]; Satoshi Kurita[1]; Mariko Teramoto[5]; Nana Higashio[6]; Satoshi Kasahara[7]; Shoichiro Yokota[8]; Yoshizumi Miyoshi[1]; Iku Shinohara[9]
[1] ISEE, Nagoya Univ.; [2] ISAS/JAXA; [3] ISAS, JAXA; [4] ISEE,Nagoya univ.; [5] ISEE, Nagoya University; [6] JAXA; [7] The University of Tokyo; [8] Osaka Univ.; [9] ISAS/JAXA

A detailed study of electron fluxes measured by the HEP instrument onboard the Arase satellite is conducted to calibrate flux values by empirically evaluating the relative detection efficiency between azimuthal channels and its short- to long-term variations. For this purpose, we made a statistical analysis of the HEP Level-2 data obtained mainly during the first 1-year period since the regular observations started on March, 2017. Our preliminary results indicate that no substantial decrease in measured flux level has not been seen in terms of the long-term trend of observed fluxes, implying that no significant degradation has occurred so far for the instrument detectors. Detailed comparison of flux values between azimuthal channels shows that there is some non-uniformity in detection efficiency and relative offset of the background flux level between the channels. On the basis of the statistics, we seek to derive a set of correction coefficients to normalize the efficiency difference of the channels, which is essential to obtain a correct 3-D distribution function of energetic electrons.

あらせのHEPによる放射線帯内帯での粒子観測

戸田 穂乃香 [1]; 三宅 亙 [2]; 三谷 烈史 [3]; 高島 健 [4]; 三好 由純 [5]; Park Inchun[6]; 堀 智昭 [5]
[1] 東海大・工; [2] 東海大・工; [3] 宇宙研; [4] 宇宙研; [5] 名大 ISEE; [6] 名大 ISEE

Particle observation in the inner radiation belt with HEP onboard the Arase satellite

Honoka Toda[1]; Wataru Miyake[2]; Takefumi Mitani[3]; Takeshi Takashima[4]; Yoshizumi Miyoshi[5]; Inchun Park[6]; Tomoaki Hori[5]
[1] Engineering,Tokai Univ.; [2] Tokai Univ.; [3] ISAS/JAXA; [4] ISAS, JAXA; [5] ISEE, Nagoya Univ.; [6] ISEE,Nagoya univ.

HEP instrument on board the Arase satellite measures electrons with energies from 70 keV to 2 MeV. However, the HEP has detected unexpected counts even at MeV energy channels in the inner radiation belt where no MeV electrons are expected. The unexpected counts are supposed to result from contamination of energetic protons. In order to identify energy of protons we compare the spatial distribution of HEP counts with three kinds of proton distribution models AP8MAX, AP9 mean, CRRESP-PRO quiet and two kinds of electron distribution models AE8MAX and AE9 mean. The distribution of HEP counts is almost equivalent among different energy channels. When the energy of the model is low, the location of the peak deviates from that of the observed distribution. CRRESPRO quiet of >55 MeV, AP8MAX, and AP9 mean of >30 MeV seems to be consistent with HEP observations. Even raising the energy further, the position of the peak does not change in the models. The model distribution with high energy did not extend far to larger L value and the distribution from HEP observation seems to be a combination of the sharp peak at small L and the spread to larger L.

あらせに搭載されたHEPは70 keV～2 MeVのエネルギーの高エネルギー電子を観測する．しかしHEPは放射線内帯で，Van Allen Probesでは存在しないとされたMeVエネルギー帯で予想外のカウントを検出していた．これは高エネルギープロトンのコンタミネーションと考えた．そこで本研究ではHEPで観測されているプロトンのエネルギーを明らかにするため，AP8MAX，AP9 mean，CRRESPPRO quietの3種類のプロトン分布モデルと，AE8MAX，AE9 meanの2種類の電子分布モデルを用い，HEP観測による分布との比較を行った．またGeant4を用いた高エネルギープロトンが入射した場合のモデル計算との比較も行ってみた．HEPによる分布はエネルギーチャンネルが変わってもほぼ中心は変化せしない．モデルのエネルギーが低い（＞10 MeV）とHEPによる分布のピーク位置よりも外側にとずれてしまう．CRRESPRO quietは＞55 MeV以上のモデルAP8MAXとAP9 meanは＞30 MeV以上のモデルと一致するように見える．これ以上エネルギーを上げてもモデルのピークの位置は変わらなかった．エネルギーが高いモデルはL値の遠いところまで伸びておらず，HEPのカウントの分布はLが小さいところのピークとLが大きいところへの広がりが組み合わされているように考えられた．

Radial profiles of phase space density of relativistic electrons in the radiation belt during magnetic storms in 2017

Nana Higashio[1]; Kanako Seki[2]; Kunihiro Keika[3]; Naritoshi Kitamura[4]; Iku Shinohara[5]; Takeshi Takashima[6]; Ayako Matsuoka[7]
[1] JAXA; [2] Dept. Earth & Planetary Sci., Science, Univ. Tokyo; [3] University of Tokyo; [4] University of Tokyo; [5] ISAS/JAXA; [6] ISAS, JAXA; [7] ISAS/JAXA

Radiation belt electrons drastically vary during geomagnetic storms. However, the relative significance of physical mechanisms of the acceleration and loss remains unclear. Two types of the electron acceleration processes have been proposed. One is the adiabatic acceleration due to radial transport of electrons from the plasma sheet to the inner magnetosphere (adiabatic transportation). Another process is the non-adiabatic acceleration of sub-relativistic electrons to the relativistic energies in heart of the radiation belt. Radial profiles of phase space density (PSD), i.e., PSD profile along $L*$(McIlwain L-parameter), have used to distinguish the two acceleration processes [e.g., Reeves et al., Science, 2003]. The peak in a PSD profile is considered as an evidence of the non-adiabatic acceleration, while the diffusion-type radial transport will result in the monotonic decrease of PSD from high to low $L*$.

In order to investigate the electron acceleration processes, we examine variations of radial profiles of relativistic electrons PSD based on observations by the eXtremely high-energy Electron exPeriment (XEP) onboard the Arase satellite, which measures electrons from 400 keV to 20 MeV. Six geomagnetic storms that commenced from (a) March 27, (b) May 27, (c) September 7, (d) September 27, (e) November 7 and (f) December 4, 2017 are studied. The minimum Dst of the storm events (a)-(f) was -74, -125, -142, -76, -70, and -50 nT, respectively. The events (b) and (c) are related to CMEs, and others are associated with CIRs. In order to minimize the error from the assumption in pitch angle distributions (PADs), we only use data obtained in low MLAT regions and do not conduct interpolation of PADs, while the energy spectrum is interpolated to obtain PSD profiles of the fixed magnetic moment. The time variations of PSD profiles as a function of $L*$are investigated. In all events, PSD of relativistic electrons decreases in the main phase and then increase in the recovery phase. We observed a clear peak in the PSD profiles during the early phase of the electron PSD increase. Locations of the PSD increase tend to become closer to Earth (lower $L*$) with increasing minimum Dst. We will also report on the magnetic moment dependence of the timing and location of the PSD increase in details.

Energy spectra variations of high energy electrons depending on magnetic latitude and longitude observed by ARASE and HIMAWARI

Takeshi Takashima[1]; Nana Higashio[2]; Takefumi Mitani[3]; Tsutomu Nagatsuma[4]; Yoshizumi Miyoshi[5]
[1] ISAS, JAXA; [2] JAXA; [3] ISAS/JAXA; [4] NICT; [5] ISEE, Nagoya Univ.

The ARASE spacecraft was launched in December 20, 2016 to investigate mechanisms for acceleration and loss of relativistic electrons in the radiation belts during space storms.

Interactions between waves and particles are the cause of particle acceleration and disappearance in the radiation belt. Because of these interactions, it appears as a change in the power low index of the energy spectrum and flux changes in the observation. The relativistic electrons in the outer radiation belt were disappeared/increased and their energy spectra were changed dynamically in some storms observed by XEP/HEP onboard the ARASE spacecraft. So, detailed calibration between observation instruments, HEP, XEP on ARASE and SEDA-e on HIMAWARI, is required to identify affected energy by wave-particle interactions. We have carried out mutual calibration using data of HEP, XEP and SEDA-e.

When comparing the energy spectra, there are times when the spectrum matches or does not match. It is also observed that the change in the power low index of the energy spectrum differs with time. These phenomena are observed even when there are two satellites at the same local time. We investigate the influence of difference of magnetic latitude on energy spectrum because ARASE satellite and HIMAWARI satellite have different inclination angles on orbits and we will report results.