# 3D analysis of discrete arcs based on auroral computed tomography

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We have studied the magnetosphere-ionosphere (MI) coupling process in the auroral region by using data obtained from ground-based network observation. In this study we present three-dimensional (3D) distribution of discrete arcs observed in Northern Europe on March 14, 2015 and interpret it in terms of the MI coupling process. We focus on multiple vortex structure in the discrete arcs, which was observed by the multi-point monochromatic imagers (wavelength = 427.8 nm) during 22:15-22:20 UT.

We applied the auroral computed tomography method to the multiple monochromatic images. As a result, 3D distribution of the optical emission and horizontal distribution of precipitating electron's energy were obtained every 10 second during 22:15-22:20 UT. It was newly found that the averaged energy of precipitating electrons was higher around the center of auroral vortices where the total energy flux was also greater. This result can be explained by the Ohm's law along the field lines, i.e., the relation that the field-aligned current is proportional to the field-aligned potential difference. In addition, the altitude profile of the 427.8 nm emission was similar to the electron density profile simultaneously observed by the EISCAT UHF radar. Thus, we could estimate the height-integrated conductivity in the area of 150km x 300km from the optical emission with the MSIS atmosphere model. By combining the ionospheric conductivity with the geomagnetic field observed by the IMAGE magnetometer network, we will further investigate the distribution of the ionospheric current and field-aligned current, i.e., 3D current system for the discrete arcs.

# Ionospheric Polarization: Deformation of Ionospheric Convection and Effects on Magnetosphere

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Recently [Nakamizo and Yoshikawa, 2019], we showed that the ionospheric polarization can deform the high-latitude ionospheric convection field, which is widely considered to be a manifestation of the convection field in the magnetosphere.

We performed in a potential solver 'the Hall polarization field separation' modified from the complete separation theory/method by Yoshikawa et al. [2013a,b]. We adopted dawn-dusk and north-south symmetric distributions of conductance and region 1 (R1) field-aligned current (FAC) to understand the essential effects of the conductance nonuniformity on the potential pattern eliminating asymmetries arising from that of the conductance and FAC distributions themselves.

The pair of the primary field of the R1 system and each gradient of Hall conductance generates the Hall polarization field and consequently causes potential deformations as follows. (a) The equatorward gradient causes clockwise rotation. (b) The gradient across the terminator, together with the effect of the equatorward gradient, causes the dawn-dusk asymmetry. (c) The high conductance band in the auroral region causes kink-type deformations. In particular, a nested structure at the equatorward edge of the band in the midnight sector well resembles the Harang Reversal. (It was also found that the Pedersen polarization is important because it determines the formation of the primary field, which is the source for the secondary field (Hall polarization field)).

Result (a) explain the clockwise bias inexplicable by the IMF-By effect alone, the combination of (a) and (b) explain the clearness and unclearness in the round or crescent shapes of the dawn-dusk cells depending on the IMF-By polarity, and (c) suggests that the ionosphere may not need the upward-FAC for the formation of the Harang Reversal.

The above result suggests that the final structure of the ionospheric potential is established by the combined effects of the magnetospheric requirements (external causes) and ionospheric polarization (internal effect). Our next question is how and in what way does the ionospheric polarization play a role in the convection and dynamics of the magnetosphere-ionosphere system through the coupling process?

We show that the ionospheric polarization actually controls the magnetospheric configuration/dynamics in a global MHD model. The topic includes the dawn-dusk asymmetry of the magnetosphere, formation of the Harang Reversal in the magnetosphere, and the NENL formation. We also show the effects of north-south conductance asymmetry due to the precession between the rotation and magnetic axes of Earth on the magnetosphere. We will discuss the results, revisiting the M-I algorithm of current global models.

# 惑星間空間磁場朝夕成分反転を伴わないトランスポーラーアーク形成過程

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# Transpolar arc formation in the absence of an interplanetary magnetic field By switch

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The transpolar arcs is literally the large-scale aurora that extends across the polar cap in the Sun-Earth direction. It is known that the transpolar arc tends to appear during periods of strongly northward interplanetary magnetic field (IMF). The arc, together with the auroral oval, is also named 'theta aurora' from the resemblance of the overall shape to the Greek letter theta. One formation process of the transpolar arc is that triggered by an IMF By sign change. This formation process can be reproduced by global magnetohydrodynamic (MHD) simulations. According the statistics by Kullen et al. [2002], however, transpolar arcs associated with an IMF By change are minor, with the majority of the arcs appearing without an IMF By switch. The purpose of this study is to clarify the formation process of transpolar arcs in the absence of an IMF By switch. Using the Reproduce Plasma Universe (REPPU) code (Tanaka, 2015), we performed MHD simulations by trial and error and found several cases in which the transpolar arc structure seems to be reproduced. One is the case when the IMF intensity is strong (˜20nT) and the IMF clock angle (measured from due north) rotates from ˜60 degrees to ˜30 degrees. In this case, in the ionosphere, a region of open magnetic flux intrudes into the dawnside or duskside plasma sheet from postmidnight or premidnight, respectively, toward the dayside, thus forming a transpolar arc structure. In numerical MHD modeling, such transpolar arc formation that initiates on the nightside has never been reported previously. In this presentation, we report the detailed analysis of this simulation. We also discuss observations that may support the simulation results.

トランスポーラーアークとは極冠を太陽-地球方向に横断する大規模なオーロラであり、惑星間空間磁場（interplanetary magnetic field, IMF）が強い北向きの時に出現しやすい。トランスポーラーアークはオーロラオーバルを含めたその形状から、シータオーロラと呼ばれることもある。トランスポーラーアーク形成の一過程として IMF By 成分（朝夕成分）反転が引き金になるものがあり、この過程は MHD(magnetohydrodynamic) シミュレーションにより再現されている。しかしながら、Kullen et al.[2002] が行った統計的な研究によると IMF By 成分反転を伴うトランスポーラーアークは少数であり、大多数のトランスポーラーアークは IMF By 成分反転を伴わず生じている事が分かった。本研究では IMF By 成分反転を伴わないシータオーロラ形成過程を明らかにすることを目的とする。Reproduce Plasma Universe (REPPU) コードを用いて試行錯誤的に数値実験を行ったところ、トランスポーラーアークと似た構造が得られる例がいくつかあった。その一つは IMF 強度が大きく（20nT 程度）、時計角（真北から測る）が 60 度から 30 度程度に回転する場合である。このとき電離圏において、朝方側または夕方側プラズマシートに開磁力線領域が夜側から太陽方向に陥入してゆき、トランスポーラーアークと似た構造が形成された。MHD シミュレーションでこのように夜側から昼間側へ延びる構造が報告された例は過去にないので、講演ではこのシミュレーションの詳細な解析結果を報告する。またシミュレーション結果を支持する観測例がないかについても調査し報告する。

# Ionospheric flow fluctuations at mid-latitudes during storms as seen by SuperDARN-Van Allen Probes-Arase conjunctions

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The recent Super Dual Auroral Radar Network (SuperDARN) observations show that ionospheric flow fluctuations of the mHz or lower frequency range appear even in the subauroral to mid-latitude region during magnetic storm times. An interesting feature of the flow fluctuations is that they appear to propagate azimuthally either westward or eastward, and occasionally bifurcate toward the both directions. Taking a closer look with high spatial resolution measurements provided by the radars reveals that those flow fluctuations consist of meso-scale patchy structures of ionospheric convection with a significant latitudinal flow component and a longitudinal scale of ˜1h MLT. The azimuthal propagation properties strongly suggest that westward-drifting ions and eastward-drifting electrons of tens of keV in the inner magnetosphere can be the moving sources responsible for excitation of MHD waves seen by the radars at the ionospheric footprint. However, only few observations in the magnetosphere have been reported on the source of the waves at the subauroral to mid-latitudes. Recent observations in the inner magnetosphere by the Arase satellite and the Van Allen Probes have provided a good opportunity to examine their magnetospheric counterpart in further detail. On the basis of in-situ measurement of ring current particles and the magnetic field in the inner magnetosphere, we discuss the generation mechanism of the observed flux tube fluctuations in terms of resonant or non-resonant processes.

# Study of the occurrence characteristics of SAPS observed by the SuperDARN Hokkaido East Radar with the beam-swing technique

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We investigate occurrence characteristics of Sub-Auroral Polarization Streams (SAPS), using Super Dual Auroral Radar Network (SuperDARN). We mainly use the Hokkaido East radar data. In this study, we statistically analyze about 10-year data for years from 2007 to 2016 and studied the occurrence frequency of flows that can be considered as SAPS, and their dependence on MLT and MLAT. We use the beam-swing technique, which calculates the real flow velocity and angle from the line of sight velocity of all the radar beams. We set criteria for the SAPS event, i.e., the flow should exceed 150 m/s and have westward component. We obtained most of the overall characteristics of SAPS distribution that were reported in past studies, i.e., the equatorward shift of the high occurrence rate region with increasing MLT and geomagnetic activity. Some other characteristics, however, are different from those identified by past studies (e.g., Kunduri et al., 2017). The SAPS region seems to be expanded toward higher latitudes than the past studies, and the SAPS occurrence peak region is located at later MLTs. These differences might be due to the difference in geographic longitude, as well as the relative values between geographic and geomagnetic latitudes (Far-East Siberia to Pacific vs North American region). We also found new characteristics, i.e., westward flows from midnight to morning at relatively low geomagnetic latitudes, which could not be studied by the previous studies, probably due to the limited fields of view at mid latitudes (equatorward of about 50 degrees geomagnetic latitude). Study of the seasonal and solar activity dependence of SAPS distribution is also in progress.

# SuperDARN レーダーで観測された SAPS 振動の複数イベント解析

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# Multi-event study of SAPS Wave Structures observed by the SuperDARN radars

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SAPS Wave Structures are wavy phenomena embedded in the Sub-Auroral Polarization Streams structure. It was first reported by Erickson et al. (2003), and was also reported using the SuperDARN radar network mainly in the mid-latitude region(e.g., Makarevich and Bristow, 2014; Hori et al., 2018). Because of the limited number of examples studied so far, their generation mechanism is not fully understood yet.

One problem in identifying the SAPS wave structure in the SuperDARN data is that because the temporal resolution of the standard SuperDARN operation mode is 1 to 2 minutes, so that the radar sometimes cannot identify the shorter-scale wavy variations.

In this study we used the SuperDARN Hokkaido Pair of (HOP) radars data with special operation modes to study the wavy variations of embedded in the fast flow structure. Using the data using the new fitting algorithm (fitacf Ver. 3) we had more extended coverage of the echo regions. In this paper we focus mainly on the events on Sep 08, 2017 and Aug. 26, 2018. Both events occurred near the peak of large geomagnetic storms. These events were registered by the SuperDARN radars with higher temporal resolution (3 and 12 seconds respectively) camping beams. Using both camping beam data and 2-dimensional data (with 1 to 2 min temporal resolution) we can discuss period, wavelength and propagation speed of these wave structures. Similarity and differences between these two events, as well as their possible generation mechanisms, will be discussed.

# Dynamics of the Ionosphere/Plasmasphere System: Comparisons Between Arase/PWE Observations and the IPE Model Simulations

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We compared an extreme erosion of the plasmasphere arising from the September 2017 storm between Arase observations and the Ionosphere-Plasmasphere Electrodynamics (IPE) model simulations. The cold electron density is identified from the upper limit frequency of upper hybrid resonance waves observed by the Plasma Wave Experiment instrument onboard the Exploration of energization and Radiation in Geospace/Arase satellite. The electron density profiles reveal that the plasmasphere was severely eroded during the recovery phase of the storm and the plasmapause was located at L = 1.6-1.7 at 23 UT 8 September 2017. This is the first report of deep erosion of the plasmasphere (LPP < 2) with the in situ observation of the electron density. The Arase/PWE's wide coverage of frequency (10 kHz - 10 MHz) enables continuous observation of electron density from sparse magnetosphere to dense ionosphere and detection of the plasmapause even if it is during the deep erosion event. The degree of the severity is much more than what is expected from the relatively moderate value of the SYM-H minimum (-146 nT). We attempt to find a possible explanation for the observed severe depletion by using both observational evidence and numerical simulations. Our results suggest that the middle latitude electric field had penetrated from the high-latitude storm time convection for several hours. Such an unusually long-lasting penetration event can cause this observed degree of severity.

# 高エネルギー電子降下による cosmic noise absorption(CNA) の変動とオーロラの形態変化

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# Variations of cosmic noise absorption (CNA) by energetic electron precipitation (EEP) and changes of the auroral morphology

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Temporal and spatial variations of the aurora morphology in association with substorm have been studied for more than half century. In this study we focus on pulsating aurora, which is characterized by quasi-periodic oscillations in the emission intensity at periods of a few to tens of seconds, and auroral patches observed embedding in the pulsating aurora. Both types of aurora are known as typical phenomena at the recovery phase of substorm, especially from midnight to dawn. It is known that these types of aurora are often accompanied by energetic electron precipitation (EEP) exceeding several hundreds of keV [Miyoshi et al., 2015]. Elucidation of causality to produce pulsating aurora and EEP is an important theme to understand relationships between the radiation belt and upper-middle atmosphere of the earth. Analyzing measurements from satellite observations and ground-based optical/radio technique observations, the generation mechanism is thought to be mainly attributed to wave particle interactions due to plasma wave and electrons in the magnetosphere. In this study, we study relationships between auroral morphological changes, in particular spatiotemporal evolutions of patches and coinciding precipitations of the energetic electron.

Some previous studies have presented changes in morphology from diffuse aurora to finger like structures and dependence of magnetic local time of EEP [Shiokawa et al., 2014; Hosokawa and Ogawa, 2015]. The wave-particle interaction has been widely accepted with experimental evidences to support generation of pulsating aurora and EEP [Miyoshi et al., 2015; Kasahara et al., 2018]. However, our understanding has not yet reached its maturity of presenting spatiotemporal evolutions of auroral morphology and associated electron precipitation. Oyama et al. [2017] presented enhancements of cosmic noise absorption (CNA) coinciding with appearance of the patch structure but with only two events and the horizontal area to be analyzed was relatively narrow with several hundred kilometers. In this study, we conducted observations to capture simultaneously time evolutions and spatial distributions of auroral morphology and EEP by utilizing a network of Electron Multiplying Charge Coupled Device (EMCCD) cameras operated by Japan and riometers operated by Finland in Scandinavia.

This study will present two events (March 6-7 and 29-30, 2017) with pulsating aurora and auroral patches. For the camera count of the portion where the overlapping the EMCCD camera and the field of view of the riometer, running average processing is performed to remove the luminance fluctuation with a period of 40 seconds or more. After that, frequency analysis is performed, and spectra at each time are calculated. Among the frequency components, the spectrum of the emission intensity around the main pulsation was extracted by removing the frequency component from 1 to 5 Hz corresponding to the internal modulation of the pulsating aurora, and was integrated in the frequency direction. The results were compared with the CNA. From the transmission characteristics of the optical filter attached to EMCCD, the aurora measured by EMCCD camera is considered to be emission layer around 100 km altitude represented by molecular nitrogen emission. On the other hand, although the sensitivity characteristic of the riometer has a gradual dependence on the altitude, it may be considered that the measured CNA fluctuates in accordance with the variations of the electron density around the altitude of 90 km. Thus, although the altitude represented by each device is different, the relationship between the CNA and the intensity of the main pulsation has a linear relationship of similar inclination before and after changes aurora morphology. This result indicates that the main pulsation synchronized with the precipitating electrons of several tens of keV changes the CNA.

サブストームに関連したオーロラの形態の時間変化や空間分布は半世紀以上にわたり研究されてきた。比較的明るく、東西方向に伸展した形状をしたディスクリートアークや、それよりは輝度が低く、しかしかなりの広範囲に分布するディフューズオーロラなど、様々なオーロラの種類が知られている。そのなかでも、数秒から数十秒の周期で輝度が明滅する脈動オーロラや、その周辺に出現するパッチ状のオーロラは、サブストームの回復相、特に、真夜中から明け方にかけて現れ、数百 keV を超える高エネルギーの電子降下（Energetic Electron Precipitation）を伴っていることが知られている。脈動オーロラと高エネルギー電子降下の発生メカニズムの解明は、放射線帯と地球超高層・中層大気との関係を知る上で重要なテーマであり、あらせ衛星を始めとする衛星観測や、地上光学・電波観測による研究の結果、磁気圏のプラズマ波動と電子による波動粒子相互作用が主要因と考えられている。本研究では、地上から観測された脈動オーロラ、特に、空間構造がパッチ状に変化していく過程と、高エネルギー降下電子の時間・空間発展との関係に着目する。

ディフューズオーロラがあるときを境に構造を細分化させ、所謂、指状構造へと遷移する現象 [e.g., Shiokawa et al., 2014] や、高エネルギー降下電子の磁気地方時依存性 [e.g., Hosokawa and Ogawa, 2015] が報告されている。また、脈動オーロラや EEP の生成機構として、波動粒子相互作用が広く受け入れられている [Miyoshi et al., 2015; Kasahara et al., 2018]。

しかし、我々の理解はまだオーロラの形態やそれに関連する電子降下の時空間的発展について十分ではない。Oyama et al. [2017] では、パッチ構造の出現に合わせ、CNA (cosmic noise absorption) が増加することを示したが、２例のみの事例解析結果であり、解析対象の空間領域が水平数百 km と、比較的狭かった。そこで本研究では、北欧に日本が展開した EMCCD (Electron Multiplying Charge Coupled Device) カメラと、フィンランドが運用するリオメータのネットワークを活用し、オーロラ形態と高エネルギー降下電子の時間発展と空間分布を同時にとらえる観測実験を実施した。

本研究ではソダンキュラ上空で脈動オーロラとオーロラパッチが出現した 2 イベント (2017 年 3 月 6-7 日、3 月 29-30 日) を解析しその結果について報告する。EMCCD カメラとリオメータの視野が重複する部分のカメラカウント値に対し、走査平均処理を行うことで 40 秒以上の周期の輝度変動を取り除いた後、周波数解析を行い、各時刻におけるスペクトルを計算した。周波数成分の内、脈動オーロラの内部変調に相当する 1-5Hz の周波数成分を取り除いた、主脈動を中心とした発光強度のスペクトルを抽出し、それを周波数方向に積分した。この計算結果とソダンキュラのリオメータが観測した CNA との比較を行った。EMCCD に取り付けられた光学フィルターの透過特性から、本 EMCCD カメラが測定したオーロラは、窒素分子発光（例：427.8 nm）に代表される高度 100km 付近の発光と考えられる。一方、リオメータの感度特性は高度に対して緩やかな依存性があるものの、測定される CNA は高度 90km 付近の電子密度の変動に順じて変動すると考えてよい。このことから、EMCCD カメラとリオメータは、異なる高度の電離と励起を代表する、すなわち EMCCD カメラのカウント値の方がリオメータ測定の CNA よりも、低いエネルギーの降下電子に応答する傾向があると言える。このように各装置が代表する高度が違うにも関わらず、CNA と主脈動の強度の関係は、オーロラの形態変化の前後で同様の傾きの線形関係となった。この結果は、光で見る脈動と同期する数十 keV の電子の降込みが、 CNA の変動、つまり高度約 90km の D 領域の電子密度を変動させせることを示している。またスカンジナビア半島のカメラネットワークを使用することでさらに広範囲の数十 keV の EEP の時間的発展や空間分布を観測するための手段として発展していくことが期待される。

# オーロラ爆発と脈動オーロラの昭和基地-あらせ衛星-チョルネス共役観測

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# Syowa-Arase-Tjoernes conjugate observation of auroral breakup and pulsating aurora

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Auroral breakup and subsequent pulsating aurora were observed by ground-based high-speed imagers at Syowa station in Antarctica and at its magnetic conjugate station, Tjoernes in Iceland simultaneously on 22 September 2018. Arase satellite was located on the magnetic field line connecting these two stations at that time and observed sudden increase in electron fluxes and following decrease of geomagnetic y-component, and subsequent chorus emissions. The auroral breakup was characterized by its large longitudinal displacement of the initial brightening position in both hemispheres, while the subsequent pulsating auroras showed good conjugacy. The variation of chorus emission intensity observed by the Plasma Wave Experiment onboard Arase satellite shows a good correlation with the intensity variation of pulsating aurora. We report the whole sequence of the event to examine the difference of the conjugate points derived from the observations and from several magnetic field models.

# Spatial distribution of multiple temporal variations of pulsating aurora

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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 distinct temporal variations. One is so-called main pulsation whose period ranges from a few to a few tens of seconds. The other is a few Hz modulation (internal modulation), which is occasionally seen during the ON phase of the main pulsation. Previous studies have 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 one to one correspondence between the amplitude variation of chorus waves and the luminosity modulation of PsA. However, there have been no studies which analyzed the spatial distribution of multi-scale temporal variations of PsA(i.e. the main pulsation and internal modulation).

To reveal the spatial characteristics of the multi-scale temporal variation of PsA, we need to perform frequency analyses on multi-scale temporal variations of PsA by using data from high speed optical cameras capable of providing a wide spatial coverage.

For this purpose, we make use of highly sensitive EMCCD cameras, which have been in operation in Sodankyla and Kevo, Finland, Tromsoe, Norway, and Tjautjas, Sweden. All-sky aurora images are taken with the temporal resolution of 0.01 sec. The temporal resolution of these cameras is sufficient to identify the multi-scale temporal variation of PsA. Note that in this study, to make the analysis easily, the images have been down-sampling to 25 Hz.

In the frequency analysis, we have employed all-sky images taken on March 14, 15, and 23, 2018. We computed the average frequency of internal modulation from each pixel of the EMCCD cameras and derived the spatial distribution of their dominant frequencies. Regardless of the magnetic latitude, the luminosity of pulsating patches was fluctuating with a similar frequency. We also derived the frequency spectrum of several pulsating patches existing at different locations in the north-south direction and found that these frequency spectrums of pulsating patches showed peaks at around 3 Hz. These results indicate that the frequency of internal modulation does not depend on latitude, and the frequency of internal modulation is highly collimated on 3 Hz.

Following the method mentioned above, we will also compute the average periodicity of the main pulsation and derive the spatial distribution of main pulsation. In this presentation, we will discuss what factor controls the multi-scale temporal variation of PsA by taking into account their latitudinal and longitudinal dependences.

# Large-scale signatures of pulsating aurora characterized by ambient parameters in the magnetosphere

# Satoshi Ebukuro[1]; Keisuke Hosokawa[1]; Yoshizumi Miyoshi[2]; Shin-ichiro Oyama[2]; Yasunobu Ogawa[3]; Satoshi Kurita[2]; Yuki Kawamura[1]; Ryoichi Fujii[4]
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Pulsating aurora (PsA) is one of the predominant classes of diffuse aurora in the morning side. They are characterized by quasi-periodic blinking of luminous patches. There are two types of periodicity in the brightness variation of PsA, that are main pulsation and internal modulation. The main pulsation ranges from a few to a few tens of seconds, and the internal modulation, which is often embedded within the ON time of the main pulsation, shows a few Hz modulation in brightness. A recent study by Kasahara et al. [2018] indicated a one-to-one correlation between the luminosity of PsA, the electron flux in the loss cone and the intensity of chorus waves near the magnetic equator. This result indicates that the observation of PsA in the ionosphere can be used for monitoring the activity of chorus waves and resultant occurrence of wave-particle interaction in the magnetosphere.

In this study, we conducted a frequency analysis for a PsA event which was observed by 100 Hz sampling EMCCD cameras in Northern Scandinavia on March 28, 2017 (23:30 to 24:10 UT). By applying the Fourier analysis to data from all the pixels of the cameras, we succeeded in deriving so-called frequency map, which shows the distribution of dominant modulation frequency of PsA. We also estimated the spatial distribution of chorus waves by mapping the frequency distribution of PsA onto the equatorial plane of the magnetosphere with the Tsyganenko 04 model. As a result, we found that there were three regions showing different modulation characteristics. We named these regions region A, region B, region C which were divided by the difference in periodicity. The equatorward most region (region A) only showed the internal modulation and the poleward most region (region C) showed both the internal modulation and main pulsation. In region B, which is sandwiched by regions A and C, we only observed the main pulsation. An interesting thing is the boundaries between these three regions were quite sharp indicating that similar sharp boundaries in the characteristics of chorus could have existed in the magnetosphere. We also employed outputs from the ring current-atmosphere interactions model with self-consistent magnetic field (RAM-SCB) simulation runs for this interval and found that the electron flux of more than 30 keV increases only in region A. We also found that the linear growth rate becomes higher as L increases in the range of 4.75 to 5.75 where regions A and B exist. In the presentation, we focus on regions A and B and discuss how the ambient parameters, such as linear growth rate, cold plasma density and energetic electron distribution, can contribute to producing the observed differences in the characteristics of chorus and PsA, especially the existence/absence of internal modulation.

R006-12 会場: A 会場（6F ホール） 時間: 10 月 24 日 14:45-15:00

# 低高度衛星からの光学観測を用いた磁気嵐時の孤立型プロトンオーロラの汎地球的連続観測


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# Optical observations of isolated proton aurora from low-altitude satellite during magnetic storm


# Haruki Kawai[1]; Keisuke Hosokawa[2]; Yuta Hozumi[2]; Kazuo Shiokawa[3]; Satoshi Kurita[4]; Mitsunori Ozaki[5]; Takeshi Sakanoi[6]; Boris Shevtsov[7]; Igor Poddelsky[7]; Tero Raita[8]
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Isolated proton aurora (IPA) is a localized region of proton precipitation observed well equatorward of the main auroral oval. IPA is considered to be caused by precipitation of protons scattered by electromagnetic ion cyclotron (EMIC) waves near the equatorial plane of the magnetosphere. EMIC waves are thought to be generated by the energetic ring current ions (10-100 keV) having temperature anisotropy near the magnetic equator. EMIC waves play a role in rapid removal of relativistic electrons from the radiation belts during magnetic storms; thus, it is important to understand the behavior of IPA during magnetic storms to understand the loss of radiation belt electrons. It has been known that IPA tends to appear during the late recovery phase of magnetic storms. However, it has been difficult to monitor the occurrence of IPA continuously from the beginning to the end of a single magnetic storm mainly due to the limitation in the availability of ground-based optical observations.

In this study, we investigated auroral images taken by IMAP VISI on International Space Station (ISS) and SSUSI on DMSP satellites (F16-F19) obtained during a magnetic storm from June 22 to 30, 2015 (minimum Dst was less than -200 nT). We have extracted 38 IPA events in total. Most of them were observed in the recovery phase, which is consistent with the previous results. It was also identified that IPAs tend to be observed in the dusk sector during the high Kp interval. This tendency is also consistent with the previous statistical analysis of ground-based optical observations. We identified 4 intervals of simultaneous occurrence of IPAs at the magnetic conjugate points in the northern and southern hemispheres in the DMSP/SUSSI data, which confirmed that IPAs are caused by a single source region (region of EMIC wave) near the equatorial plane of the magnetosphere. In the presentation, we also show the longitudinal extent of IPA/Pc1/EMIC inferred by combining satellite measurements of IPA with Pc1 observations by 3 induction magnetometer data on the ground.

孤立型プロトンオーロラ (IPA) はオーロラオーバルより低緯度に見られる局所的なプロトンオーロラである。EMIC 波動との相互作用によって陽子がピッチ角散乱を受け、地球の超高層大気に降り込むことで生成される。EMIC 波動は磁気赤道面付近で温度異方性を有するリングカレントイオン（10-100 keV）によって励起される。EMIC 波動は地上で観測することができ、地上で観測した時には Pc1 地磁気脈動 と呼ばれる。EMIC 波動は放射線帯の相対論的電子も散乱することが可能であるため、IPA の性質を理解することは磁気嵐時の放射線帯電子の消失過程を理解する上で非常に重要である。IPA は磁気嵐の回復相に観測される傾向があることが知られているが、地上観測では天候によって観測ができないこともあり、単一の磁気嵐の初相から回復相に至るまで、IPA の分布を連続的に、かつ汎地球的に観測することは困難であった。

本研究では、国際宇宙ステーション (ISS) に搭載された可視分光撮像装置 (ISS-IMAP VISI) と 4 機の DMSP 衛星（F16 - F19）に搭載された紫外撮像装置（SSUSI）を用いて、2015 年 6 月 22 日 から 2015 年 6 月 30 日の期間に発生した磁気嵐（Dst < -200 nT）を対象として、IPA の発生を連続的に抽出することを試みた。この磁気嵐中に、IPA は南北半球合わせて合計 38 例抽出され、その発生を磁気嵐のフェーズと比較したところ、当初の予想通り、その殆どが磁気嵐の回復相において観測されていることが分かった。また Kp 指数と IPA の発生を比較したところ、先行研究で示されている「Kp が大きいほど夕方側の MLT で観測される」という傾向も見て取ることができた。これらに加え、地上の 3 箇所における誘導磁力計による Pc1 地磁気脈動の観測も組み合わせて IPA/Pc1/EMIC 波動の経度方向の広がりについて調べた結果についても報告する。

この磁気嵐中に、DMSP/SSUSI のデータから、IPA が南北両半球の磁気共役点においてほぼ同時に観測されている事例を 4 例抽出することができた。これは、IPA が磁気圏赤道面で EMIC 波動という共通のソースによって生成されているというこれまでの考え方をサポートする観測事実である。また、DMSP/SSUSI と ISS-IMAP/VISI によって同一の IPA が短い時間間隔で観測されている事例も存在し、この時間差から IPA の移動特性について調べた結果についても報告を行う。

# Pc5 磁力線共鳴に伴うオーロラアーク脈動と脈動オーロラ強度変調

# 佐藤 夏雄 [1]; 行松 彰 [2]; 田中 良昌 [2]; 堀 智昭 [3]; 門倉 昭 [4]; 櫻井 亨 [5]
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# Auroral arc pulsation and pulsating aurora modulation associated with Pc5 field line resonances

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There are two types of auroral luminosity pulsations. The first type is a short-period pulsation with the main period of a few to a few tens of seconds, which is called pulsating aurora (PsA). The second type is a longer period pulsation in the Pc5 (150-600 s) period range, which is called long-period auroral pulsation. The long-period auroral pulsations have two categories, namely, an arc aurora luminosity pulsation and a patch aurora luminosity modulation. We examine the two different types of long period auroral pulsations, which occur in association with the Pc5 field line resonances (FLRs). To understand the generation mechanism of the long period auroral pulsation we focused on the events in which the arc pulsation event and the parch intensity modulation event are observed simultaneously. In generally arc aurora appears at just poleward side of patch aurora including pulsating aurora. In this study, we examined the temporal and spatial signatures of the two types of long period auroral pulsations using the data obtained by the ground and satellite coordinated observations.

オーロラの輝度が周期的に変動する現象には、周期が数秒から数十秒で変動する短周期オーロラ脈動の脈動オーロラ（Pulsating aurora: PsA）と周期が Pc5 地磁気脈動相当の数 100 秒で変動する長周期オーロラ脈動がある。更に、長周期オーロラ脈動の中には、オーロラアークが周期的に発生するタイプとパッチ状脈動オーロラなどディフューズオーロラの輝度が周期的に変調するタイプの２種類がある。

本研究では長周期オーロラ脈動に注目し、オーロラアーク脈動と脈動オーロラ輝度変調現象の典型例とともに両方の現象が同時に観測されたイベントにも焦点を当てる。オーロラの特徴を南北方向ケオグラム表示でみると、オーロラアークはパッチ状脈動オーロラ領域のすぐ高緯度側で発生し、パッチオーロラ変調より位相が遅れて極方向への伝播を繰り返す。イメージャ表示で見ると、オーロラアーク脈動は、東西アークが西側に発達しつつ強度を増加して極方向に伝搬し、その後、輝度を弱めて消滅する。このような時間・空間的な変動が数 100 秒の周期で数回から 10 回位程度繰り返される。一方、脈動オーロラなどのディフューズオーロラ輝度変調脈動は、パッチ状などの個々の形状は変えずに領域全体が数 100 秒の周期で輝度が変調するタイプである。

本発表では、磁気緯度が同じで地磁気地方時が約 1 時間離れた地上の 2 点の全天カメラで観測されたオーロラアーク脈動と脈動オーロラ輝度変調現象の同時イベントの比較解析、及び、その現象が発生時に衛星の footprint がそれらの観測点付近に位置していた静止衛星 GOES-10 と GOES-12 衛星の Pc5 磁場データとの比較解析を行った。本研究ではこのイベント解析結果を中心に紹介する。

# Dependence of the Auroral Electrojet Intensity on the Solar Zenith Angle and Dipole Tilt

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The present study investigates the dependence of the local auroral electrojet (AEJ) intensity on solar illumination by statistically examining northward geomagnetic disturbances in the auroral zone in terms of the solar zenith angle SZA. It is found that on the dayside, both westward and eastward electrojets (WEJ and EEJ) are more intense for smaller SZA suggesting that the solar EUV-induced conductance is the dominant factor for the AEJ intensity. On the nightside, in contrast, the SZA dependence of the AEJ intensity, if sorted solely by the magnetic local time (MLT), apparently depends on the station longitude and hemisphere. However, if additionally sorted by the dipole tilt angle DTA, a consistent pattern emerges. That is, although SZA and DTA are correlated, the SZA and DTA have physically different effects on the AEJ intensity. The nightside AEJ, especially the WEJ, tends to be more intense for smaller |DTA|. Moreover, whereas the WEJ is statistically more intense when the ionosphere is dark, the EEJ is more intense when it is sunlit. The preference of the WEJ for the dark ionosphere prevails widely in MLT from premidnight to dawn, and therefore, it cannot be attributed to the previously proposed processes of the preferred monoenergetic or broadband auroral precipitation in the dark ionosphere. Instead, it may be explained, at least morphologically, in terms of the conductance enhancement due to the diffuse auroral precipitation, which is also prevalent from premidnight to dawn and is more intense in the dark hemisphere.

# あらせ(ERG) で観測されたヘクトメータ線スペクトルの励起源と波動特性

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# Sources and Wave Characteristics of Hectometric Line Spectra found by the Arase (ERG) satellite

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We report on the excitation source and wave characteristics of the hectometric line spectra (HLS) in the wavelength range of 100 m observed by the Arase (ERG) satellite. Although HLS is mainly a line spectrum of constant frequency, there are also components whose frequencies fluctuate. In comparison with $f_oF_2$, etc., although the medium wave broadcasting wave cannot pass through the ionosphere in the ordinary manner, it is thought that the broadcast waves can penetrate the ionosphere. Therefore, we considered the following mechanism [1].

1. Due to the presence of ionospheric disturbances such as plasma bubbles, the frequency of the broadcasting wave is converted to Z mode in the region equal to the plasma frequency.
2. The Z mode can exist from the L-mode cutoff frequency, which is lower than the plasma frequency, to the upper hybrid resonance frequency.
3. Near the upper hybrid resonance frequency, instabilities at 1.5 times the cyclotron frequency can occur, and amplification of the broadcasting wave and natural excitation are observed.
4. Naturally excited ones fluctuate in frequency, such as continuum and artificially stimulated emissions in the VLF band, but when a broadcast wave exists, the frequencies of the emissions are entrained to that of the broadcasting wave.
5. Due to the existence of ionospheric disturbance, Z mode is converted to L-O mode in the region where the frequency of radio wave is equal to the plasma frequency and propagates in a wide range.

The following observation results were obtained to demonstrate these.

1. HLS waves were observed in the area considered to be inside the plasma bubble.
2. In the observation by GPS TEC, the density decrease due to a bubble was recognized.
3. Polarization was observed in some parts of the HLS wave,
4. When observed with high frequency resolution (1.2 kHz), the frequencies of integer multiples of 9 or 10 of 1 kHz corresponding to those of the medium wave broadcasting waves were confirmed.
5. Trapped Z-mode waves which fill the whole possible region of the Z mode were confirmed. This is impossible by the upgoing waves only.
6. Other natural excitations or waves possibly excited by the broadcasting waves were also observed.

As mentioned above, the mechanism considered so far is being confirmed.

[1] Hashimoto et al., Hectometric Line Specta found by the Arase (ERG) satellite, SGEPSS fall meeting, Nagoya, 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 (HLS) の励起源と波動特性について報告する。HLS 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。$f_oF_2$ 等との比較で，中波の放送波は通常の方法では電離層を抜けられないが，電離層に浸透した放送波が主体であると考えられる。そこで以下の機構と考えた [1]。

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。

これらを実証する以下のような観測結果が得られた。

１．赤道プラズマバブル内と考えられる場所で HLS 波動が観測された。

２．GPS TEC による観測でも，バブルと考えられる密度減少が認められた。
３．HLS 波動の一部で偏波が観測された，
４．高周波数分解能 (1.2kHz) で観測したところ，中波放送波に対応する，1kHz の 9 または 10 の整数倍の周波数が確認された。
５．Z モードの存在領域を満たすトラップされた Z モード波動が確認された。下方からの伝搬だけでは不可能である。
６．放送波の他の自然励起または放送波で励起された可能性がある波動も観測された。トラップされた波動は，粒子との相互作用を起こす機会が多くなる。

以上の様に，これまで考えてきたメカニズムが確認されつつある。

[1] 橋本他，あらせ (ERG) で観測されたヘクトメータ線スペクトル，S001-03，SGEPSS 秋学会，名古屋, 2018.

# 地磁気脈動の可視化の新しい手法

# 高橋 主衛 [1]; Heilig Balazs[2]
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# A new data display technique for magnetic pulsations

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We studied the spatiotemporal structure of ground magnetic pulsations on the dayside by displaying magnetic field perturbations detected by the European quasi-Meridional Magnetometer Array (EMMA) as 2-D images in the magnetic L value versus time space, called EMMAgrams. We generated EMMAgrams from observations made on 15 August 2015, including a previously studied pulsation event associated with an interplanetary shock. In addition to signatures of field line resonance (FLR) driven by a cavity mode oscillation, we found poleward-propagating structures with L-independent periods in the Pc2 band. The Pc2 structures are attributed to periodic magnetohydrodynamic pulses (upstream waves) originating from the ion foreshock and propagating in the magnetosphere along the path proposed by Tamao. Ringing of local field lines at L-dependent periods (transient pulsations) is also clearly detected as dispersive poleward-propagating structures not only immediately after the shock impact but also during time periods of less obvious external disturbances. A transient pulsation decays after a few wave periods, and cross-spectral analysis of transient pulsations detected at two stations with a small latitudinal separation indicates elevation of the cross phase in a band delimited by the FLR frequencies at the stations. Successive excitation of transient pulsations by variations of the solar wind dynamic pressure contributes to formation of similar cross-phase peaks that are widely used in magnetoseismic studies.

# Revisiting the energy conversion process of Birkeland current generation in the M-I coupled system

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As shown by Vasyliunas [1970], the magnetospheric diamagnetic current has a finite divergece when it crosses the region with a finite B gradient and connects to the Field-Aligned Current (FAC). A pressure gradient force, the origin of the diamagnetic current in a force balance to the Ampere force, never twists plasma flow. While for the development of magnetic shear, which corresponds to FAC, combination of Ampere's law, Faraday's induction law and MHD Ohm's law require the gradient of plasma vortex along B-field. In other words, for the existence of a quasi-steady FAC in the MHD scheme, the plasma vorticity along the B-field is inevitably required. Of course, for the development of plasma vorticity, we need a dynamical process that twists the plasma. What is the dynamical process that twists the plasma as FACs are generated due to the divergence of the diamagnetic current? A conventional answer to this question is a mode conversion between the compressional mode and the Alfven mode when the diamagnetic current is growing (in inductive process). However, in principle, the magnetosphere-ionosphere coupling system forms a dissipative structure in the open solar-terrestrial system. Therefore, even in a macroscopic quasi-steady system, the constant conversion from the thermal energy to the magnetic energy and the internal mode conversion from magnetic compression to the magnetic shear should continuously take place. In this sense, we need to revisit the dynamical process of FAC. In this presentation, we will discuss what is the dynamical process and what is the quasi-steady state of FACs in a dissipative structure of the open magnetosphere-ionosphere system.

# 不均一電離圏での共鳴型キャビティーモード

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# Resonant cavity mode with ionospheric inhomogeneity

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The feedback instability in the IAR (Ionospheric Alfven Resonator) region in Earth's magnetosphere has been investigated by many researchers. Inhomogeneity of the Alfven speed in the IAR causes a resonance known as a cavity mode (Lysak [1991]). Most of previous studies have neglected inhomogeneity of the ionosphere and treated it as a height-integrated conductive layer, assuming that the thickness is much shorter than wavelength of the Alfven waves. However, a recent work claims that the height dependence of ionosphere parameters has stabilizing effects of the feedback instability (Sydorenko and Rankin [2017]). On the other hand, low-frequency and long-wavelength modes associated with the field line resonance (FLR) have unstable solutions even with the inhomogeneous ionosphere (Watanabe and Maeyama [2018]).

The purpose of this study is to elucidate what kind of influence the height dependent of ionospheric inhomogeneity has on the cavity modes. In particular, we focus on the ion-neutral collision frequency in the ionosphere, and investigate the influence of stabilization in each mode. In the study by Sydorenko and Rankin (2017) with the inhomogeneous ionosphere, they performed a linear numerical simulation where time development of plasma density is calculated from an arbitrary initial value. In contrast, we performed the linear eigenvalue analysis so that we could distinguish the cavity modes due to IAR and other modes related to FLR, and could investigate them independently. It is expected to reveal differences between the two results, that is, Sydorenko and Rankin (2017) and Watanabe and Maeyama et al (2018).

In the present study, we extend study the model used in Watanabe and Maeyama et al (2018) including the height dependence of the Alfven speed (Lysak [1991]) so that we can deal with the cavity and long-wavelength modes simultaneously. For comparison with the height-integrated ionosphere model, we employ the same normalization and numerical box size as those in Lysak (1991). Our linear analysis confirms that the ionospheric inhomogeneity strongly stabilizes the cavity mode. In a weak ionospheric inhomogeneity, however, the cavity mode remains unstable. Simultaneously, we find that the ionospheric inhomogeneity has no serious impact on the low-frequency and long-wavelength modes related to FLR, which is also consistent to Watanabe and Maeyama (2018).

Furthermore, we has been working on the initial value analysis including the inhomogeneous Alfven speed profile. In the work by Sydorenko and Rankin (2017), it was not clearly which modes are included in the simulation because the initial condition is given by an arbitrary density perturbation. In contrast, our initial value analysis starting from the initial condition given by the linear eigenfunction enables us to find time-development of the cavity mode related to IAR.

地球磁気圏の底部と電離圏の間には IAR(Ionospheric Alfven Resonator) と呼ばれる領域があり、そこでのフィードバック不安定性についてはこれまでに多くの研究がなされてきた。IAR 領域では Alfven 速度に急峻な変化があり、それに起因してキャビティーモードと呼ばれる固有の共鳴現象が存在することが知られている（Lysak [1991] など）。この分野の先行研究では、電離圏の厚さが Alfven 波の空間スケールに対して十分に小さいと仮定して、電離圏に対しては高さ平均をとった厚さを持たない平面として扱われてきた。しかし、最近の研究では、その電離圏の高度依存性にはフィードバック不安定性を安定化させる効果があることが示唆された (Sydorenko and Rankin [2017])。一方、FLR (Field Line Resonator : IAR 領域だけでなく磁気圏全体を伝う磁力線の共鳴現象) に起因するより低周波・長波長のモードは、不均一電離圏モデルでも不安定解を持つことが Watanabe and Maeyama (2018) らの研究によって示されている。

本研究の目的は、高度依存性のある不均一電離圏がキャビティーモードに対してどのような影響を与えるのかを解明することにある。その中でも、電離圏におけるイオンと中性粒子の衝突周波数に着目し、それぞれのモードごとにおける安定化の影響を調査する。上記の Sydorenko and Rankin (2017) らの不均一電離圏での研究では、電離圏でのプラズマ密度に適当な初期揺動を与え、それを時間発展させる線形初期値解析が行われた。一方、本研究では、線形固有値・固有モード解析を行った。その理由は、線形固有値解析では FLR に起因するモードと IAR に起因するキャビティーモードを区別し、独立に解析を行うことができるからである。これにより、Sydorenko and Rankin (2017) と Watanabe and Maeyama (2018) の相違をより明らかにできる。

本研究では、Watanabe and Maeyama (2018) のモデルで一定とされていた Alfven 速度分布に、Lysak (1991) の IAR と同様の高度依存性を与え、キャビティーモードと長波長モードが同時に扱えるように拡張した。また高さ平均モデル (Lysak [1991]) との比較のために、無次元化の値や計算領域などは Lysak (1991) に準拠している。線形固有値解析の結果、IAR に対応しているキャビティーモードは、電離圏の不均一の効果を強く受け安定化されることが分かった。しかし、電離圏の不均一性が弱い場合ではキャビティーモードでも不安定解を持ち得ることも新たに分かった。一方 FLR に対応する低周波のモードは電離圏不均一化の影響を受けないことが改めて確認でき、Watanabe and Maeyama (2018) 氏らの研究結果とも矛盾しないことが確認できた。

さらに、電離圏不均一効果を取り入れた場合の線形初期値解析にも取り組んでいる。Sydorenko and Rankin (2017) 氏

らの線形初期値解析では、プラズマ密度に適当な初期揺動を与えていた故にどのモードによる時間発展を扱っているかが明確でなかった。一方、本研究の初期値解析では、線形固有値解析によって求められた固有関数を使って初期揺動を与え、IAR に起因するキャビティーモードの時間発展を求めることが可能となった。

# サブストームオンセットあとに励起されるＰｃ４脈動とオーロラストリーマーの動態解明に向けて

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# The THEMIS reveal morphology of Pc4 pulsations and auroral streamer excited after substorm onset

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It is well known that Pi2 pulsations are excited on substorm onset. However, it is not yet clarified about morphology of Pc4 pulsations frequently observed during expansion phase to recovery phase of substorm. Pc4 is expected to relate earthward plasma flow due to the depolarization of earth’s magnetic field and associated vortex generation.Therefore, it would become very important indicator for investigation of magnetospheric dynamics after substorm onset. In this study, by using the magnetic data obtained from ETS-VIII synchronous orbit satellite and the MAGDAS ground stations (210 meridian chain), we found that the Pi2 globally occurs after substorm onset and rapidly disappeared with several periods, while Pc4 continues during recovery phase but only at the nightside high latitudinal region (above sub aurora region). Furthermore, by using THEMIS satellites, it is found that Pi2 can be captured at the dayside magnetosphere, while Pc4 is observed only at the nightside magnetosphere with same waveform on the ground. These results suggest that Pi2 propagate from nightside to dayside magnetosphere as a compressional wave, while Pc4 is excited as shear Alfven wave at the nightside magnetosphere and propagate to the high latitude ionosphere.

In this study, we further investigate one-to-one correspondence of the aurora activity and Pc4 generation and propagation. As a result of initial analysis by direct comparison of aurora activity captured by THEMIS all -sky camera data and the band pass filter data of the Pc4 pulsation range (40-150s),we have confirmed the one-to-one correspondence of the propagation of the auroral structure (WTS,surge,etc.,) and the Pc4 generation characteristics at the same observational point. We also investigate the relationship of the auroral fine structures generation (torches,omega bands and pulsating aurora) and geomagnetic pulsations.

In this talk, we will report the detailed aspects of these relations and introduce promotion of research for time developing magnetosphere-ionosphere system during aurora substorm through investigation of aurora activity and geomagnetic pulsations.

サブストームオンセット時に Pi2 脈動が励起されることは良く知られているが、オンセットから爆発相、回復相にかけてしばしば観測される Pc4 脈動についてはその動態はあきらかにされていない。

Pc4 脈動はその継続性から、オンセット後の地球磁場の双極子化に伴う地球向きプラズマフロー及び、それに伴う渦形成と関連していることが期待され、サブストームオンセット後の磁気圏の動力学を観測的に精査する上で非常に重要である。

我々は MAGDAS/CPMN 地上磁場観測網 (経度２１０°meridian chain) の及び、ETS 衛星の磁場データを用いて、サブストームのオンセットに伴い、Pi2 脈動が全球的に観測された後、サブオーロラ帯より低緯度側では速やかに振動が収まるが、それより高緯度領域においては、爆発層から回復相にかけ Pc4 脈動が継続的に励起されるという結果を見いだした。[志々目、修士論文 2010]

また、多点衛星である THEMIS 衛星の磁場データと MAGDAS の地上磁場データを用いてサブストームの爆発層から回復相にかけての Pc4 の発現特性を調べ、Pi2 はサブストームオンセットと同時に夜側の地上、衛星の全地点で観測されるとともに、Pc4 は衛星観測では夜側サブストームの爆発層から回復相にかけて観測され、昼側は観測されないこと、地上では高緯度においてのみ衛星と同様の波が観測されることを確認した。[橋本、学士論文 2014]

以上のことから、Pi2 は圧縮波により磁気圏では夜側から昼間側に向けて拡がるのに対して、Pc4 は夜側の高緯度領域に局在し、磁力線に沿った Alfven 波として地上に伝播していることが予測される。

我々は、これらの知見を更に発展させ、オーロラのアクティビティと Pc4 脈動発生の一対一対応性を精査する事によって、地磁気脈動をつうじたオーロラ活動の磁気圏電離圏結合の理解を深めるための研究を推進している。

THEMIS 全天カメラデータで捉えたオーロラアクティビティと、Pc4 周期帯（40～150 秒）のバンドパスフィルターデータの直接比較による初期解析の結果、WTS、サージなどのオーロラ構造の伝播と直下観測点での Pc4 発生特性に一対一対応があることを確認しており、現在は更にトーチ、オメガバンド、パルセーティングオーロラなどのオーロラ微細構造の発生と地磁気脈動の関連性についても調査中である。

本講演ではこうした、地上観測によるオーロラと地磁気脈動の関連性について報告する予定である。

# Energetic electron precipitations showing ULF modulation observed by VLF/LF standard radio waves

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Possible mechanisms for how magnetospheric ULF magnetic pulsations modulate the precipitation of electrons have been proposed [Coroniti and Kennell, 1970]. Ionospheric modulation due to ultra low frequency (ULF) Pc5 waves has been observed by GPS-total electron content (TEC), high frequency (HF) Doppler sounders and SuperDARN HF radars. While modulation in the lower ionosphere has been reported based on riometer and X-ray observations [e.g., Pilipenko et al., 2014; Belakhovsky et al., 2016; Brito et al., 2012], there are few reports from observations of VLF/LF transmitter signals. We investigate the D-region signatures of the modulation due to the ULF waves using a network of very low frequency (VLF)/low frequency (LF) standard radio waves. Such VLF/LF propagation is a useful probe to detect energetic electron precipitation with energy of more than 100 keV. The transmitter signals from 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) were observed by a receiver at ATH (Athabasca, Canada, L=4.31). During 5:25 - 5:50 UT on 4 June, 2017, oscillations of the VLF/LF intensity and magnetic field delta $B_H$, delta $B_D$ and delta $B_Z$ around the NLK-ATH, NDK-ATH and WWVB-ATH paths with periods of 180-240 s (the frequency: 4.2-5.6 mHz) were seen simultaneously. A weak signature of geomagnetic substorm was observed by ground magnetometers. Doppler velocity in ground scatter echoes observed by SuperDARN HF radars along the NDK-ATH and WWVB-ATH paths also showed the same periods of the 180-240 s simultaneously. The locations of SuperDARN HF radars are Christmas Valley East and West radars(CVE and CVW) and Fort Hays West radar(FHW). In this presentation, we will discuss the cause of these VLF/LF oscillations.

# On contribution of minor ion species to the ring current of Earth's magnetosphere: Arase (ERG) satellite observations

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Two major ion species in the ring current is $H^+$ and $O^+$ ions. The $H^+$ ions are considered to mainly originate from the solar wind, while the $O^+$ ions come from the ionosphere. In addition to these ion species, some minor ion species such as $O^{++}$ [e.g., Fennell et al., 1996] and molecular ions [e.g., Klecker et al., 1986; Seki et al., 2019] are known to exist in the ring current. Nitrogen related ion species are also potential contributor to the ring current, since they are observed in the ion outflow in the high-altitude ionosphere [e.g., Yau et al., 1993]. Previous observations indicate that geomagnetic activity dependences are different between the ion species. However, difficulty in clear identification of the minor ion species prevents understanding of transport mechanisms to cause the variations and their relative contribution to the ring current.

In this study, we investigated properties of $O^+$, $O^{++}$, and molecular ions ($O_2{}^+$/$NO^+$/$N_2{}^+$) in the ring current based on observations by the Arase (ERG) satellite and their relations to the solar wind and geomagnetic conditions. The ion composition TOF-mode data of the Arase satellite obtained by the MEPi and LEPi instruments, which detects the ions less than 180 keV/q, are analyzed in details. The statistical analysis of molecular ions shows that the molecular ions exist in near-Earth space during most magnetic storms, while they are not detected during geomagnetically quiet periods. The existence of molecular ions even during small magnetic storms suggests that the magnetic storm is an effective driver of the ion loss from the deep terrestrial ionosphere. On one hand, $O^{++}$ ions contribution becomes relatively large during geomagnetically quiet periods. We also report on an attempt to identify $N^+$ ions in the ring current. Based on the results, we discuss possible cause of the different geomagntic activitiy dependences between the ion species.

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# Statistical Property of Long Lasting Poloidal Pc 4-5 Waves and Its Relation withProton Phase Space Density Variations

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Particle acceleration is one of the most important issues in the inner magnetosphere because the spatial and energy distributions of the ring current and radiation belt particles are dramatically changed through various acceleration mechanisms. Event studies of the drift-bounce resonance have revealed that ˜100 keV protons, which is the main component of the ring current pressure, often resonate with poloidal mode ultralow frequency (ULF) waves (e.g., Takahashi et al., 1990; Dai et al., 2013; Min et al., 2017, Oimatsu et al., 2018). Therefore, the drift-bounce resonance between ˜100 keV protons and the poloidal waves can change the ring current intensity, and the resonance should be examined in more detail to understand the ring current dynamics. However, the contribution of the poloidal waves to the acceleration of the ring current ions is not fully investigated. This is because substorm injections and the convective electric field can cause variations of ion fluxes at less than ˜100 keV and mask the variations by the wave-particle interaction.

To examine the effect of ULF waves on variations of particle distributions, we statistically analyzed energetic proton flux data provided by the Van Allen Probes (Mauk et al., 2012). First we examined the occurrence distributions and storm phase dependence of long-lasting poloidal waves because such long lasting waves are related to significant variations of the proton phase space density and hence their distributions and excitation mechanism is important. We found that the long lasting poloidal waves are often observed 0-3 days after the main phase of CME driven storms. Superposed epoch analysis of the radial distributions of the energetic protons revealed that the high occurrence rate of the poloidal waves is attributed to a steep earthward gradient during the recovery phase.

Next, we selected the data period when the |MLAT|is less than 10 degree, |SYM-H|is less than 15 nT, and the standard deviation of the SYM-H index is less than 5 nT to exclude flux variations due to geomagnetic disturbances and the latitudinal dependence. We obtained the ratio between the proton phase space density averaged over the long lasting poloidal wave intervals and that over no wave intervals. The proton phase space density during the wave intervals is greaterthan that during no wave intervals at almost all energy and L-shell, but the phase space density enhancement is suppressed at a specified energy and L > 4.5, where the poloidal waves are detected. Observed magnitude of the magnetic field and wave frequencies are used to examine the drift-bounce resonance condition. Assuming that azimuthal wave number (m) is ˜200, we find that resonance energy well corresponds to the energy for the suppression of proton phase space density enhancement. Therefore, we consider that the drift-bounce resonance can cause the energy-dependent suppression of the proton phase space density enhancement. We also estimated the contribution of the suppression to ring current decay by using Dessler-Parker-Sckopke relation (Dessler & Parker, 1959; Schopke, 1966) and we found that the variation of the Dst index due to the drift-bounce resonance is ˜0.6 nT.

# ドリフト運動論モデルに基づく環電流イオンとのドリフトバウンス共鳴によって励起される storm-time Pc5 ULF 波動の研究

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# Study of storm-time Pc5 ULF waves excited by drift-bounce resonance with ring current ions based on the drift-kinetic simulation

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Storm-time Pc5 ULF waves are electromagnetic pulsations 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 the injection from the magnetotail during substorms. The excitation mechanism and global distribution of Pc5 waves are keys to understand dynamic variation of the outer radiation belt, since Pc5 waves are considered to contribute to the radial transport of radiation belt electrons [e.g. Elkington et al., 2003]. Promising candidate of excitation mechanism of the storm-time Pc5 waves is the drift-bounce resonance [Southwood, 1976]. Previous spacecraft observations suggest both drift resonance [e.g. Dai et al., 2013] and drift-bounce resonance [e.g. Oimatsu et al., 2018] excitation of ULF waves. Theoretically, Yamakawa et al. [2019] confirmed the drift resonance excitation of storm-time Pc5 waves under the initial condition of phase space density (PSD) with north-south symmetry based on the global drift-kinetic simulation. However, drift-bounce resonance excitation of ULF waves was not detected in the case of the symmetric initial PSD distribution, while this type of resonance was suggested by some spacecraft observations [e.g. Oimatsu et al., 2018]. This study aims to investigate the condition for the excitation of ULF waves associated with drift-bounce resonance based on the global drift-kinetic model.

In order to simulate the excitation 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 PSD of ring current ions and Maxwell equations are solved self-consistently under the assumption that the first adiabatic invariant is conserved. In order to simulate consequence of ion injection from the plasma sheet, we put a localized high-pressure region around midnight consisting of H+ ions. We compare two cases of the initial velocity distribution; the Maxwellian velocity distribution with the isotropic temperature of 16 keV (Case a) and the velocity distribution with asymmetric distribution in pitch angle direction in addition to the background Maxwellian distribution (Case b). In Case a, the simulation results show the drift resonance excitation of both poloidal and toroidal mode waves in Pc5 frequency range in the dayside dusk sector. These waves are fundamental mode waves with azimuthal wave number m ˜- 20 propagating westward. 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 [Yamakawa et al., 2019]. In Case b, excitation of the 2nd harmonic poloidal-mode Pc3 ULF waves due to the drift-bounce resonance was also identified in the dusk sector in addition to Pc5 ULF waves. The power spectra of both Pc5 and Pc3 poloidal mode ULF waves show correlation with the local growth rate. Ions contributing to the growth of poloidal mode ULF waves tend to have the pitch angle of about 90 degrees for Pc5 waves and oblique pitch angle for Pc3 waves. We will also report on characteristics of excited ULF waves with a focus of the relative contribution of the drift and drift-bounce resonances.

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# Relations between ULF waves and ion distributions in the magnetosphere: MMS observations

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Recent studies investigating wave-particle interactions between Pc5 waves and ions in the magnetosphere have shown selective local enhancement of $O^+$ ion fluxes due to drift-bounce resonance [e.g., Oimatsu et al., 2018; Zong et al., 2012; Yang et al., 2011]. However, there has not been a sufficient number of comprehensive studies that focused on the relation between ULF waves and ion flux variations. As a result, it is not clear if ULF waves generally play an important role in modifying ion populations. Recently, the Hot Plasma Composition Analyzer (HPCA) onboard the Magnetospheric Multiscale (MMS) constellation have been making ion composition measurements in the energy range 1 eV to 40 keV in the magnetosphere. The present study uses the HPCA data to investigate the relation between ULF waves and $H^+$ and $O^+$ ion distributions in the energy range below 40 keV. Fluxes of ionospheric origin $O^+$ ions in the magnetosphere are correlated with solar wind speed and wave power in the Pc5 frequency band on the dayside, on the other hand, $H^+$ fluxes do not show such correlation. In the presentation, we provide details of these results and discuss the general influence of ULF waves on ion dynamics in the magnetosphere.

# Statistical analysis for trunk structure of ring current ions using Arase ion observations

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The distribution of ring current ions is determined due to transportation, acceleration and loss process in the magnetosphere. Various structures on energy spectrum are seen along the satellite orbit. Besides well-known structures such as 'nose' or 'wedge' structures, 'trunk' structures are newly found by Van Allen Probes. The structure looks like elephant trunk and the energy of peak flux decreases toward the Earth. A case study by Van Allen Probes showed that 'trunk' structures are seen in energy spectrums of helium and oxygen. However, detail characteristics of 'trunk' have not been well understood, and statistical survey using the long-term observation data is necessary. In this study, we investigate characteristics of 'trunk' using Low-energy particle experiments-ion mass analyzer (LEPi) / Medium-energy particle experiments-ion mass analyzer (MEP-i) onboard the Arase satellite from April 2017 to March 2019. A number of trunk structures in helium and oxygen ions as well as protons are identified. We analyze the geomagnetic activity, local time, latitude and L-value dependences of the trunk. The minimum L-shell of trunk is distributed mostly around L = 2.0 - 2.5 and off-equator, extending from dusk region to pre-midnight region. The average of the minimum Al index and maximum Kp index during 1 day before observations of helium trunk structure are ~-400 nT and 2+ respectively. Previous studies suggested that impulsive enhanced electric field or a temporal gap of injection from the tail region combined with charge exchange causes formation of the 'trunk'. Beside 'trunk' structures, more typical 'nose' events and 'inverse trunk' in which the typical energy gets increase in the lower L-shell are also found from the Arase observations. We show statistical characteristics of 'trunk' and 'inverse trunk' from the Arase observations. Moreover, we discuss how charge exchange affects the formation of the 'trunk' by comparing with RAM-SCB simulations.

# 2017 年 3 月 28 日にあらせ衛星で観測された SAR アークのソース領域における初めてのプラズマ・電磁場観測

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# First plasma and field observations in the magnetospheric source region of Stable Auroral Red (SAR) arc by the Arase satellite

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Stable Auroral Red (SAR) arc is characterized by a 630.0 nm emission observed at subauroral latitudes. The energy of precipitating electrons that cause the SAR arc emission is several electron volts (eV). Precipitation of low-energy electrons is expected to occur due to spatial overlap between the plasmasphere and the ring current, where high-energy (more than 10 keV) ring current ions heat low-energy (less than 1 eV) electrons in the plasmasphere. Simultaneous observations of SAR arcs using the ionospheric satellite and ground all-sky cameras have been already done [e.g., Foster et al., 1994]. However, there has been no report on in-situ measurements of plasma and electromagnetic fields in the inner magnetosphere, where the plasmaspheric plasma is heated by the ring current. In this study, we report simultaneous observations of a SAR arc at 22:04 UT on March 28, 2017, by using an all-sky camera at Nyrola (62.34 N, 25.51 E, MLAT 59.4 N) at subauroral latitudes and the Arase satellite. We analyze the all-sky camera data and the satellite data of this event to investigate the generation mechanism of the SAR arc. Medium-Energy Particle Experiments Ion Mass Analyzer (MEP-i) onboard the Arase satellite and electron density calculated from UHR frequency show that spatial overlap between plasmasphere (plume) and ring current occurs at the SAR arc crossing. This result is consistent with that expected from models [e.g. Kozyra et al., 1997]. We find interesting features in the electric field data observed by the electric field detector of the plasma wave experiment (PWE/EFD) onboard the Arase satellite at the crossing of the SAR arc. A negative excursion of the Ez component of the electric field (SM coordinate system) with an amplitude of ~2.4 mV/m was observed at the crossing time. The Bx component of the magnetic field (SM coordinate system) was negative. Thus the direction of the E x B drift is westward, which is consistent with the westward auroral motion observed in the SAR arc by the ground all-sky camera. At the SAR arc crossing, the energy flux of oxygen ions around 10-keV is intensified. We will discuss these observations in relation to the proposed SAR-arc generation mechanisms.

Stable Auroral Red (SAR) アークは、オーロラオーバルより低緯度側に位置するサブオーロラ帯で発生する、酸素原子の発光 (630.0 nm) が卓越するオーロラである。この発光の元となる降り込み電子のエネルギーは数 eV と言われている。この降り込み電子の生成は、プラズマ圏とリングカレントの空間的重なりにより、プラズマ圏の電子がリングカレントのイオンによって温められることで起こると予測されている。これまでに、SAR アークを電離圏衛星と全天カメラで同時観測した例はあるが、電子加熱が起こっている内部磁気圏で、SAR アークに対応するプラズマ粒子や電磁場変動が直接観測されたことはない。しかし、2017 年 3 月 28 日 22:04 UT に、サブオーロラ帯にあるフィンランドの Nyrola (62.34 N, 25.51 E, MLAT 59.4 N) に設置された全天カメラと内部磁気圏衛星あらせによって、世界で初めて同時観測が成立した。そこで本研究では、内部磁気圏における SAR アークの発生メカニズムについて調査した。調査の結果、あらせ衛星に搭載された中間エネルギーイオン質量分析器 (MEP-i) と、プラズマ波動電場観測機器の高周波受信器 (PWE/HFA) から算出された電子密度より、SAR アークの種となる熱はプラズマ圏 (プルーム) とリングカレントの overlap region がソースとなっていることが示唆された。これはこれまで考えられていたモデル [e.g., Kozyra et al., 1997] に一致する。また、あらせ衛星が SAR アークを横切った時間に、あらせ衛星に搭載されたプラズマ波動・電場観測器の低周波受信器 (PWE/EFD) で計測された電場に特異な特徴が現れた。SM 座標系での観測電場の Ez 成分は、SAR アークを横切った時間のみに約 2.4 mV/m 程度負に振れていて、この時間の SM 座標系での観測磁場データの Bx 成分は負であった。この結果から E x B ドリフトの向きは西向きになり、これは地上観測の SAR アークの移動方向に一致した。さらに、MEP-i で計測された酸素イオンエネルギーフラックスは、SAR アークの源となっていると思われる領域付近で 10-keV 前後で特異な強いフラックス領域を示した。講演では、これらの観測事実を、これまで提案されてきた SAR アークの発生メカニズムに照らし合わせて議論する。

# Molecular ion upflow observed by EISCAT in conjunction with Arase during the September 7, 2017 magnetic storm

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Molecular ions ($O_2^+/NO^+/N_2^+$) originated from the ionosphere have been observed in the magnetosphere [e.g., Klecker et al., 1986; Christon et al., 1994]. Recently, the Arase satellite also observed the molecular ions even in the small geomagnetic disturbance periods [Seki et al., 2019]. However, it is not revealed how these molecular ions are transported from the ionosphere, especially in the low-altitude ($<$~300 km) region where molecular ions are abundant. It is considered that some heating mechanisms such as ion frictional heating, ion resonance heating, and local plasma instabilities cause the ion upflow and transport molecular ions upward. The previous study of Peterson et al. [1994], on one hand, reported that these mechanisms cannot create ion upflows fast enough to overcome the loss of molecular ions by chemical reactions and transport them into the high-altitude ionosphere where the ion outflows usually take place. Therefore, it is necessary to reveal what mechanism causes molecular ion upflows. In this study, we aim at the observational assessments of molecular ion upflow mechanisms in the low-altitude ionosphere based on a conjugate observation by the EISCAT radar and the Arase (ERG) satellite.

The EISCAT radar and the Arase (ERG) satellite have the conjunction event during the large magnetic storm with the minimum Dst of -124 nT on September 8, 2017. During the event, the Arase satellite was located in the dusk-side inner magnetosphere and observed molecular ions in the energy range of 12-180 keV/q. The EISCAT radar simultaneously observed the ion upflow (with the upward velocity of ~50-150 m/s) from the low-altitude ionosphere (~250-400 km) together with strong ion heating ($>$~2000 K). The convective electric field was also enhanced by a factor of 2 in the same region. We estimated each term in the equation of motion for ions. The result indicates that the ion upflow reached stable equilibrium because the upward ion and electron pressure gradients are balanced with the downward gravitational force. It is suggested that the ion upflow can take place from the low-altitude ionosphere due to the strong ion pressure gradient. We also estimated the flux decrease of molecular ions due to dissociative recombination. The $O_2^+$ ($NO^+$) flux decreased to ~1 (~0.001) % at 350 km compared with 280 km. The estimated upflow flux of $O_2^+$ ($NO^+$) at 350 km is at least ~$10^{10}$ (~$10^7$) $m^{-2}$ $s^{-1}$. These results indicate that the strong ion frictional heating during magnetic storms enabled molecular ions to be transported upward from the low-altitude ionosphere and provide a source of molecular ion outflows into the magnetosphere.

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# Field-aligned and transverse plasma accelerations and spatial distributions observed by Reimei and FAST in the auroral regions

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It is prevailingly known that the magnetic reconnection and shock mechanisms in the collisionless plasma systems are powerful and universal particle accelerators, both of which can be directly observed in and near the terrestrial and planetary magnetospheres in our solar system. Recently, the plasma wave-particle interaction mechanisms particularly in the radiation belts are also arousing our interests from the viewpoint of the high-energy electron accelerations. While these are very important as fundamental plasma acceleration mechanisms in the magnetospheric plasma system, the terrestrial and planetary ionospheric plasma could be energized in the space-Earth/planet coupling regions represented by the polar auroral regions through the different or somewhat similar types of the plasma acceleration mechanisms, namely the field-aligned electric field accelerations and the transverse ion accelerations due to the wave-particle interaction processes. These mechanisms are considered to drive the terrestrial and planetary atmospheric plasma outflows, which have to be more intensively investigated in coming decades because not only the planets in our solar system but the exoplanets should be comprehensively and integratedly understood from the viewpoint of the universal space-planet coupling system.

In particular, the continuous energy and mass transports in these near-Earth space are mostly controlled by the electromagnetic field effects on the ionized atmospheric particles and the space plasmas. While state-of-the-art measurements in these important regions for understanding the space-Earth(planet) couplings have not been achieved yet, the previous space missions, represented by DE-1/2, Viking, Freja, Akebono, POLAR, FAST, CLUSTER-II, and Reimei, have being providing us with considerable elemental knowledge. Particularly, the acceleration and transport processes regarding the electrons and ions could be surveyed in more systematic and carefully based on the database of these satellite missions. We, therefore, have been analyzing the observational results made mainly by Reimei and FAST because these data are open, accessible, and easily investigated with some updated tools. The high-time resolution data obtained by these two satellites are available for studying the spatial distributions or time variations of the space plasmas by field-aligned electric fields and the wave-particle interaction processes although there are not made any simultaneous observations by Reimei and FAST.

In this presentation, we discuss the similarities and differences seen in the Reimei and FAST observations by focusing on the dynamics of the electrons and ions at the altitudes ranging from 400-4000 km in the midnight polar regions.

# 宇宙空間における電子とイオンの同時観測のための二重殻式広視野エネルギー分析器の開発

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# Development of double-shell type wide field of view energy analyzer for simultaneous electron and ion measurements in space

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In-situ observations of the charged particles such as electrons and ions filling the terrestrial and planetary magnetospheres and the interplanetary space, so-called the space plasma have been conducted by using satellites carrying particle instruments, such as the top-hat type electrostatic energy analyzer. Essentially, obtaining three-dimensional velocity distributions of the space plasmas or energy-pitch angle distributions help us understand the dynamics of the space plasmas. Because the top-hat type analyzer is cylindrically symmetric and has a 360 degrees planar field of view, it can independently measure the wide angular and energy distributions of incident particles. Also, three-dimensional velocity or energy-pitch angle distributions can be obtained by utilizing the satellite spin motion.

In general, the top-hat type electrostatic energy analyzers can measure the ions when a negative potential is applied to the inner electrode and the electrons by a positive potential with the outer electrode grounded. Therefore, in the design of the top-hat type analyzer, the sensor heads separate for the ion and electron observations, respectively. Because of the recent miniaturization of the satellites, the size, weight and space of the instruments mounted on the small and micro satellites are getting severely restricted. However, if two sensor heads for electron and ion observations are combined into one sensor head, it is possible to save the size, weight and space on the small and micro satellites. Therefore, we have been developing double-shell type energy analyzer which can simultaneously measure the ions and the electrons and have a wide field of view of 360 degrees with one sensor head.

We optimized the shapes of the collimator and the double-shell dome-shaped electrodes so that the electrons and the ions with appropriate energies pass through the inner gap and the outer gap by applying a negative potential to the central electrode and part of the collimator with the inner and outer electrodes grounded, respectively. We made the numerical simulations using SIMION which is a charged particle simulator program and investigated the performance and characteristics as the electrostatic analyzer. Consequently, we confirmed that the electrons and the ions can be analyzed with one sensor head by only applying negative high voltage to the electrodes. Also, we investigated the performance of the energy analyzer with serration. We are conducting the calibration experiment of MCP for two-dimensional position detection to investigate the angular resolution of the energy analyzer by putting two-dimensional position detectable MCP at the exit of energy analyzer. So far, we use MCP assembly for the electron detection and we consider the detection unit using Time-Of-Flight velocity spectrometer for the discrimination of the ion mass as the part where the ions are detected. The design of TOF-type mass analysis unit as ion mass analysis unit is one of subjects for future work.

地球および惑星の磁気圏、そして惑星間空間を満たしている電子とイオンのような荷電粒子、いわゆる宇宙プラズマのその場観測は、トップハット式静電型エネルギー分析器のような粒子計測器を搭載している探査機・人工衛星を利用することによって行われており、我々が宇宙プラズマの 3 次元速度分布またはエネルギー・ピッチ角分布を得ることは、宇宙プラズマのダイナミクスを理解するのに役立つ。トップハット式静電型エネルギー分析器は軸対称構造であり、360 度の平面視野を持っているため、入射粒子の角度とエネルギー分布を独立して観測できる。さらに、人工衛星の自転運動を利用することによって 3 次元の速度分布またはエネルギー・ピッチ角分布も取得できる。

トップハット式静電型エネルギー分析器は外側の電極を GND にした状態で、イオンを観測する場合は内側の電極に負の電圧を印加し、電子を観測する場合は内側の電極に正の電圧を印加するのが一般的である。従って、トップハット式静電型エネルギー分析器を宇宙探査で適用するには、センサーヘッドがイオンと電子の観測用に、それぞれ分かれている。最近は探査機・人工衛星が (超) 小型化されており、搭載できる機器の寸法・重量および位置は大幅に制限される。しかし、電子・イオン用の 2 つのセンサーヘッドを 1 つのセンサーヘッドにまとめることができれば、超小型人工衛星の制限にも対応可能である。そこで、我々は 1 つのセンサーヘッドでイオンと電子を同時に観測でき、360 度の広い視野角を実現可能な二重殻式エネルギー分析器を開発している。

我々は内側と外側のドーム型電極を GND にし、コリメーターの一部の電極と内側と外側に挟まれた中央ドーム型電極に負の電位を印加した状態で、適切なエネルギーを持った電子とイオンが、内側と外側の隙間をそれぞれ通過するように、コリメーターおよび二重殻のドーム型電極の形状および印加電圧を最適化した。我々は荷電粒子シミュレータープログラムの SIMION を使って数値シミュレーションを行い、静電分析器としての性能と特徴を調べた。その結果、負の高電圧を電極に印加するだけで、イオンと電子が 1 つのセンサーヘッドで分析できることが確かめられた。また、太陽紫外線およびそれによってセンサーヘッド内で生成される 2 次電子が検出部に到達して雑音になることを防ぐために

中央の電極にセレーションを付けるが、セレーションを付けた場合の分析器の特性も確認し、どのようなセレーションであれば、分析器の特性が維持可能であるかについても調査を行った。ドーム型電極の後段の検出部に 2 次元位置検出可能な MCP(micro channel plates) を設置してエネルギー分析器の角度分解能を調べるために、2 次元位置検出用 MCP の較正実験も実施しつつある。電子の検出には MCP を使用するが、将来的にはイオンを検出する部分にはイオン質量を識別するために TOF を使った検出部を組み込むことを考えている。イオン質量分析部としての TOF 型質量分析部の設計は今後の課題である。

# 粒子センサ用高速粒子検出回路の集積化に関する研究

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# Study on integration of high speed particle detection circuit for particle sensor

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Plasma filling the space is very rarefied. Ions and electrons in space plasma do not exchange their kinetic energies through their collisions but through plasma waves. This is so-called "wave-particle interaction," and it is indispensable for understanding space electromagnetic environments. A conventional observation method of wave-particle interaction is to transmit plasma wave spectrum and particle velocity distribution function from a satellite to the ground. This method has problems that the time resolution is larger than several tens of milliseconds and phase difference information of the plasma wave vector and the particle velocity vector is lost. Therefore, it is impossible to calculate the energy conversion amount quantitatively. WPIA (Wave-Particle Interaction Analyzer) is a new sophisticated method. It calculates inner product of plasma wave vectors observed by a plasma wave receiver and particle velocity vectors of each particle observed by a plasma instrument on a satellite and determines the energy conversion amount directly. The high relative time precision for detecting vectors of plasma waves and particles is essential in the WPIA. This requires a synchronous performance of plasma wave receivers and particle instruments. We introduce a system that feeds particle detection pulses of particle detectors into plasma wave receivers to achieve the synchronization. The chip we developed consists of two stages. The first stage is the current-voltage conversion circuit. It picks up each current pulse and convert into voltage signals with enough amplitudes to drive the second stage. The second stage contains comparator and peak-hold circuits. The comparator ensures picking up real signals by setting a threshold level and the peak-hold circuit has a role to keep the level to connect to a next stage. In this study, we designed the circuits so that it is within several nanoseconds from the arrival of a particle to the convergence of the detection signal. Conventional circuits are made of discrete electronic parts. That requires large resources in their sizes and weights. However, the chip we developed is small and light-weight. In this study, we integrate detection circuits using ASIC (Application Specific Integrated Circuit) technology and we aim to accommodate at least 16 channels of circuits within 5 mm square chip.

In this presentation, we show the details of the chip designed for the particle detection circuits. We also examine the verification test results in the operation of those circuits. Furthermore, we describe the development plan for the future WPIA system integration.

宇宙空間は非常に希薄なプラズマで満たされているため、エネルギーの授受はプラズマ波動を介して行われる。これを波動粒子相互作用といい、そのメカニズムの解明は宇宙電磁環境を理解する上で欠かせないものである。従来の波動粒子相互作用の研究手法は、プラズマ波動強度と粒子の速度分布関数を人工衛星から地上に送信し、関係性を調べるというものであった。この手法は粒子観測の時間分解能が数十 msec 以上と低い上、波動粒子相互作用を考える際に重要なプラズマ波動ベクトルと粒子速度ベクトルの位相差情報を喪失している点に問題があり、エネルギー変換量を定量的に求めることが不可能であった。そこで、波動と粒子速度ベクトルのデータを人工衛星上で処理し、エネルギー変換量を直接求める波動粒子相互作用解析装置 (WPIA: Wave-Particle Interaction Analyzer) が提案された。WPIA は、プラズマ波動受信器によって観測された波動ベクトルの瞬時値と、プラズマ粒子観測器によって観測された各粒子の速度ベクトルからエネルギーの交換量を計算する。したがって、プラズマ波動受信器と粒子観測器を同期させ、波動ベクトルと速度ベクトルの位相差情報を取得することが必要である。本発表では、粒子観測器の粒子検出パルスをプラズマ波動観測器へ高速に伝達し、両者の同期を取るために開発した粒子センサ用高速粒子検出回路システムを紹介する。この回路は、電流パルスを電圧信号に変換して増幅する粒子検出用高速アンプと、信号検出を行うコンパレータおよびピークホールド回路の 2 段から構成されている。波動ベクトルと同時刻のデータを得るためには、粒子の到来から数 ns 後に検出信号が立ち上がる高速応答性が求められる。従来の粒子検出回路はディスクリートで実現されており、回路規模が大きく小型衛星への搭載が困難であった。本研究では特定用途向け集積回路 (ASIC: Application Specific Integrated Circuit) 技術を用いた集積化を行い、高速応答性を維持しつつ 5 mm 四方のワンチップに少なくとも 16 チャンネルの粒子検出回路が収まるよう小型化することに成功した。

本発表では、この粒子検出回路システムの詳細と、動作実験の結果を紹介する。また、WPIA システム全体の小型化に向けた今後の開発計画について述べる。

# Arase 衛星 S-WPIA 解析におけるプラズマ波動及び粒子の較正に関する評価

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# Calibration of the plasma wave and particles dedicated to the measurement of the S-WPIA of the Arase Satellite

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One of the science targets of the Arase satellite mission is to clarify the mechanism of the generation/extinction of relativistic high-energy electrons accumulated in the outer radiation belt. It is thought that the wave-particle interaction is a plausible mechanism for generation/extinction processes of relativistic electrons. For the purpose of observing the interaction between this plasma wave and particles, the Arase satellite is equipped with the Software-type Wave-Particle Interaction Analyzer (S-WPIA). In the S-WPIA, it is possible to evaluate the wave-particle interaction quantitatively by calculating the time change of kinetic energy of particle by taking the inner product of the instantaneous vector of electric field of the plasma wave and the velocity vector of a particle, or by observing the relative phase angle distribution between the instantaneous vector of the magnetic field of the plasma wave and the velocity vector of a particle.

However, the data of the electromagnetic field obtained from the plasma wave observation device is affected by the amplitude and phase by various amplifiers of the sensor and the observation device. In particular, the antenna impedance changes dynamically depending on the plasma environment around the satellite. Therefore, it is necessary to accurately calibrate the amplitude and phase of the electromagnetic field vector of the plasma wave in consideration of the characteristics of the observer and the antenna and the plasma environment around the satellite. We picked up some events of the whistler-mode chorus waves. Then, we compared the refractive index calculated from the calibrated electromagnetic field data with its theoretical value obtained from the Appleton-Hartlee equation.

On the other hand, when the plasma wave is obliquely propagating, the electromagnetic field does not rotate with a constant phase change in the polarization plane. Therefore, the relative phase angle between the instantaneous vector of the magnetic field and the velocity of a particle is unevenly observed. Then, it is necessary to make the observation possibility uniform by weighting the distribution of the relative phase angle with the observation frequency. We uniformed the observation possibility of the relative phase angle between the instantaneous vector of the magnetic field and the velocity of a particle, and corrected the distribution of the relative phase angle, and calculated the phase angle distribution between the plasma wave and a particle.

In the presentation, we will discuss the accuracy of the calibrated electromagnetic fields data of the plasma wave and the results of calibrating the relative phase angle distribution between the instantaneous vector of the magnetic field and the velocity vector of the particle, and aim to improve the accuracy of S-WPIA observation.

放射線帯外帯に蓄積されている相対論的高エネルギー電子の生成と消滅、及び宇宙嵐の発達のメカニズムを明らかにするべく、Arase 衛星が打ち上げられた。相対論的高エネルギー電子の生成・消失の過程には、粒子とプラズマ波動の間に起こる相互作用が関係していると考えられている。このプラズマ波動と粒子間の相互作用を観測することを目的として、Arase 衛星には S-WPIA(Software-type Wave-Particle Interaction Analyzer) が搭載された。S-WPIA では、プラズマ波動の電界の瞬時ベクトルと粒子の速度ベクトルの内積を取ることで粒子の運動エネルギーの時間変化を計算する方法、あるいはプラズマ波動の磁界の瞬時ベクトルと粒子の速度ベクトルの相対位相角の分布を観測する方法により波動粒子相互作用を定量的に評価することができる。

しかし、プラズマ波動観測機から得られる電磁界のデータは、センサーや観測器の各種アンプによって振幅、位相に影響を受けている。特に電界を捉えるセンサーであるアンテナの複素インピーダンスは衛星周辺のプラズマ環境によってダイナミックに変化する。従って、観測器やアンテナなどの特性や衛星周辺のプラズマ環境を考慮し、プラズマ波動の電磁界ベクトルの振幅と位相を正確に較正する必要がある。我々は、ホイッスラーモードコーラス波のいくつかのイベントをピックアップした。そして、較正した電磁界の波動データから得る屈折率を Appleton-Hartlee の分散関係式から算出される屈折率の理論値と比較することでプラズマ波動の calibration の精度を確認した。

一方、プラズマ波動とプラズマ粒子観測との観測位相比較において、プラズマ波動の伝搬ベクトルが、少しでも斜めであると、電磁界は偏波面で一定の位相変化で回転しない。そのため、磁界の瞬時ベクトルと粒子の速度ベクトルの相対位相角の観測可能性は不均一になる。従って、その相対位相角の分布を観測される頻度で重みをつけることにより観

測可能性を均一にする必要がある。我々は、磁界の瞬時ベクトルと粒子の速度ベクトルの相対位相角の観測可能性を均一にし、その相対位相角の分布を補正した上で、プラズマ波動と粒子との位相角分布を計算した。

講演では、較正したプラズマ波動の電磁界データの精度、及び磁界の瞬時ベクトルと粒子の速度ベクトルの相対位相角の分布を較正した結果について議論を行い、S-WPIA 観測の精度向上を目指す。

# 惑星探査用高エネルギー電子観測器の ASIC 開発

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# Development of ASIC for energetic electron detector for future planetary explorations

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Energetic electrons have been observed in all planetary magnetospheres in our solar system. Some fraction of these electrons precipitate into the atmosphere and deposit their energy. However, it is difficult to quantitatively evaluate the effects of energetic electrons on the atmospheric dynamics and chemistry of outer planets and their satellites, due to the lack of detailed measurements. For such future observations, it is important to cover the large solid angle, since the energetic electron flux is not necessarily isotropic. Keeping this in mind, we develop an energetic (20 - 100 keV) electron detector which has hemispherical field of view without the spacecraft spin. For planetary explorations, which place stringent limitation on payload mass, we aim to miniaturize the sensor by applying the ASIC (Application Specific Integrated Circuit) technology to analog signal processing circuits. It is composed of preamplifiers, shaping amplifiers, peak holders, and Analog-to-digital converters. We designed an ASIC so that its dynamic range and the wave form peaking time to be ~$10^6$ $e^-$ and ~1 us, respectively, in consideration of the gain and the noise characteristics of the assumed detector (Avalanche Photodiode, APD). The performance was confirmed in the simulation.

高エネルギー電子は太陽系のあらゆる惑星磁気圏で観測されており，それらの一部は惑星大気へ降り込んで大気にエネルギーを与えると考えられるが、観測例の少ない外惑星やその衛星では，高エネルギー電子の大気への影響の評価は難しい。この電子フラックスは必ずしも等方的ではなく、今後の観測で大気への影響を定量的に評価するには広い立体角をカバーする必要がある。そこで我々は将来の惑星探査を念頭に、衛星スピンに依存しない半球状の視野を持つ高エネルギー (20 - 100 keV) 電子観測器を開発している．ペイロード重量制限の厳しい惑星探査に向けて，本研究では特に，電子検出信号処理部を ASIC (Application Specific Integrated Circuit) 化することで、コンパクトな観測器の実現を目指している。我々の電子観測器の電子検出信号処理回路は前置増幅部、波形整形部、ピークホールド部、AD 変換部で構成されている。我々は，想定している検出器（Avalanche Photodiode, APD）の増幅率やノイズ特性を考慮して，ダイナミックレンジ ~$10^6$ $e^-$・波形整形回路の時定数 ~1 μ s となるような回路設計を行い、シミュレーション上での動作を確認した.

# X 線天文衛星「すざく」を用いた地球磁気圏における電荷交換 X 線発光イベントの系統解析

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# A systematic analysis of charge exchange events in the Earth’s magnetosphere with Suzaku

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Geocoronal solar wind charge exchange has been established by recent X-ray astronomical observations such as Suzaku (Fujimoto et al. 2007 PASJ, Ezoe et al. 2010 PASJ). High charge state solar wind ions strip an electron from exospheric neutrals extending over 10 Earth radii, and then release soft X-ray photons when the electron cascades into the grand state. Geocoronal X-ray signals provide not only an immediate background for all the X-ray astronomical observations but also useful information such as the exospheric density by using the data taken form solar wind monitoring satellites. In addition, its spatial distribution is expected to be high at the dayside magnetosheath and the magnetospheric cusps, which leads to the imaging of the Earth’s magnetosphere (Ezoe 2018 The astronomical herald).

In order to explore the geocoronal X-ray signals, we systematically analyzed all the archival Suzaku data which has one of the highest sensitivities to soft X-rays. We searched the data for time variation of the soft X-ray background, and then compared it with the simultaneously observed solar wind data (Ezoe et al. 2011 PASJ, Ishikawa et al. 2013 PASJ, Ishi et al. 2019 PASJ). Among 2031 data sets covering from 2005 August to 2011 September, 38 events showed the geocoronal X-ray signals (Ishikawa 2013 Ph. D. thesis). We newly found 52 events from 1024 data sets covering 2011 October to 2015 May. These events cover one solar cycle. The number of the geocoronal X-ray events seems to correlate with the solar activity and the event rate is reletively high at the direction of the magnetospheric cusps. However, the geocoronal X-ray emissivity normalized by the solar wind proton flux seems not to be particularly strong in the magnetospheric cusps. This is probably due to uncertainties of the solar wind ion ratio and/or the exospheric density. We report on a systematic analysis of charge exchange events in the Earth’s magnetosphere with Suzaku and discuss the representative events in combination with the simultaneously observed XMM-Newton data.

近年、X 線天文衛星「すざく」などの活躍により、地球周辺の電荷交換 X 線発光 (Charge eXchnage, CX) が確立してきた (Fujimoto et al. 2007 PASJ, Ezoe et al. 2010 PASJ)。地球周辺 CX では、太陽風に含まれる高階電離したイオンが 10 地球半径以上に広がる希薄な超高層大気の中性物質から電子を奪い、それが基底状態に落ちる際に軟 X 線を放出する。これは X 線観測の前景雑音として重要な上、太陽風観測衛星のプラズマフラックスを併用すれば、発光強度から中性大気の密度分布を知ることができる。更に太陽風プラズマの空間分布は磁気圏構造を反映するため、発光場所から磁気圏の衝撃波や境界面の可視化が期待でき、特に太陽風プラズマまたは中性大気の密度が高くなるシースやカスプ領域が明るくなると予想されている (江副 2018 天文月報)。

そこで我々は広がった X 線に対して高い感度と分光性能を持つ「すざく」衛星の公開データを用いた地球周辺 CX 発光イベントの系統解析を行った。視野内から明るい天体を除去した上、軟 X 線バックグラウンドの有意な時間変動を探し、なおかつ太陽風変動と有意な相関があるものを地球周辺 CX とみなす (Ezoe et al. 2011 PASJ, Ishikawa et al. 2013 PASJ, Ishi et al. 2019 PASJ)。我々は 2005 年 8 月から 2011 年 9 月の 2031 データから 38 イベントの検出に成功している (石川 2013 博士論文)。更に同様の手法で 2011 年 10 月から 2015 年 5 月の 1024 データから今回新たに 52 イベントを検出した。これらは 1 太陽周期 11 年分をカバーする。各観測年のイベント検出数と太陽活動に相関が見られ、その検出率はカスプ方向で高い傾向にあった。一方、太陽風プロトンフラックスで規格化した CX 発光強度に有意な視線方向依存性は見られず、これは太陽風中のイオン比もしくは中性大気密度の時間変動の不定性が影響していると考えられる。本講演では、「すざく」衛星による地球周辺 CX 発光イベントの系統解析の結果を報告するとともに、代表的なイベントに関しては別の軌道を周回する欧 XMM-Newton 衛星のデータを併用して議論する。

# Homogeneity of soft electron precipitation in the cusp for northward IMF

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When IMF is northward, electrons and ions are injected into the cusp along open magnetic field lines after reconnection poleward of the cusp. It is well understood that the injected ions often produce the dayside proton auroral spot at 75-85 MLAT at ionospheric heights, and that the cusp reconnection plays a significant role for the distribution of the cusp ion precipitation. In contrast, the electron precipitation in the cusp is rather homogeneous, and the redline cusp aurora, produced by the electron precipitation, is generally less structured than that for southward IMF even if the northward component of IMF is strong. In this study, using 630-nm aurora data from an all-sky imager at Longyearbyen, Svalbard, and precipitating electron/ion data and field-aligned current data from the DMSP spacecraft traversing the region above the cusp auroras, we examined what is reflected by the homogeneity of the cusp electron precipitation. From five winter seasons, we took more than 20 events for which the 630-nm aurora appears at latitudes higher than 75 MLAT, the DMSP observed the cusp ion precipitation concurrent with the field-aligned current associated with northward IMF. Results of the analysis have shown that the solar wind speed is important for the homogeneity of the soft electron precipitation in the cusp for northward IMF. We discuss this result in terms of the electron distribution in the upstream solar wind.

# Self-consistent particle simulation of falling tone emissions via nonlinear wave-particle interactions

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We perform one-dimensional electromagnetic particle simulations, to study fundamental processes of whistler-mode wave propagation from the equator and their interaction with energetic electrons. Approximating the dipole magnetic field by a parabolic magnetic field, we assume a cylindrical model for particle dynamics with a parabolic magnetic field taken along the axis of the cylinder, while we solve Maxwell's equations including Poisson's equation on the axis. The parallel electrostatic field, which has been neglected in most studies on whistler-mode chorus emissions, is included in the simulation. We put an antenna perpendicular to the background magnetic field, and oscillate the antenna current at fixed frequencies with different duration.

We observe falling tone emissions for a short triggering pulse with a frequency close to half the electron cyclotron frequency. We also find rising tone emissions is generated with a long triggering pulse. Through the process of falling tone emissions, we find entrapped particles generates the resonant current parallel to the wave magnetic field, which decreases the frequency of the seed waves near the equator. By changing the wave frequency and the length of the triggering wave packet, we can control the occurrence of rising and falling tone emissions.

# 地球近傍での磁気リコネクション境界領域における粒子加熱に関する統計解析

# 荒木 瑞穂 [1]; 星野 真弘 [1]; 桂華 邦裕 [1]; 北村 成寿 [2]; 齋藤 義文 [3]
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# Statistical study on plasma heating around the reconnection separatrices in the near-Earth magnetotail

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Magnetic reconnection is an important physical mechanism that converts magnetic energy into thermal and kinetic energy of plasmas. The energy conversion is mainly performed at the X point, while it is possible to occur in the reconnection separatrix regions where topology of magnetic fields changes (Petschek et al., 1964). Moreover, it was observationally confirmed that cold ions are accelerated in the plasma sheet boundary layer (PSBL) of the distant magnetotail (Saito et al., 1995). The main purpose of this study is to understand how ions and electrons are heated and accelerated through the boundary. Particularly, we perform a statistical study on the heating, using high time resolution data. Ions around the boundary are known to be multiple components (e.g., Ueno et al., 2001), and it is therefore necessary to discuss about variations of plasma characteristics at the level of three-dimensional distribution function. In addition, in order to investigate the mixing of multiple-component plasma, plasma data with high time resolutions are required to analyze short time-scale phenomena less than the ion cyclotron frequency (~1 Hz in the plasma sheet). We statistically examine plasma heating around the separatrix regions by analyzing velocity distributions observed by the MMS (Magnetospheric Multiscale) spacecraft.

An example of reconnection separatrix observations is the event from 06:27:15 to 06:32:15 on July 16, 2017. We use three-dimensional distribution function data (Ion: 6.7 Hz, Electron: 33 Hz) obtained from FPI (Fast Plasma Investigation) and magnetic field data (128 Hz) obtained from FGM (Flux Gate Magnetometer) on board the MMS1 spacecraft, which was located in the near-Earth magnetotail at GSM-X ~-15.7 Re. The X component of the magnetic field decreased from 55 to 20 nT, and the X component of the ion bulk velocity perpendicular to the magnetic field increased from 0 to 150 km/s. This indicates that the spacecraft passed through the boundary between the northern lobe region and the plasma sheet on the earthward side. Three-dimensional distribution functions showed a low-energy component and high-energy beams in both parallel and anti-parallel directions to the magnetic field. The temperature of low-energy components (<1 keV) increased from 30 to 170 eV. The temperature of the parallel beam (pitch angles of 0-45 degrees) increased from 2 to 3.8 keV. The temperature of the anti-parallel beam (pitch angles of 135-180 degrees) is approximately constant at about 2.5 keV.

In addition to such data-oriented analysis of multiple component plasma, we perform non-linear 2- or 3-component fits to three-dimensional velocity distribution functions. This analysis is necessary to extract multiple components from complex velocity distributions for a large number of events that we have already found in the MMS tail seasons. In this presentation, we show changes in extracted plasma parameters (temperatures, anisotropies, etc.) across the separatrix regions to discuss about heating and mixing processes.

磁気リコネクションは磁場エネルギーをプラズマの熱・運動エネルギーに変換する重要な物理機構である。エネルギー変換は主に X ポイントで行われているとされるが、磁場のトポロジーが変化するリコネクション境界領域においてもエネルギー変換が起こりうることが示唆されている (Petschek et al.,1964)。また磁気圏尾部の境界領域ではイオンが加速している様子も観測されている (Saito et al., 1995)。本研究では、高時間分解能データを用いて、境界領域のイオンの加速・加熱についての統計解析を行う。境界領域のイオンは複数の異なる速度分布が共存していることが多いため (Ueno et al., 2001)、成分ごとに選り分けた上での 3 次元分布関数レベルの議論が必要となる。また、複数成分の混合を議論するためには、イオンのサイクロトロン周波数 (尾部プラズマシートでは 1Hz 程度) 以上の高時間分解能のデータを用いる必要がある。我々は、MMS(Magnetospheric Multiscale) 衛星で観測された境界領域における複雑な速度分布を成分ごとに選り分け、複数のイベントについて粒子混合および加熱を調査する。

典型的なリコネクション境界を横切った時のデータを解析した一例として、2017 年 7 月 16 日 06:27:15~06:32:15 のイベントを挙げる。我々は MMS 衛星 1 号機に搭載された FPI(Fast Plasma Investigation) の 3 次元分布関数データ (Ion-6.7 Hz、Electron-33 Hz) と FGM(Flux Gate Magnetometer) の磁場データ (128 Hz) を用いて解析を行った。この時衛星は GSM-X~-15.7 Re の地球近傍尾部にいた。この境界の前後で、磁場は GSM-X 成分が 55 から 20 nT まで減少し、イオンのバルク速度の磁場垂直成分のうち GSM-X 成分が 0 から 150 km/s に増加している。よって衛星は北半球側のローブ領域から境界を通過し、地球向きアウトフローのあるプラズマシートへ進入したと考えられる。また 3 次元分布関数を見ると、境界では低エネルギー成分と、磁場平行・反平行方向の高エネルギーのビームがある。それぞれ速度分布のうち 1 keV 以下、1 keV 以上かつピッチ角 0~45 度 (磁場平行方向)、1 keV 以上かつピッチ角 135~180 度 (反平行方向) と定め温度を計算すると、低エネルギー成分は 30 から 170eV に、磁場平行のビームは 2 から 3.8 keV にそれぞれ増加しているのに対し、磁場反平行のビームは 2.5 keV でおおよそ一定である。

我々は、上記のような典型例だけに限らず、単にエネルギーやピッチ角の範囲を定めるだけでは複数成分選別が困難な分布関数に対しても各成分のプラズマ物理量を得るために、2 成分や 3 成分 Maxwell 分布を仮定した非線形 3 次元フィッ

ティングを行っている。本発表では、これまで解析を行ってきた 20 イベントについて、フィッティングで得られた温度やその異方性を示し、境界領域におけるプラズマ加熱や複数成分プラズマの混合を議論する。

# 地球磁気圏尾部リコネクション領域におけるイオン・電子温度のフロー速度依存性

# 渡邊 香里 [1]; 桂華 邦裕 [2]; 星野 真弘 [2]; 北村 成寿 [1]; 斎藤 義文 [3]
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# Dependence of ion and electron temperatures on bulk flow speed in the near-Earth reconnection regions

# Kaori Watanabe[1]; Kunihiro Keika[2]; Masahiro Hoshino[2]; Naritoshi Kitamura[1]; Yoshifumi Saito[3]
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It remains an unresolved problem what determines the energy partition between ions and electrons during magnetic reconnection. It is thus important to investigate ion electron temperature ratio around the reconnection regions. Plasma in the Earth's magnetosphere are heated up to 1-10 keV and stored in the plasma sheet in the magnetotail. Magnetic reconnection is a major process that heats/accelerates plasma up to this energy range by releasing the magnetic energy accumulated in the lobe. Heated/Accelerated plasma are transported both earthward and tailward as fast flows with a speed of several hundred kilometers per second or faster. Such fast plasma flows have been observed in the plasma sheet [e.g., Angelopoulos et al., 1994] and are termed as bursty bulk flows (BBFs). It has been reported that the properties of plasma sheet plasma such as ion temperature $T_i$, electron temperature $T_e$, and ion electron temperature ratio $T_i/T_e$ depend on fast flow conditions and spatially vary [Kaufmann et al., 2005, Wang et al., 2012, Runov et al., 2018]. However, there have been few studies which focus on macroscopic profiles of ion and electron temperatures around reconnection regions in the magnetotail.

In this study, we examine the average profiles of the temperatures and their ratio in the plasma sheet in the range of -25 $R_E < X_{GSM} <$ -15 $R_E$ and -10 $R_E < Y_{GSM} <$ 10 $R_E$ by using data obtained from MMS for a period from May 1st to September 30th in 2017. We reconstruct both inflow and outflow regions of the reconnection using the X and Z components of the magnetic field. We then present spatial characteristics of ion and electron temperatures and their ratio. We also examine the flow speed dependence of the spatial characteristics.

Our analysis shows that $T_i$, $T_e$ and entropy increase as they get farther from the neutral point in the outflow region. The entropy increase indicates nonadiabatic heating. $T_i/T_e$ in the outflow region are smaller than in the inflow region. Both $T_i$ and $T_e$ decrease with increasing flow speed for earthward flow. $T_i$ do not change when flow speed increases in the outflow regions while $T_e$ decrease with increasing flow speed for tailward flow so that $T_i/T_e$ in tailward flow are larger than in earthward flow.

The results suggest that electrons are heated more effectively than ions on the separatrix. In addition, the results indicate that less energy partitions into thermal energy when more energy partitions into kinetic energy if magnetic field in lobe regions are constant.

**R006-39** 会場: A 会場（6F ホール） 時間: 10 月 26 日 10:00-10:15

# あらせ衛星の HEP 観測器による内帯・スロット領域での MeV プロトン観測

# 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]
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# Observation of MeV protons by HEP/Arase in the inner belt and slot region

# Honoka Toda[1]; Wataru Miyake[2]; Takefumi Mitani[3]; Takeshi Takashima[4]; Yoshizumi Miyoshi[5]; Inchun Park[6]; Tomoaki Hori[5]
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The Arase satellite was launched on December 20, 2016 for studying the radiation belt dynamics. The Arase is equipped with the high-energy electron experiments (HEP) instrument to observe high energy electrons. HEP is designed to measure electrons with energies of 70 keV to 2 MeV. HEP often detects significant counts in the MeV energy range, though the Van Allen Probes have observed less MeV electrons in the inner belt. We consider that this is due to contamination of high energy protons to HEP. We simulated HEP for the incidence of the energetic protons using by Geant4. The results show that protons of 1-2 MeV, > 6MeV, and > 60 MeV can be observed by HEP. We will report dynamics of MeV protons based on HEP observations.

あらせ衛星には高エネルギー電子を観測する HEP（High-energy electron experiments）観測器が搭載されている．HEP は HEP-H と HEP-L の 2 つのモジュールがあり，それぞれ 70 keV から 2 MeV のエネルギー電子を測定するように設計されている．Van Allen Probes の観測によると，MeV の高エネルギー電子は放射線内帯ではほとんど存在しない．しかし HEP では MeV エネルギー帯で粒子のカウントを検出していた．これは HEP の観測に高エネルギープロトンが混入していると考え，Geant4 による高エネルギープロトン入射のモデル計算を行った．Geant4 の計算結果では，HEP-H では＞ 6 MeV と> 60 MeV，HEP-L では 1-2 MeV と> 60 MeV のプロトンが混入していることが示された．その空間分布は AP9 から予想される空間分布とほぼ一致している．これらのうち，> 60 MeV プロトンに関しては安定で，時間的な変動はほとんど見られない．しかし，> 6 MeV プロトンは内向きのゆっくりとした広がり，1-2 MeV プロトンは短時間での変動が認められた．

R006-40 会場: A 会場（6F ホール） 時間: 10 月 26 日 10:15-10:30

# 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]
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Relativistic electron flux of the outer radiation belt dynamically changes in response to solar wind variations. Variations of solar wind cause the flux drop-out of the outer belt electrons. Magnetopause shadowing (MPS) has been proposed to cause rapid loss of relativistic electrons of the outer belt (e.g.,Kim et al.,2008). In general, it has been expected that MPS is a cross-field transportation due to convection and/or the dayside compression of the magnetosphere. However, the gyro-radius of relativistic electrons of the outer belt seems to be too small compared with the spatial scale of gradient of the dayside magnetopause to escape across the magnetopause. In this study, we investigate another escaping process of relativistic electrons into the interplanetary space. We conduct a code-coupling simulation of a test-particle simulation code (GEMSIS-RB: Saito et al., 2010) and a global MHD magnetosphere simulation code (GEMSIS-GM: Matsumoto et al., 2010). We calculate a number of trajectories of guiding-center of electrons in electromagnetic fields calculated from GEMSIS-GM. In the simulation, electrons are initially distributed from $R_e$ = 6 to 11 with initial energies from 1 MeV to 10 MeV. Initial pitch angles of electrons are distributed from 50 degrees and 90 degrees. In this simulation, the solar wind dynamic pressure and the magnetopause stand-off distance change as follows; [i] The stand-off distance of the magnetopause is 12 $R_e$ with the initial dynamic pressure of 1.0 nPa, $B_{y\_IMF}$ of 0.005 nT, $B_{z\_IMF}$ = 3.0 nT. [ii] The solar wind dynamic pressure increases to 2.5 nPa, and the magnetopause moves to 9 $R_e$ . In this period, the pitch angle scattering of electrons with L value larger than 9.0 occurs by Drift Shell Bifurcation (DSB). [iii] The dynamic pressure decreases, and the inflation of the magnetopause takes place. The stand-off distance of the magnetopause moves back to 10 "R" _"E" . In this period, electrons with L value larger than 9.25 are scattered by DSB. During phase [ii], the high-latitude magnetic reconnections occur at dawn-side. Several electrons are scattered by DSB and the mirror points change to the high latitude where electrons can escape into the interplanetary magnetic field along the field line. During the periods, the high-latitude reconnections occur at the high-latitude in the dusk side. In phase [iii], the trapped electrons in the magnetosphere escape from the field lines that connect to the interplanetary magnetic field in both the dawn and dusk sides. The flux decreases are found in not only higher-L shell but also the lower L-shell, because ExB drift by the induced dawn-to-dusk electric fields cause the outward movement of relativistic electrons. As a result, some electrons move from closed magnetic field to open magnetic field, which cause the loss of trapped electrons in the lower L-shells at least L = 8.75 during the inflation of the magnetosphere. In our study, it is found that outward transport tends to occur at high energy, because electrons with large drift velocity observes dawn to dusk electric field for large periods. The study reveals some electrons at outer radiation belt escape to high latitude into the interplanetary magnetic field along the field line, which are different process from the traditional MPS.

# Relative contribution of ULF and chorus waves to the radiation belt variation

# Naoko Takahashi[1]; Kanako Seki[2]; Mei-Ching Fok[3]; Yihua Zheng[4]; Yoshizumi Miyoshi[5]; Satoshi Kasahara[6]; Kunihiro Keika[7]; David Hartley[8]; Yoshiya Kasahara[9]; Yasumasa Kasaba[10]; Nana Higashio[11]; Ayako Matsuoka[12]; Shoichiro Yokota[13]; Tomoaki Hori[5]; Iku Shinohara[14]
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Earth’s radiation belt exhibits a dramatic variation during the active condition of the magnetosphere such as magnetic storms. The dynamic variation of the radiation belt is, in part, contributed by various wave-particle interactions, including: (1) the radial diffusion of 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 have separately shown the evidence for the contribution of ULF and chorus waves to the relativistic electron flux enhancement. However, comparison of the relative contribution of ULF and chorus waves has not been extensively studied yet.

Here we investigate the relative contribution of both waves to the relativistic electron flux enhancement during a specific magnetic storm. The target event is 27 May 2017 storm, which is triggered by coronal mass ejections. Both Arase (post-midnight) and Van Allen Probe (RBSP)-B (dusk) detect the significant increase of relativistic electron fluxes during the early recovery phase. Then the relativistic electron fluxes further enhance especially at L~4 during the middle recovery phase. The flux enhancement is hardly seen during the late recovery phase. We examined L-value dependence of wave power during each orbit. During the early recovery phase, ULF wave activity is high in wider L range (L=3.5-6), while chorus waves distribute around L=4. On the other hand, ULF wave activity is low during the middle recovery phase, whereas chorus wave activity is higher than the early recovery phase.

We also perform the comprehensive ring current model (CRCM) coupled with Block-Adaptive-Tree Solar-Wind Roe-Type Upwind Scheme (BATSRUS) simulation in order to grasp the global contribution of waves. The simulation well reproduces the global distribution of ULF waves. We also simulate the energetic electron dynamics. The estimated temperature anisotropy is large during the period when chorus waves are observed by Arase and RBSP-B, especially with the energy of 10-40 keV. In this presentation, we will further discuss how observed chorus wave power can be estimated from the simulated electron dynamics.

# Global spatio-temporal development of magnetospheric ELF/VLF waves based on ground-satellite observation and RAM simulation

# Yuhei Takeshita[1]; Kazuo Shiokawa[2]; Yoshizumi Miyoshi[3]; Mitsunori Ozaki[4]; Yoshiya Kasahara[4]; Shin-ichiro Oyama[3]; Martin Connors[5]; Jryki Manninen[6]; Craig A. Kletzing[7]; Vania Jordanova[8]; Dmitry Baishev[9]; Alexey Oinats[10]; Volodya Kurkin[10]
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The magnetospheric ELF/VLF waves are plasma waves generated by energetic electrons from several keV to tens of keV with temperature anisotropy at magnetospheric equatorial plane of the inner magnetosphere. These ELF/VLF waves with frequencies lower than local half-gyro frequency (lower-band) can propagate to the ground along geomagnetic field lines. It is also known that the ELF/VLF waves interact with electrons drifting longitudinally in the inner magnetosphere, and help accelerating accelerate them to relativistic energies. It is important to know the spatial-scale of magnetospheric ELF/VLF waves to estimate the amount of generated relativistic electrons.

Takeshita et al. [submitted to JGR 2019] statistically investigated the longitudinal extent of the magnetospheric ELF/VLF waves using six ground-based stations for two months, and showed the typical extent of the ELF/VLF waves as ˜80 degrees in longitude. On the other hand, Jordanova et al. [JGR, 2010] investigated the global distribution of linear growth rate of whistler mode chorus waves using global ring current-atmosphere interactions model (RAM), and showed that the region of large linear growth rate can extend ˜180 degrees in longitude during the geomagnetic storm of 22 April 2001.

In this study we investigate the spatio-temporal distribution of the source region of magnetospheric ELF/VLF waves using three methods, (A) wave observation using ground based stations and satellites, (B) proxy of ELF/VLF waves using precipitating electrons observed by POES/MetOP, and (C) linear growth rate calculated by RAM simulation during the geomagnetic storm period from 26-30 March 2017.

(A) Wave observations are investigated using ground based observations at Athabasca (ATH; 54.7N, 246.4E, MLAT: 61.3N), Kapuskasing (KAP; 49.4N, 277.8E, MLAT: 58.7N), Kannuslehto (KAN: 67.7N, 26.3E, MLAT: 64.5N) and satellite-based observations by ERG with an apogee in the pre-dawn sector and RBSP-A and RBSP-B with an apogee in the post-dusk sector.

(B) proxy of ELF/VLF waves were estimated by precipitating electrons observed by POES/MetOP satellites [e.g. Li et al. 2013, Chen et al. 2014]

(C) Global distribution of linear growth rate of ELF/VLF waves obtained by the RAM simulation [Jordanova et al. 2012]. The self-consistent magnetic field and the Volland-Stern electric field are used as ambient magnetic and electric fields. The night-side boundary conditions are determined from plasma sheet flux measurements by LANL geosynchronous spacecraft.

We compared the global distribution of magnetospheric ELF/VLF waves deduced from these three methods. We found that the magnetospheric ELF/VLF waves with an extent from 0 MLT to 12 MLT associated with substorm onset were observed by three methods. In this presentation, we will also report comparison with another geomagnetic storm event during 19-24 Nov 2017. Seven ground based stations are were operated during this event, so that we can estimate spatio-temporal development of waves in more detail.

# Mass- and charge-dependent ion energization in the near-Earth magnetotail: Arase observations

# Kunihiro Keika[1]; Satoshi Kasahara[2]; Shoichiro Yokota[3]; Masahiro Hoshino[1]; Kanako Seki[4]; Takanobu Amano[1]; Lynn M. Kistler[5]; Masahito Nose[6]; Yoshizumi Miyoshi[7]; Tomoaki Hori[7]; Iku Shinohara[8]
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The ion pressure in the inner magnetosphere is generally dominated by protons with energies of a few to a few 100s keV. Oxygen ions of ionospheric origin, $O^+$, can make a significant contribution to the ion pressure during geomagnetically active periods. Our previous study (Keika et al., 2018, GRL) showed clear oxygen-proton differences in the contributing energies (energy ranges that makes the dominant contribution to plasma pressure) in the outer part (L larger than 5) of the ring current region. The results provided in situ evidence of the contribution from mass-dependent/selective acceleration processes to the energization of the outer part of the ring current.

The present study extends this analysis toward different ion species, that is, ions with different mass and/or charge states than $H^+$ and $O^+$. We primarily use data from the MEP-i (Medium-Energy Particle experiments - ion mass analyzer) on board the Arase spacecraft. MEP-i measures ions with energies of ~10 to 180 keV/q and distinguishes between different ion species. We analyze the MEP-i data during the magnetic storms that occurred in May, July, and September 2017; the apogee of Arase was located on the night side. Contributing energies were higher for $He^+$ and $O^+$ than $H^+$. Energy density of $O^+$ was contributed from higher-energy (higher than 100 keV) ions as well as lower-energy ions. For doubly-charged ions, contributing energies were similar, ~50-~100 keV. $O^{2+}$ energy density was also contributed from higher-energy (higher than 100 keV) ions. Contributing energies per charge are higher for lower-charge-state ions. The results indicate that energization processes in the near-Earth magnetotail are mass- as well as charge-dependent. This suggests that the ion energy gain in the magnetotail is not determined by a complete displacement across the global electric field potential only. An important factor is likely the limited spatial scale of the electric field associated with narrow flow channels during magnetic field reconfiguration (dipolarization), which can be comparable to gyro-radii of heavy ions.

# あらせ衛星と線形解析による電子サイクロトロン高調波とその発生環境に関する考察

# 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]; 松岡 彩子 [12]
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# Consideration of electron cyclotron harmonic waves and the environment observed by the Arase satellite with linear analysis

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Electron cyclotron harmonic (ECH) waves are commonly observed in the low latitude region just outside the terrestrial plasmapause. They are purely electrostatic and their frequency spectra show harmonic structures. The observed ECH waves are classified into two types. They are the diffuse ECH waves and the enhanced ECH waves. The diffuse ECH waves are weak and they appear as continuous emissions that last for more than a few minutes. The enhanced ECH waves are the sudden enhancements of the diffuse ECH in shorter periods.

We believe that ECH are excited by background electrons because of their intensity change, but observed velocity distribution function don't change simultaneously corresponding to the intensity of ECH. Moreover it's difficult to explain emphasis of enhanced ECH spectra from fundamental wave to high order wave by growth rate calculation with linear dispersion analysis. However there remain uncertain of results of linear analysis because we assume the distribution of cold core electron outside the observation range of low-energy particle experiments-electron analyzer (LEP-e). Electro static wave such as ECH have characteristic that their wavelength is short and that their phase velocity is very slow compared to other electromagnetic waves. The Arase satellite has interferometry mode that observe phase velocity of such waves. In this paper, we calculate phase velocity with ECH data observed by the interferometry mode and derivate temperature of cold core electron by comparing the results with dispersion relation. Using calculation results, we consider the plasma environment where ECH are excited.

電子サイクロトロン高調波 (ECH : Electron Cyclotron Harmonic waves) は低緯度夜側の地球 plasmapause 外側で頻繁に観測される静電波である。ECH は磁力線に垂直に振動する縦波であり、基本波とその整数倍の周波数に現れる高調波構造をもつ。ECH はその強度によって二つのタイプに分けられる。一つが時間的に連続で比較的その強度が弱い diffuse タイプ、もう一つが突発的に強くなる enhanced タイプである。Enhanced タイプの ECH はその強度変化から、背景電子からのエネルギー供給が予想されるが、同時に観測している電子の速度分布関数の変化から、特徴的な変化を見いだすことができていない。また、線形分散解析による成長率の計算では、enhanced タイプの特徴である基本波から高次の高調波にいたる ECH のスペクトルの強調を説明することが難しい。ただし、線形解析では、電子観測器では観測できていない低温コア電子の分布を仮定しているため、その結果に不確定な部分を残している。一方、ECH のような静電波は一般的に波長が短く、また、その位相速度も電磁波モードに比べて非常に遅い。Arase 衛星では、このようなモードの位相速度を捉えることができるインターフェロメトリモードをもっている。本稿では、この Arase 衛星によるインターフェロメトリモードによる ECH の観測結果から、その位相速度を求め、ECH の分散関係を参照して、低温コア電子の温度の導出を試み、ECH が発生しているプラズマ環境について考察を行う。

# Pitch angle scattering by electrostatic electron cyclotron harmonic waves based on Arase observations

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Pulsating auroras (PsAs) are thought to be generated by precipitating electrons scattered by lower-band chorus (LBC) waves near the magnetic equator through cyclotron resonance. One-to-one correlations between LBC wave intensity observed by satellites near the magnetic equator and PsA intensity obtained by ground-based all-sky imager have been reported by previous studies [e.g., Nishimura et al., Science, 2010, Nishimura et al., JGR, 2011]. In addition, electrostatic electron cyclotron harmonic (ECH) waves can also interact with magnetospheric electrons and scatter their pitch angle theoretically [e.g., Lyons, JGR, 1974]. In our previous study [Fukizawa et al., GRL, 2018], we reported that not only LBC but also ECH wave intensity has correlation with the PsA intensity using coordinated Exploration of Energization and Radiation in Geospace (ERG, also called Arase) satellite and ground-based imager observations. Recently, Kasahara et al. [Nature, 2018] reported that LBC wave intensity had correlation with electron flux inside a loss cone and pulsating auroral intensity based on coordinated Arase satellite and ground-based optical observations. Their study confirmed that wave-particle interactions indeed occur between LBC waves and electrons with the energy of 24.5 keV and cause pulsating auroral emissions. On the other hand, correlations between ECH wave intensity and loss cone electron flux have not been reported yet. Therefore, this study aims to reveal whether wave-particle interactions between ECH waves and electrons occur or not at the magnetic equator.

To verify whether ECH waves indeed scatter electrons into a loss cone, we compared ECH wave intensity with electron flux inside the loss cone obtained with low-energy particle experiments-electron analyzer (LEP-e) onboard Arase. Cross-correlation coefficients between ECH intensity and loss cone electron flux in the energy range of 4-6 keV were statistically significant while those between LBC intensity and loss cone electron flux in the same energy range were not statistically significant. To estimate the cyclotron resonance energy of ECH waves, we fitted the observed distribution function by a sum of four subtracted Maxwellian components [e.g., Ashour-Abdalla and Kennel, JGR, 1978]. The dispersion relation was calculated with Kyoto University Plasma Dispersion Analysis Package (KUPDAP), which is a dispersion solver developed by the Space Group at Kyoto University, with changing the wave normal angle of ECH waves from 84.00 degrees to 89.99 degrees. In the case that the wave normal angle is 85.50 degrees, the growth rate has a peak at a frequency of 1.6 fce, where fce is the electron cyclotron frequency. In the case that the wave normal angle is 89.00 degrees, the growth rate has two peaks at 1.3 and 1.6 fce. We suggest that wave normal angle was close to 89.00 degrees since ECH waves observed by OFA had two peaks at 1.1 and 1.6 fce. Using the dispersion relation calculated by KUPDAP, we estimated the cyclotron resonance energy of ECH waves as a function of wave normal angle. The result indicates that the resonance energy reaches the energies of 4-6 keV which cross-correlation coefficients were statistically significant if the wave normal angle is larger than 89.98 degrees. However, the calculated growth rate has single peak at 1.1 fce when the wave normal angle is 89.98 degrees, which is inconsistent with the wave power spectrum observed by OFA. It would be necessary to take effects of wave propagation into account because the observed wave spectrum possibly contains ECH waves not only locally enhanced but also propagated from different source region [e.g., Horne et al., JGR, 2003].

Unfortunately, we could not compare ECH wave intensity and loss cone flux with pulsating auroral intensity at the Arase's footprint due to contamination of sunlight. However, this study suggests that ECH waves scatter a few keV electrons which contribute to cause auroral emission.

# Comparison of EMIC wave distributions between the magnetic equator and higher magnetic latitudes

# Chae-Woo Jun[1]; Yoshizumi Miyoshi[2]; Yoshiya Kasahara[3]; Yasumasa Kasaba[4]; Shoya Matsuda[5]; Masafumi Shoji[2]; Fuminori Tsuchiya[6]; Atsushi Kumamoto[7]; Ayako Matsuoka[8]; Iku Shinohara[9]
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To understand the generation and propagation processes of electro-magnetic ion cyclotron (EMIC) waves between the magnetic equator and higher magnetic latitudes, we performed a comparison study of spatial distributions of EMIC waves based on the Van Allen Probes (RBSP) and Exploration of energization and Radiation in Geospace (ERG) observations. From 2017 to 2018, we identified EMIC wave events observed by both satellite missions and categorized them with respect to wave bands (H+ and He+ EMIC waves) and relative satellite locations from the plasmasphere (inside and outside the plasmasphere). We found two significant observational differences based on RBSP and ERG observations: 1) H+ EMIC waves observed by RBSP are dominantly observed outside the plasmasphere at 11-14 MLT at L˜4-6 near the magnetic equator, while ERG observations at higher magnetic latitudes showed no significant peak wave occurrence regions and relatively lower wave occurrence rates than RBSP observations, indicating that H+ band EMIC waves are easily damped due to unguided wave propagation. 2) For He+ EMIC waves, RBSP observations showed peak wave occurrence regions at 9-14 MLT at L˜4-6 inside the plasmasphere. He+ EMIC waves observed by ERG have two different peak occurrence regions: 14-17 MLT at L˜6-8 inside the plasmasphere, 5-7 MLT at L˜8-11 outside the plasmasphere. In the presentation, we show the details of spatial distributions of EMIC waves between RBSP and ERG observations and the relationship between EMIC waves and geomagnetic conditions.

**R006-47** **会場: A 会場（6F ホール）** **時間: 10 月 26 日 12:15-12:30**

# Rapid Precipitation of Relativistic Electrons caused by EMIC Rising-tones

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On 23 February 2014, Van Allen Probes sensors observed quite strong electromagnetic ion cyclotron (EMIC) waves in the outer dayside magnetosphere. The maximum amplitude was more than 14 nT, comparable to 7% of the magnitude of the ambient magnetic field. The EMIC waves consisted of a series of coherent rising tone emissions. Rising tones are excited sporadically by energetic protons. At the same time, the probes detected drastic fluctuations in fluxes of MeV electrons. It was found that the electron fluxes decreased by more than 30% during the 1 min following the observation of each EMIC rising tone emissions. Furthermore, it is concluded that the flux reduction is a nonadiabatic (irreversible) process since holes in the particle flux levels appear as drift echoes with energy dispersion. We examine the process of the electron pitch angle scattering by nonlinear wave trapping due to anomalous cyclotron resonance with EMIC rising tone emissions. The energy range of precipitated electrons corresponds to the presumed energy for the threshold amplitude for nonlinear wave trapping. This is the first report of rapid precipitation (<1 min) by the mechanism of relativistic electrons by EMIC rising tone emissions and their drift echoes in time observed by spacecraft.

# 内部磁気圏におけるホイッスラーモード・コーラス波動の非線形成長領域：電磁流体-移流シミュレーション

# 海老原 祐輔 [1]; 池田 拓也 [2]; 大村 善治 [3]; 田中 高史 [4]; フォック メイチン [5]
[1] 京大生存圏; [2] 京大・工・電気; [3] 京大・生存圏; [4] 九大・国際宇宙天気科学教育センター; [5] NASA/GSFC

# Preferred region of nonlinear growth of whistler-mode chorus waves in the inner magnetosphere: MHD and advection simulations

# Yusuke Ebihara[1]; Takuya Ikeda[2]; Yoshiharu Omura[3]; Takashi Tanaka[4]; Mei-Ching Fok[5]
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Using a global magnetohydrodynamics (MHD) simulation and a drift advection simulation, we show preferred regions of nonlinear growth of whistler-mode chorus waves in the inner magnetosphere. The MHD simulation provides large-scale electric and magnetic fields. A comprehensive inner magnetosphere-ionosphere (CIMI) model solves the advection of phase space density of electrons under the electric and magnetic fields obtained by the MHD simulation. We imposed the southward interplanetary magnetic field condition on the boundary condition of the MHD simulation. Hot electrons penetrate deep into the inner region due to a combination of the enhanced convection and substorm-associated electric fields. Cold electrons also drift sunward, resulting in a contraction of the plasmasphere. We obtained the following results. First, the nonlinear growth rates can be ~3 orders of magnitude larger than the linear ones at wave frequency of maximum linear growth. Secondly, the optimum wave amplitude is high outside the plasmapause, suggesting that the nonlinear growth is effective. These results imply that the nonlinear growth of chorus waves is preferred to occur in the wide area outside the plasmapause, and that nonlinear growth of the chorus waves could make a significant contribution to loss and acceleration of electrons trapped in the inner magnetosphere.

# Strong diffusion of energetic electrons by chorus waves in the dawnside magnetosphere

# Satoshi Kasahara[1]; Yoshizumi Miyoshi[2]; Shoichiro Yokota[3]; Yoshiya Kasahara[4]; Shoya Matsuda[5]; Ayako Matsuoka[6]; Kunihiro Keika[7]; Tomoaki Hori[2]; Satoshi Kurita[2]; Iku Shinohara[8]
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For sub-relativistic energetic electrons (10-100 keV), one of the promising loss mechanisms is precipitation into the atmosphere due to pitch-angle scattering by whistler chorus waves, but the efficiency of scattering has yet to be quantified. Using in-situ measurements by ERG spacecraft, here we demonstrate that full filling of energetic electron loss cones occurs quite often associated with moderate to intense (wave magnetic power of >50 pT) chorus waves. Spatial distribution of loss-cone filling indicates the efficient scattering takes place at |MLAT|< 10ˆo for the dataset used here, consistent with that of chorus waves.

# Dynamics of relativistic electrons interacting with whistler mode chorus emissions in the outer radiation belt

# Yikai Hsieh[1]; Yoshiharu Omura[2]
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Nonlinear whistler mode wave-particle interaction is one of the processes to generate energetic electrons in the Earth's outer radiation belt. Applying test particle simulations with a large number of electrons and a pair of whistler mode chorus emissions generated at the magnetic equator, we traced the electrons in various initial energies, pitch angles, gyrophases, and locations along a L=4.5 magnetic field line to build a set of Green's functions to analyze the electron distribution functions in a kinetic energy and pitch angle phase space. Setting up the initial distribution function and then employing convolution integral, we can track the evolution of the electrons as interacting with consecutive chorus emissions. We compare the simulation results among three wave models. The first one is a pure parallel wave model. The others are oblique wave models with gradually increased wave normal angles and the maximum wave normal angles are 20 degree and 60 degree. Multiple resonances result in higher probability of nonlinear trapping of electrons and the different tendency of pitch angle scattering. Hence the trapped electrons for the oblique cases are scattered to a wider range of pitch angles than those for the parallel case. In addition, owing to the subpacket structure of the waves, a single electron has a chance to be trapped by different resonances during the lifetime of an oblique wave. Oblique chorus emissions can accelerate 10-30 keV electrons to MeV level rapidly in a few wave cycles, which is much faster than that of the parallel emission. In case of larger time scale, the pure parallel wave can accelerate electrons to more than 6 MeV. However, electrons with energy greater than 3 MeV cannot receive much energy from the oblique waves neither via cyclotron resonance nor Landau resonance. Therefore, when electrons reach MeV level, the acceleration rate becomes much slower, and the electrons only reach about 4 MeV after hundred cycles interacting with the oblique waves. This study first shows evolution of the radiation belt electron flux through nonlinear interactions with oblique chorus emissions.

# Effects of convection electric field on nonlinear drift resonance between electrons and Ultralow frequency waves

# LI LI[1]; Yoshiharu Omura[2]
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We derive nonlinear equations describing drift resonant interaction between relativistic electrons and ultralow frequency waves in the presence of convection electric field based on Li et al. (2018). The equation of motion can be approximately expressed in the form of nonlinear pendulum equations with the external driver (azimuthal inhomogeneity factor S), which is defined as a ratio of driving amplitude to the square of trapping frequency. We compare the dynamics of electrons with different S values at different resonant energies (corresponding to different ULF wave numbers). The trajectories of electrons show an obvious transition from periodic motion to chaotic motion as wave number m becomes larger. We compute trajectories of a large number of electrons with the same initial energy and L shell uniformly distributed around the earth, and follow the evolution of the distribution function in energy and L shell phase space. We find that drift resonant electrons can remain trapped by the low-m ULF waves under the strong convection electric field, while trajectories are significantly modified considering a high-m ULF wave. The simulation results demonstrate that the convection electric field plays a role for the transport of the trapped electrons under high-m ULF waves but rarely affects the trapping motion under low-m ULF waves.

# Correlations of low-energy electrons with chorus emissions observed by ERG: An event study

# Yoichi Kazama[1]; Hirotsugu Kojima[2]; Yoshizumi Miyoshi[3]; Yoshiya Kasahara[4]; Hideyuki Usui[5]; Iku Shinohara[6]; B.-J. Wang[7]; S.-Y. Wang[8]; Sunny W. Y. Tam[9]; Tzu-Fang Chang[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]
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Interactions between electrons and chorus emissions have been studied by spacecraft in-situ observations, and in this study, we report close relations of electrons with energies below ~20 keV to upper-/lower-band chorus emissions observed by the ERG satellite late on March 18, 2017. ERG was located in the post-midnight at L~6, crossing the magnetic equator. Around 23:45UT, the satellite observed an electron injection and chorus wave intensification. The observation indicates good correlations of field aligned electron fluxes to both upper-band and lower-band chorus emissions and also relatively low correlation coefficients in between those bands. Moreover, electron energy distributions have a dip at the band gap. These results suggest that in this event, low energy electrons were being scattered by upper- and lower-band emissions simultaneously toward the magnetic field directions by cyclotron resonance, resulting in less increase of parallel electron fluxes at the upper-lower band gap.

# 畳み込みニューラルネットワークによる Arase/PWE の観測に基づいた自動電子密度推定

# 松田 昇也 [1]; 長谷川 達人 [2]; 熊本 篤志 [3]; 土屋 史紀 [4]; 笠原 禎也 [5]; 三好 由純 [6]; 笠羽 康正 [7]; 松岡 彩子 [8]; 篠原 育 [9]
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# Evaluation of Automatic Electron Density Determination by using a Convolutional Neural Network: Arase PWE measurement

# Shoya Matsuda[1]; Tatsuhito Hasegawa[2]; Atsushi Kumamoto[3]; Fuminori Tsuchiya[4]; Yoshiya Kasahara[5]; Yoshizumi Miyoshi[6]; Yasumasa Kasaba[7]; Ayako Matsuoka[8]; Iku Shinohara[9]
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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. The HFA measures wide frequency range (0.1-10 MHz) electric power spectra with a time resolution of 8 or 60 s. This covers a typical frequency range of Upper Hybrid Resonance (UHR) frequency in the inner magnetosphere. We developed a technique for automatically determining UHR frequencies using a Convolutional Neural Network (CNN) to derive the electron density along the orbit of the Arase satellite. In this study, we evaluate the performance of electron density determination by using a CNN model from the point of view of science.

# コロナホール流に伴う放射線帯外帯電子の発達：あらせ観測

# 三好 由純 [1]; 栗田 怜 [1]; 片岡 龍峰 [2]; ジョルダノヴァ ヴァニア [3]; 東尾 奈々[4]; 高島 健 [5]; 篠原 育 [6]; 寺本 万里子 [7]; 三谷 烈史 [8]; 堀 智昭 [1]; Park Inchun[9]; 松岡 彩子 [10]; 笠原 慧 [11]; 横田 勝一郎 [12]; 桂華 邦裕 [13]; 笠原 禎也 [14]; 松田 昇也 [15]; 土屋 史紀 [16]; 熊本 篤志 [17]; 小路 真史 [1]
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# Evolutions of energetic electrons associated with the coronal hole streams: Arase observations

# Yoshizumi Miyoshi[1]; Satoshi Kurita[1]; Ryuho Kataoka[2]; Vania Jordanova[3]; Nana Higashio[4]; Takeshi Takashima[5]; Iku Shinohara[6]; Mariko Teramoto[7]; Takefumi Mitani[8]; Tomoaki Hori[1]; Inchun Park[9]; Ayako Matsuoka[10]; Satoshi Kasahara[11]; Shoichiro Yokota[12]; Kunihiro Keika[13]; Yoshiya Kasahara[14]; Shoya Matsuda[15]; Fuminori Tsuchiya[16]; Atsushi Kumamoto[17]; Masafumi Shoji[1]
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Large flux enhancements of relativistic electrons of the outer belt often observed associated with the high-speed coronal hole streams. Both the solar wind speed and the southward IMF are important parameters to control the flux enhancement of electrons. Previous studies have shown that the flux of enhanced electrons largely depend on the solar wind parameters, while the solar wind parameter dependence of the evolution of the energy spectrum, especially highest energy, have not been well known. In this study, we investigate evolutions of the energy spectrum during the high-speed streams after the Arase launch by using the energetic electron data from Arase/XEP/HEP/MEPe instruments. As a result, the hardening of the energy spectrum depends on the southward IMF after the stream interface crossing. Average heating rate of ˜20-30 keV/days at the heart of the outer belt are found from the analysis during the high-speed streams, and the heating rate depends on the southward IMF. During the periods, continuous chorus wave enhancements are observed outside the plasmapause during the same periods, which suggests that chorus waves contribute to heating of energetic electrons.

# 超小型探査機搭載の極端紫外撮像機（PHOENIX）によるプラズマ圏の光学観測

# 吉岡 和夫 [1]; 桑原 正輝 [2]; 疋田 伶奈 [3]; 吉川 一朗 [4]
[1] 東大・新領域; [2] ISAS/JAXA; [3] 東大・新領域・複雑理工; [4] 東大・理・地惑

# The remote observation Earth's plasmasphere From EUV imager (PHOENIX) on board ultra-small spacecraft.

# Kazuo Yoshioka[1]; Masaki Kuwabara[2]; Reina Hikida[3]; Ichiro Yoshikawa[4]
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The nano-spacecraft mission named EQUULEUS is now under development. It will be launched in 2020 as one of the payloads of SLS (Space Launch System) mission of NASA. EQUULEUS will fly to a the libration orbit around the Earth-Moon L2 point and demonstrate trajectory control techniques within the Sun-Earth-Moon region for the first time as a nano-spacecraft. A small telescope in extreme ultraviolet named PHOENIX will be boarded on EQUULEUS. It consists of multilayer-coated entrance mirror (diameter of 6 cm) and photon counting device with microchannel plate and resistive anode, and electronics parts. The reflectance of mirror is optimized for the emission line of ionic helium (wavelength of 30.4 nm) which is the important component of the plasmasphere of the Earth. By flying far from the Earth, the entire image of plasmasphere can be obtained with 1-hour temporal resolution . In this presentation, the mission concept and the design of the telescope, and the latest development status will be shown.

# 惑星間空間磁場北向き時に現れる極冠分岐（交換セル構造）の磁気流体モデリング

# 渡辺 正和 [1]; 田中 高史 [2]; 藤田 茂 [3]
[1] 九大・理・地惑; [2] 九大・国際宇宙天気科学教育センター; [3] 気象大

# Magnetohydrodynamic modeling of a polar cap bifurcation (exchange cell configuration) for northward interplanetary magnetic field

# Masakazu Watanabe[1]; Takashi Tanaka[2]; Shigeru Fujita[3]
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When the interplanetary magnetic field (IMF) is northward, there occurs occasionally a bifurcation of the polar cap (an open magnetic flux region) associating a large-scale transpolar arc. Upon the basis of observations, Watanabe et al. [2004] proposed the 'exchange cell' configuration for a bifurcation process. The exchange cell configuration is a consequence of sequential reconnection described as follows. First, Dungey-type reconnection on the dayside in one hemisphere produces open magnetic flux. The open flux is stacked on the dayside magnetopause, resulting in an overdraped lobe. Subsequently, in order to facilitate the tailward open flux transport, lobe-to-closed reconnection takes place in the same hemisphere. In the ionosphere in the opposite hemisphere, this sequential reconnection produces an intrusion of open magnetic flux into the flankside plasma sheet (a closed magnetic flux region) and creates the bifurcation of the polar cap. In numerical modeling, Tanaka (1999) demonstrated a magnetohydrodynamic simulation indicative of the exchange cell configuration. However, subsequent simulation codes developed by Tanaka have not been successful in reproducing the exchange cell configuration even for the same IMF conditions. It appears that the exchange cell does not occur under simple IMF conditions. For the purpose of reproducing the exchange cell configuration, we performed the following simulation. In order to promote the overdraped lobe formation, we tilted the Earth's dipole axis by 25 degrees (boreal winter). Similarly, in order to further Dungey-type reconnection in the summer hemisphere, we set the IMF to Bx=5nT By=0, and Bz=5nT. We produced a quasi-stationary magnetosphere under these conditions and after that rotated the IMF clock angle from due north by 40 degrees in about 30 minutes without changing the IMF magnitude. With this simulation, we obtained a solution with a polar cap bifurcation that is similar to the exchange cell configuration. In the presentation, we report the detailed analysis of the simulation results. From this modeling, it is suggested that the Earth's dipole tilt plays an important role in forming the exchange cell configuration.

惑星間空間磁場北向き時には、極冠（閉磁力線領域）が分岐して大規模なトランスポーラーアークが現れることがある。観測に基づき、Watanabe et al.（2004）は交換セル構造による極冠分岐モデルを提唱した。交換セル構造は以下のような一連のリコネクションにより生じる。まず昼間側の一半球で Dungey 型リコネクションにより開磁束ができるが、尾部方向に輸送されずに磁気圏前面を覆うローブ（overdraped lobe）が形成される。続いて開磁束を尾部への輸送するため、同半球で開磁力線と閉磁力線でリコネクションが起こる。この一連の過程で、反対半球の電離圏では開磁束領域が朝側または夕側のプラズマシート（閉磁束領域）に陥入し、極冠が分岐する。数値モデリングでは、交換セルとおぼしき構造を Tanaka（1999）が磁気流体シミュレーションで再現しているものの、後継のコードでは同じ IMF 条件下でも再現実験に成功していない。どうも単純な IMF 条件下では再現できないようである。交換セル構造の再現を目指し、我々は以下のようなシミュレーションを行った。磁気圏前面を覆うローブが形成しやすいように、地球双極子磁場を 25 度傾け（北半球の冬）、かつ夏半球で Dungey 型リコネクションが起こりやすいように IMF Bx=5nT、By=0、Bz=5nT とした。この条件で準定常磁気圏をつくり、その後 IMF の大きさを変えないまま約 30 分かけて時計角を真北から 40 度回転させた。その結果交換セル構造に似た対流パターンと極冠分岐を作り出すことに成功した。講演では得られたシミュレーション結果の解析を報告する。このモデリングから、地球双極子の傾きが交換セル形成に大きな役割を果たすことが示唆される。

# 微小北向き惑星間空間磁場下における磁気圏カスプ形成過程

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# Process of magnetospheric cusp formation for infinitesimal northward interplanetary magnetic field

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The interaction between the solar wind and the magnetosphere is manifested in the development of the region 1 field-aligned current system and the formation of the ionospheric two-cell convection. The energy source of the region 1 current system is the high-pressure plasma in the magnetospheric cusp. Thus, understanding the cusp formation process is one critical issue in magnetosphere physics. On the other hand, solar activity has been modulating anomalously since solar cycle 23. In particular, a prolongation of the minimum period and a weakening of the maximum period have been reported. If this trend continues, it is expected that the interplanetary magnetic field (IMF) will become very small. Therefore, investigating the virtual cusp for infinitesimal IMF (for which reconnection effects are minimal) in comparison with the normal cusp for southward IMF, contributes significantly not only to better understanding of the solar wind-magnetosphere interaction but also to future prediction of the global environment. For this purpose, we reproduced the magnetosphere under very small IMF using the Reproduce Plasma Universe (REPPU) code (Tanaka, 2015). In the simulation, a quasi-steady state magnetosphere was produced under the solar wind and IMF conditions of density=5cm$^{-3}$, Vx=-370km/s, Bx=0.0nT, By=-0.05nT, Bz=0.086nT (total intensity B=0.1nT and clock angle 30 degrees), and temperature=340,000K. We then visualized the spatial distribution of electromagnetic energy, thermal energy and kinetic energy in the magnetosphere. From this analysis, we found a clear difference between the virtual cusp for infinitesimal IMF and the normal cusp for southward IMF. Normally, the cusp consists of the equatorward 'load' in which electromagnetic energy is converted to thermal energy and the poleward 'dynamo' in which thermal energy is converted to electromagnetic energy. The dynamo on the high latitude side is the energy source for the region 1 current system. Although this structure does not change even for infinitesimal IMF, a salient feature for infinitesimal IMF is the imbalance between the load and the dynamo. In the normal cusp, the load and the dynamo are almost balanced. However, in the cusp for infinitesimal IMF, the load is much smaller than the dynamo. This imbalance implies the existence of more than one energy supply route to the cusp dynamo, with one of them emerging solely for infinitesimal IMF. In the presentation, we report the detailed analysis of the simulation data and discuss the role of the cusp from the point of view of the functional aspect in the solar wind-magnetosphere interaction.

太陽風と磁気圏の相互作用は、region 1 沿磁力線電流系の発達と電離圏 2 セル対流の形成として具現する。Region 1 電流系のエネルギー源は磁気圏カスプの高圧プラズマが担う。したがってカスプの形成過程を理解することは磁気圏物理学の重要課題である。ところで、太陽活動度は第 23 太陽周期の極大期以降特異な変調をしており、特に極小期の長期化と極大期の弱体化が報告されている。この傾向が続くと、今後惑星間空間磁場（interplanetary magnetic field, IMF）が小さくなってゆくことが予測される。IMF が微小でリコネクションの影響が小さい場合の磁気圏カスプを、IMF 南向きの場合のカスプと比較して研究することは、太陽風ー磁気圏相互作用の理解だけでなく将来の地球環境予測にも資する。そこで我々は、Reproduce Plasma Universe (REPPU) コード（Tanaka, 2015）を用い、微小北向き IMF 時の磁気圏を再現した。IMF のパラメータは密度が 5 個/cc,Vx=-370km/s,Bx=0nT,By=-0.05nT,Bz=0.086nT,T=340,000K, 強度 B=0.1nT, 時計角 30 度（真北から測る）で固定して準定常磁気圏を作り、磁気圏内での電磁エネルギー、熱エネルギー、運動エネルギーの分布を可視化した。この結果、通常の（IMF 南向きの場合の）カスプとの違いが以下のように明らかになった。通常のカスプは低緯度側が電磁エネルギーを熱エネルギーに変える「ロード」で、一方高緯度側が熱エネルギーを電磁エネルギーに変える「ダイナモ」である。高緯度側のダイナモが region 1 電流系のエネルギー源になっている。この構造は微小 IMF の場合も変わらないが、大きな違いは、通常のカスプはロードとダイナモが均衡しているのに対し、微小 IMF のカスプはロードがダイナモに比べて極めて小さい。この不均衡は、カスプダイナモのエネルギー供給ルートが複数あり、微小 IMF のカスプはその一つが顕在した場合と考えられる。講演ではシミュレーションデータの解析結果を報告するとともに、太陽風ー磁気圏相互作用におけるカスプの機能面での役割について考察する。

# シューティング法を用いた交換型リコネクションの磁場トポロジー解析

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# Magnetic field topology analysis of interchange-type reconnection using the shooting method

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Reconnection in the magnetosphere is classified into Dungey-type reconnection (IMF-to-closed and open-to-open) and interchange-type reconnection (IMF-to-open and open-to-closed). While the former is well known, the latter is less well understood. Although some phenomena indicative of interchange-type reconnection can be reproduced by global MHD simulations, there is no in-depth study that examined the separatrix structure, magnetic field line geometry, or magnetic field topology near the magnetic neutral point. In the first place, it is not obvious whether interchange-type reconnection exists mathematically. In order to help understand interchange-type reconnection, for the numerical solutions obtained by global MHD simulations, we attempt to determine the global magnetic field topology and calculate the field-aligned electric fields on separatrices. The global topology is determined by the magnetic neutral points and the separators connecting the nulls. Since the separator is an intersection of separatrices, it is necessary to determine the separatrix radiating from each neutral point. However, tracing the separatrix (a magnetic surface) numerically is very difficult, and consequently successful cases were very few up until now. In this study, we trace separatrices using the shooting algorithm proposed by Krauskopf & Osinga (1999). In the presentation, we report the initial results of the analysis and discuss the existence of interchange-type reconnection.

磁気圏におけるリコネクションは IMF-to-closed または open-to-open の Dungey 型リコネクションと、IMF-to-open または open-to-closed の交換型リコネクションに分類される。前者は比較的研究されているのに対し、後者はあまり知られていない。グローバル MHD シミュレーションにおいて交換型リコネクションの結果と解釈できる現象がいくつか再現されているが、磁気中性点近傍のセパラトリックス構造や近傍の磁力線形状・トポロジーまで踏み込んだ研究はない。そもそも交換型のリコネクションが理論上存在するかどうかも自明ではない。本研究では、交換型リコネクション解明の一助として、グローバル MHD シミュレーションで得られた解に対して、大域的磁場トポロジーの決定とセパラトリックス上の沿磁力線電場の算出を試みる。大域的トポロジーは磁気中性点とそれらを結ぶセパレータで決定される。セパレータはセパラトリックスの交線であるので、セパラトリックスを決定する必要がある。しかしながらセパラトリックス（磁気面）を数値的に追跡することは困難を伴い、これまであまり成功例がない。本研究では Krauskopf & Osinga (1999) が提唱したシューティング法のアルゴリズムを用いてセパラトリックスを追跡する。講演ではその初期結果を報告し交換型リコネクションの存否を議論する。

# カスプの高速プラズマフロー時に見られる電子降下の時間空間発展

# 長房 勇之介 [1]; 田口 聡 [1]; 小川 泰信 [2]; 細川 敬祐 [3]
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# Spatio-temporal evolution of the electron precipitation for the fast plasma flow in the cusp

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As the IMF southward component increases, fast poleward plasma flow occurs in the cusp region. Furthermore, there sometimes occurs localized enhanced plasma flow in the fast poleward flow. These ehnaced flow regions are generally thought to be at the footprint of the flux transfer event (FTE), and there have been some reports that the fast plasma flow is accompanied with the poleward moving cusp aurora. On the other hand, it is not well understood whether the electron precipitation distribution always shows poleward-moving features or not. In this study, to understand the temporal and spatial evolution of electron precipitation during the fast plasma flow in the cusp, we analyzed data from simultaneous observations of an all sky imager, EISCAT Svalbard Radar (ESR) in Longyearbyen Svalbard, and the Super Dual Auroral Radar Network (SuperDARN) Hankasalmi radar. Since the increase in plasma flow is observed as an increase in ion temperature, we searched for events of fast plasma flow by requiring that the ion temperature in the lower F region should be greater than 2000 K. We identified five simultaneous observation events from the six winter seasons from December 2012 to January 2018. Four of the five events show that the enhanced electron precipitation occurs immediately equatorward of the region where fast plasma flow was observed, and in three of the four the electron precipitation region does not show any poleward-moving features. Based on the result from the detailed analysis, we discuss the temporal and spatial evolution of the electron precipitation region for the flow burst seen in the ionosphere.

IMF 南向き成分が大きくなるとカスプには極向きの速いプラズマの流れが生じる。また、その流れの中には部分的に周囲より大きな速度をもつ領域が形成されることもある。例えば，極向きの流れの中に、お互いに逆向きに回転する 2 つの隣接した渦の形状を持つプラズマの流れがあれば、その渦が接触する部分ではプラズマの流れが一層速くなる。こういった領域は、フラックストランスファーイベントの足元であると一般には考えられており、カスプで孤立して極側に動くオーロラを捉え、それに伴ってプラズマの流れが増大していることを示す報告もある。一方で、カスプで速いフローが起きている時には、常に、極側へと動く電子降下分布が形成されるのか、あるいは別の電子降下分布が形成されることが多いのかについてはよくわかっていない。

本研究では、スバールバル諸島に設置しているオーロライメージャーと EISCAT スバールバルレーダー (ESR)、および SuperDARN による同時観測データを用いて、カスプでの高速フローが生じている時の電子降下の時間空間発展を明らかにする。高速のイオンの流れはイオン温度の上昇として観測されるため、ESR による F 層下部のイオン温度が 2000 K 以上に上昇しているイベントに注目した。イオン温度が 2000 K を超えるのは、プラズマの流れがおおむね 2 km/s を超えていることを意味する。2012 年 12 月から 2018 年 1 月の冬季 6 シーズンから、SuperDARN の Hankasalmi レーダーが十分なエコーを観測し、かつ 630 nm のオーロラ画像が得られている条件も加えてイベントを探したところ、5 例のイベントが見つかった。

解析から、1 例においては、カスプの低緯度側の境界が磁気緯度で約 72 度まで下がったために、ESR 固定式レーダーはカスプではなく、極冠域に生じた高速フローを捉えていることがわかった。それを除く 4 例においては、速いプラズマの流れは、その低緯度側において増大した電子降下領域を伴っていることがわかった。前後のオーロラの分布を調べると、そのうち 3 例では、その電子降下領域は、フラックストランスファーイベントとの関連が示唆されるような顕著な動きは見られなかった。詳細なデータの解析をもとに、電離圏で見られるフローバーストに伴う電子降下領域の時間空間発展を議論する。

# 惑星間空間磁場斜め北向き時に現れる夜側電離圏対流系の起源

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# Origin of the nightside ionospheric convection system for oblique northward interplanetary magnetic field

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When the interplanetary magnetic field (IMF) is northward, there appears an ionospheric convection system on the nightside that depends on the By component of the IMF. For negative By, this convection is clockwise in the Northern Hemisphere when viewed from above the ionosphere and counterclockwise in the Southern Hemisphere when viewed from the Northern Hemisphere through the glass Earth. For positive By, the above-mentioned rotation direction reverses in both hemispheres. Taguchi et al. (1993) and Grocott et al. (2005) proposed that this convection system was a consequence of Dungey-type reconnection in the magnetotail. However, the idea is rudimentary, and a quantitative modeling is needed for further discussion. The purpose of this study is to clarify the origin of the above-mentioned nightside convection system by quantitative numerical modeling.

The Reproduce Plasma Universe (REPPU) code (Tanaka, 2015) solves the solar wind-magnetosphere-ionosphere coupled system in a self-consistent manner by magnetohydrodynamic approximation. Using the REPPU code, we reproduced the By-dependent convection system in the simulated magnetosphere after integrating about 120 minutes under the IMF conditions of B=5nT (intensity) and theta=35 degrees (clock angle). The locus of the vortex approximately coincides with the maximum of the field-aligned current intensity, indicating that the convection system and the field-aligned current system are formed in a self-consistent manner. We traced the current line from the field-aligned current peak in the ionosphere to the magnetosphere, and identified the dynamo region where j.E is negative (with j and E being the current density and the electric field, respectively). In the dynamo region, thermal energy is converted to electromagnetic energy. In addition, in the dynamo region, div(Vperp) is negative (Vperp being the plasma velocity component perpendicular to the magnetic field). This result is interpreted by expanding slow mode disturbances. The dynamo region is located at the end of the high pressure plasma region protruded from the plasma sheet into the lobe. The formation of this protrusion appears to involve interchange instabilities in the magnetotail. Therefore, we conclude that the conventional model in terms of Dungey-type reconnection in the magnetotail is incorrect for the explanation of the By-dependent nightside convection system.

惑星間空間磁場 (interplanetary magnetic field, IMF) が北向き時、真夜中付近に発達する IMF By 成分に依存する電離圏対流系がある。この対流系は By が負のとき、北半球では上空からみて時計回り、南半球では地球から見上げて（透明な地球を北半球からみて）反時計回りの渦になる。また By が正では北半球、南半球とも渦の回転方向が逆転する。この対流系の起源は磁気圏尾部リコネクションであるとする説があるが (Taguchi et al., 1994; Grocott et al., 2005)、定量的な議論は行われていない。本研究の目的は、数値モデリングにより IMF By に依存した夜側対流系の起源を解明することである。

Reproduce Plasma Universe (REPPU) コード (Tanaka, 2015) は太陽風ー磁気圏ー電離圏結合系を電磁流体近似で自己無撞着に解く。REPPU コードを用い、IMF 強度 5nT・時計角 35 度の条件で約 120 分間積分し準定常状態磁気圏を作ったところ、前述の IMF By に依存する対流系を再現することができた。渦の中心は沿磁力線電流強度が極大になる点とほぼ一致しており、対流系と沿磁力線電流系が自己無撞着に形成されている。沿磁力線電流のピークから電流線を磁気圏へ追跡し、j・E が負（j は電流密度、E は電場）となるダイナモ領域を特定した。ダイナモ領域では熱エネルギーが電磁エネルギーに変換されている。また、そのダイナモ領域では div(Vperp) が負（Vperp はプラズマ速度の磁力線に垂直な成分）となっており、膨張する slow mode 擾乱で解釈できる。ダイナモ領域は、高圧プラズマがプラズマシートからローブへ流出した構造の端にあり、この流出構造の形成には交換不安定が関与しているように見える。したがって、夜側対流系の起源を Dungey 型リコネクションで説明する従来のモデルは誤りである。

# Slow-moving faint aurora in the dayside polar cap for southward IMF

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Poleward motion of the auroral arc in the cusp is a common feature for southward IMF. There is a category of that moving auroral arc in which the arc appears with an initial brightening in a mesoscale region near the equatorward boundary of the cusp, and travels a long distance. This typical poleward moving auroral form is often identified as a detached arc immediately poleward of the main redline auroral band in the daytime sector. In this study, by using the 630-nm aurora image data obtained by an all-sky imager at Longyearbyen, Svalbard, and the particle data from DMSP spacecraft, we present features of the moving redline aurora that can fall in a category that is different from that of the typical poleward-moving auroral form. Those redline auroras are detached from the poleward boundary of the main auroral band, and seen deep in the dayside polar cap during southward IMF. The aurora is very faint; intensities are mostly less than 1 kR. Simultaneous observations from the all-sky imager and the DMSP spacecraft show that there exist multiple mesoscale regions of electron precipitation slightly enhanced from the background polar-rain type precipitation over the faint aurora in the dayside polar cap, demonstrating that the 630-nm emission is caused by electron impact, not recombination. The simultaneous observation also shows that there is no concurrent ion precipitation over the aurora, indicating that this type of auroral arc does not fall in the category of cusp aurora. The detailed analysis of the 630-nm image data shows that the typical longitudinal length of the aurora is 0.2 to 0.4 MLT. The aurora moves poleward at speeds of 100 - 300 m/s. Simultaneous observations with the SuperDARN radar at Hankasalmi shows that those speeds are much lower than the speed of the plasma convection in that region. The solar wind data and the SYM-H geomagnetic index indicate that any significant change in the solar wind dynamic pressure did not occur at the appearance of this type aurora. From these characteristics, we discuss the generation mechanism of the slow-moving redline faint aurora in the dayside polar cap.

# SC に伴うオーロラのシミュレーション研究

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# MHD simulation of the auroras associated with the Sudden Commencement

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There are many SC studies concentrated on the magnetospheric and ionospheric disturbances associated with the preliminary impulse and the main impulse. These disturbances appear in the latitudes in and lower to the auroral oval. On the other hand, the FAC also exhibits peculiar enhancement in the cusp region. This FAC probably relates to the shock auroras [Zhou and Tsurutani, 1999; Zhou et al., 2003; Liu et al., 2011]. There are few simulation studies about the FAC in the cusp region at the SC [Samsonov et al., 2010]. However, detailed studies about energy conversion in the dynamo region of the FAC and nature of the plasma disturbances are not done yet. In the talk, we will present the topics about the shock auroras obtained by the global MHD simulation. We will also explain how the FAC is generated in the dynamo region, and what is the role of the reconnection in the dayside magnetopause.

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# 低高度衛星の紫外線観測を用いたオーロラオーバル赤道側境界の統計解析

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# Statistical analysis of equatorward boundary of auroral oval seen by FUV imager onboard low-altitude satellite

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There have been several experimental models expressing the spatial distribution of auroral oval, especially the dependence of the latitude of auroral oval on the level of magnetic disturbance (e.g., Kp index). However, the amount of data used for constructing such models was rather limited; thus, the models are still inaccurate especially during severely disturbed conditions.One of the possible ways to overcome this limitation is to use a large dataset of FUV imaging from low-altitude satellite. In this study, we make use of data from SSUSI FUV imager onboard the DMSP satellite at ~850 km altitude.

By detecting the boundaries of the auroral oval automatically, we have performed a statistical analysis of the equatorward boundary of auroral oval.

During a case obtained on March 5, 2015, the signatures of auroral oval were captured by the imager when the satellite passed the polar region from dusk to dawn. By carrying out a fitting with two Gaussian distribution to the dusk-dawn cut of the emission intensity, we derived the equatorward boundary of auroral oval. In the presentation, we report the results of the statistical analyses showing the dependence of the boudary location on Kp, Dst and IMF parameters. The long-term variation of the entire shape of the auroral oval will also be discussed.

オーロラオーバルの大規模構造は，Kp 指数の関数としてのモデルが構築されるなど，これまでに多くの研究が行われてきた．地上全天カメラの観測の基づいたモデルとしては，Feldstein らによって構築されたものがある．Kp 指数が大きくなるに従って赤道方向に拡大するオーロラオーバルの様子が表現されているが，用いられたデータ量が少ないため，Kp が大きいケースについては，実観測との誤差が大きくなることが知られている．近年，Milan らが IMAGE 衛星からの紫外光観測を統計処理することによって，磁気擾乱時に赤道方向に拡大するオーロラオーバルの様子を表現している．特にオーロラオーバルが磁気嵐時に極端に赤道方向に拡大することが指摘されている．ただし，Milan らの IMAGE 衛星を用いた統計解析は，使用可能なデータの期間が数年分と限られており，オーロラオーバルの空間分布の経年変化や大規模な磁気嵐の際の赤道側への拡大過程を統計的に有意な形で表現できている訳ではない.

本研究では，オーロラオーバルの赤道側境界の位置を，大量のデータを用いて統計的に解析することを目的とする。具体的には，DMSP 衛星に搭載された紫外線分光イメージャSSUSI の撮像データから，オーロラの赤道側境界の磁気緯度を自動検出することで、その統計的な解析を行うことを試みた.

2015 年 3 月 5 日に得られた観測事例においては，夕方側から朝側へ衛星が移動する際に，オーロラオーバルを 2 度通過し，紫外線分光イメージャを用いてオーロラオーバルの赤道側境界を検出することが可能になっていた．この事例について，輝度値の朝夕断面を，2 つのガウス分布でフィッティングすることによってオーロラオーバルの概形を抽出し，赤道側境界を客観的に算出することができている.

発表では、この手法を大量のデータについて適用した結果に基づいて，オーロラオーバル赤道側境界の Kp 依存性，Dst 依存性，IMF 依存性などを示し，経年変化や朝夕の非対称性についても議論を行う予定である.

# 日本子午面上のプラズマ密度分布

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# Magnetospheric plasma density distribution on Japanese meridian plane

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To understand the mechanism of geomagnetic activity, it is important to monitor the spatial distribution of plasma density and its temporal change.

In the magnetosphere, various disturbance waves are generated by the interaction between the magnetosphere and the solar wind. One of them is the fast-mode wave that propagates across the geomagnetic field lines. Then, FLR (field line resonance) occurs at a position where the frequency of the wave is equal to the eigen-frequency of the geomagnetic field lines. Thus generated field-line eigen-oscillation is observed in the ground magnetic field H component as the geomagnetic pulsation.

By applying the amplitude-ratio method and the cross-phase method to the data of two adjacent ground magnetometers, it is possible to know the FLR frequency and the plasma density can be estimated.

The purpose of this study is to investigate the spatial distribution of plasma density on the Japanese meridional plane. Although the estimation of the spatial distribution of the plasma density has already been performed on the meridional planes of the United States and Europe, but on the Japanese meridional plane, the estimation of the spatial distribution of the plasma density has not yet been made because there are few pairs of observation points having distances generally thought to be suitable for the method (around 100km). However, in a previous research (thesis of Onoue), she succeeded in estimating the plasma density at two observation point pairs on the Japanese meridional plane which have a distance longer than the above-stated distance. Therefore, we make pairs of observation points on the Japanese meridional plane and estimate the plasma density for all the pairs. Since the FLR is observed on the dayside, if the spatial distribution of plasma density on the Japanese meridional plane is known, one of the three meridional planes will always be on the dayside, and the plasma density can be estimated continuously.

So far, we have analyzed the data of all the pairs in 2011 in the same way as in the previous research (Onoue's thesis). Based on the results obtained, we have improved the program for the FLR detection and analyzed the data on a day when the FLR was clearly seen (found by Onoue). As a result, since the FLR was observed at three observation point pairs, the plasma densities at the three pairs were estimated from the obtained FLR frequencies.

We initially expected that the plasma density estimated by the two pairs would be close, because the L values of the midpoint of the two pairs were close, but they were different by an order. Then, considering the possibility that the L value corresponding to the obtained density is different from the L value of the middle point, the line between the two observation points of the pair was divided into 100 segments having the same distance (measured in terms of L), and the plasma density was estimated for each of them. Then, we planned to investigate whether thus obtained density range overlaps with the density range in the same L range calculated by a model based on spacecraft density measurements [Gallagher et al., 2000].

At present, as a step preceding the comparison with the model, we are identifying FLR events for all the station pairs for all the days in 2011; for the identification, we first apply the Fast Fourier transformation (FFT) to the data for every 6144-second segments, adjust the smoothing width in the frequency direction and time direction so that noise is not misidentified as FLR. We then search for FLR events for each time segment. choose the first and the last of thus identified FLR events, and apply the FFT to all the timeseries data between the times of the first and the last events. We then finally determine if the FLR exists or not by visual inspection of the graph of the amplitude ratio and the cross phase calculated from the FFT'ed data.

磁気嵐などの地磁気活動は、磁気圏のプラズマ密度の変動と密接に関係している。

地磁気活動のメカニズムを理解するためには、プラズマ密度の空間分布とその時間変化をモニターすることが重要である。

磁気圏では、磁気圏と太陽風との相互作用によってさまざまな擾乱波が発生する。その一つに、地球の磁力線を横切って伝播する磁気音波がある。そして、その周波数が地球の磁力線の固有周波数と一致する位置で、FLR（磁力線共鳴）が発生する。共鳴を起こした波は、地磁気脈動として地上磁場 H 成分で観測される。

隣接する 2 つの地上磁力計のデータに二点法を用いることでその磁力計ペアの中点での FLR 周波数を知ることができ、その FLR 周波数からプラズマ密度を推定することができる。

本研究の目的は、FLR 周波数を用いて日本子午面上のプラズマ密度の空間分布を調べることである。既にアメリカ、ヨーロッパの子午面ではプラズマ密度の空間分布の推定が行われているが、日本子午面上には二点法に適した距離の観測点ペアが少ないことからプラズマ密度の空間分布推定は行われていなかった。しかし、先行研究（尾上卒業論文）で、二点法に適した距離よりも遠い距離にある日本子午面上の 2 つの観測点ペアでプラズマ密度の推定に成功した。そこで私は日本子午面上にある全ての観測点で最も緯度が近いペアを作りプラズマ密度の推定を行う。FLR は昼側で観測されるので、日本子午面上のプラズマ密度の空間分布が分かれば、いつでもアメリカ、ヨーロッパ、日本の３つの子午面の

どれかは昼側に位置することになり、プラズマ密度を連続的に推定できる。

これまでのところ、現存する磁場観測点の中から緯度方向に隣接する観測点ペアを選ぶプログラムを作成し、先行研究（尾上卒業論文）と同じ方法でその全てのペアのデータの二点法解析を試行した。その結果で得られた課題から、FLR判定のためのプログラムを改良し、先行研究（尾上卒業論文）で FLR がはっきり見られた日（2011 年 07 月 09 日）のデータの解析を行った。結果として、3 観測点ペア（CAN-HOB,MSR-ZYK,PTK-MGD）で FLR が観測されたので、そこで得られた FLR 周波数からプラズマ密度を推定した。

当初、PTK-MGD の中間位置（中点）と MSR-ZYK の中点の L 値が近い事から、2 ペアで推定したプラズマ密度が近い値になると予想していたが、10 倍ほど離れた値になった。これに対し、上記の密度に対応する L 値が中点の L 値と異なる可能性を考え、ペアの 2 観測点の L 値間隔を 100 分割し、その各点でプラズマ密度を推定し、その密度範囲を求め、それが衛星観測に基づく密度モデル [Gallagher et al., 2000] での同じ L 値範囲での密度範囲と重なるか調査するという方針をたてた。

現在、モデルとの比較をする前段階として 2011 年の全ての観測点ペアの全ての日で FLR 観測の有無を調べている。その際に FLR の判定の為に周波数方向や時間方向のスムージング幅を調整し、ノイズを FLR だと判定してしまわないようにし、更に FLR だと判定された時間範囲で振幅比と位相差 (二点法で使用) の周波数依存性のグラフを目視確認することで、FLR の特徴を正しく判定できるようにしている。

本発表では、FLR、二点法の説明、解析方法、私の研究で新しく FLR が観測された観測点ペアを紹介する。

# サブストームに伴う磁気擾乱の子午面内伝播：地上衛星多点観測

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# Propagation of substorm-associated magnetic fluctuations in the meridional plane: Multipoint ground-satellite observations

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The propagation of substorm-associated magnetic fluctuations (e.g., dipolarizations and Pi2 pulsations) has been investigated by many researchers, but the propagation in the meridional plane is not well understood because the coverage of satellites in middle-latitude magnetosphere has not been enough. The QZS-1 satellite, which has a quasi-zenith orbit with an inclination of 45$^o$, an apogee of 6.6 Re, and an orbital period of 24 h, stays the middle-latitude magnetosphere in the close meridian of the MAGDAS/KTN magnetic observatory (AACGM MLAT=71.0$^o$) located near the QZS-1 footprint, and the ETS-VIII geosynchronous satellite.

We examined a substorm event during July 09, 2013 at 15:00-16:00 UT. During the event, QZS-1 was located at 31$^o$ MLAT and 23.5 h MLT. The ETS-VIII, THEMIS-D (a radial distance of ˜10 Re) and THEMIS-E (a radial distance of ˜7 Re) satellites were located near the equator in the similar magnetic meridian. The dipolarization was first observed by THEMIS-D at 10 Re at 15:14:30 UT. Then, ˜1 min later, some magnetic changes were observed by ETS-VIII and THEMIS-E. At the same time, the Pi2 pulsation was observed at the MAGDAS/KUJ magnetic observatory at low latitudes (AACGM MLAT=27.1$^o$). These indicate the inward propagation from 10 Re in the equatorial plane. QZS-1 observed a strong azimuthal magnetic field fluctuation 15 min after the first dipolarization at THEMIS-D, indicating outward (poleward) propagation from THEMIS-D. On the ground, the TIK magnetic observatory (AACGM MLAT=66.8$^o$), which is close to the footprint of THEMIS-D, observed negative bay near-simultaneously with the dipolarization at THEMIS-D, while KTN observed the negative bay with a 13.5 min delay. We suggest that the large delay time of the magnetic fluctuation at QZS-1 in the middle-latitude magnetosphere was associated with the crossing of field-aligned current during the poleward expansion of the substorm current system. Interestingly, although the magnetic latitude of the QZS-1 footprint was slightly lower than that at KTN, the magnetic fluctuations started 1.5 min earlier at KTN. This means that the fluctuation propagated the ionosphere to the magnetosphere.

We will further statistically investigate delay times between QZS-1 and ETS-VIII.

# Automatic identification of FLR events in the SuperDARN VLOS data by using the Gradient methods

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The FLR (Field Line Resonance) excites the eigen-oscillation of a magnetospheric magnetic field line where the frequency of an incoming wave matches the eigen-frequency of the field line. The FLR-generated eigen-oscillation has the following unique manner of change in its amplitude and the phase: The amplitude is maximum, and the phase-change rate is maximum, at the resonance point. This feature enables the identification of FLR-driven events. They can be identified in the ground magnetic field data and the ionospheric plasma velocity data. From thus identified eigen-frequency ('FLR frequency' below) one can estimate the magnetospheric plasma density along the field line which passes through the ground/ionospheric observation point.

In this study we use the SuperDARN radar data to identify the FLR: For each radar beam, the ionospheric plasma Velocity along the Line of Sight (VLOS) of the beam is obtained. Unlike the ground magnetometer data, the SuperDARN data is two-dimensional, enabling two-dimensional estimates of the magnetospheric equatorial plasma density and magnetospheric region identification.

To achieve that, it is important to identify as many FLR events as possible. However, overlapping non-FLR perturbations often hide FLR events. As a countermeasure to this problem, the Gradient methods (general name referring to both the amplitude-ratio and the cross-phase methods) have been applied to the ground magnetometer data; this method cancels out the overlapping perturbations by dividing the data from a magnetometer by the data from another magnetometer having an adequate latitudinal distance from the other. The Gradient methods are effective since the FLR frequency tends to depend on the latitude more strongly than the overlapping perturbations.

The Gradient methods are also applicable to the SuperDARN VLOS data. The field of view of each beam is divided into Range Gates (RGs below) having the same length along the beam. VLOS is obtained for each RG. Thus, each RG can be regarded as a 'virtual observatory.'

A difficulty in identifying FLR events in the SuperDARN VLOS data is that there is very large amount of two-dimensional data, making it time-consuming to visually identify FLR events. The Gradient methods enable automatic identification more easily than analyses of VLOS itself, since the Gradient methods yield positive-then-negative two peaks in the amplitude ratio and a single negative peak in the phase difference, and the latter single peak is located between the former two peaks; this pattern is fairly easy to identify.

Another advantage of applying the Gradient methods to the SuperDARN VLOS data is that we can choose any distance between the two RGs to which the Gradient methods are applied, since, as stated above, RGs are evenly located along each beam. It is expected that there is the best distance between two RGs to identify the FLR; This distance reflects the resonance width, which is an important quantity reflecting the diffusion and dissipation of the FLR energy.

We have been developing a computer code to automatically identify FLR events, and checking its preciseness by comparing the identified FLR events with visually identified FLR events. So far, we have applied the code to an FLR event visually identified at a few locations (each location is specified by a set of a beam number and an RG number) of two radars (HAN and PYK). For the most of those locations, the current version of the code has identified the FLR. It has also identified locations missed by visual inspection. Furthermore, it has found a location where the FLR signal was possibly masked by overlapping perturbations. For HAN, the best distance between two RGs was two in the RG number, corresponding to the latitudinal distance of 80 km. We also plan to apply the code to other SuperDARN radars.

# One-to-one correspondence between the vertical evolution of AKR and global high-correlation Pi 2: ARASE and MAGDAS observations

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At the onset of substorms, various phenomena appear different areas of the magnetosphere. Pi 2 and auroral kilometric radiation (AKR) are detected in a wide extent of the magnetosphere, and thus those are accepted as the indicators of substorm onsets [e.g. *Saito*, 1969; *Gurnett et al.*, 1974]. AKR is believed to emanate from the auroral acceleration region, and the frequency of AKR is almost equal to the electron gyro-frequency of the region. Therefore, we can remotely monitor the altitude of AKR occurrence region with AKR frequency [e.g., *Gurnett and Anderson*, 1981; *Morioka et al.*, 2007]. It also means that vertical evolution of auroral acceleration region can be remotely diagnosed with temporal variation of AKR frequency range. *Morioka et al.* [2009] investigated AKR dynamics, and presented that there exist two-stage vertical evolution of AKR and auroral acceleration region.

Global high-correlation Pi 2 is observed on the night side and in a wide latitudinal range from high-latitude to the magnetic equator with high-correlation waveform [*Uozumi et al.*, 2009]. *Uozumi et al.* [2011] found that global high-correlation Pi 2 is also correlated with temporal variation of AKR power. This feature was further confirmed by a comparative study between AKR observed by Arase satellite and Pi 2 observed by MAGDAS/CPMN network [*Uozumi et al.*, SGEPSS fall meeting in 2018]. According to the studies of *Uozumi et al.* [2009, 2011, 2016], oscillation of global high-correlation Pi 2 is synchronized with the oscillation of the field aligned current (FAC) of the substorm current wedge (SCW). *Morioka et al.* [2009] suggested that two-stage vertical evolution of auroral acceleration corresponds to the two-step reinforcement of the FAC of the SCW. So, it is expected that there exists some correspondence between global high-correlation Pi 2 and vertical evolution of AKR.

In this study, we conducted a comparative study concerning temporal variation of AKR frequency range 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 searched for AKR events during the interval from April to October 2017, and 40 AKR events were selected. It is found that 33 out of 40 events exhibited that the maximum altitude of the AKR range ($A_{max}$) modulated in the Pi 2 period range, and temporal variations of $A_{max}$ tend to be correlated with global high-correlation Pi 2. Our observation suggests that one-to-one correspondence between each pulse of vertical evolution of AKR, FACs of SCW and global high-correlation Pi 2.

# あらせ衛星が観測したプラズマ圏内外の Pi2 地磁気脈動

# 寺本 万里子 [1]; 松岡 彩子 [2]; 笠原 禎也 [3]; 笠羽 康正 [4]; 熊本 篤志 [5]; 土屋 史紀 [6]; 松田 昇也 [7]; 能勢 正仁 [8]; 野村 麗子 [9]; 栗田 怜 [10]; 小路 真史 [10]; 今城 峻 [11]; 三好 由純 [10]; 篠原 育 [12]
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# Pi2 pulsations observed by the Arase satellite inside and outside the plasmapause

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The spatial structure of Pi2 pulsation relative to the plasmasphere has been studied using the magnetic and electric field observed from the equatorial orbiting satellite in the inner magnetosphere by Takahashi et al (2003; 1995). They showed that the nightside Pi2 pulsations in the inner magnetosphere, which have high coherence with those at low-latitude ground station, are dominated by the poloidal component (the radial and compressional components for the magnetic field and azimuthal component for the electric field). The amplitudes of the compressional magnetic field has maximum and azimuthal electric field and the compressional magnetic field have maximum and minimum in the vicinity of the plasmapause, respectively. The phase of the azimuthal electric field relative to low-latitude Pi2 pulsations on ground is 90 degrees in the plasmasphere. The radial profile of the amplitude and phase of Pi2 pulsations can be explained by a plasmaspheric cavity mode resonance.

However, the latitudinal structure of Pi2 pulsations in the electric field has not been examined. We investigate the latitudinal characteristics of off-equatorial Pi2 pulsations on the nightside and their relation to the plasmapause using the magnetic field measured by the fluxgate magnetometer measured by the Magnetic Field Experiment (MGF), the electric field measured by the Electric field Detector (EFD), and electron density derived from the spectra measured by the High Frequency Analyzer (HFA) from the Arase satellite.

# Arase observation of the source region of auroral arcs and diffuse auroras in the inner magnetosphere

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Auroral arcs and diffuse auroras are common phenomena at high latitudes, though characteristics of their source plasma and fields have not been well understood. We report the first observation of electric and magnetic fields and electron and ion spectral features, including their pitch-angle distributions, in the source region of auroral arcs and diffuse auroras, using data from the Arase satellite at L˜6.0-6.5. The auroral arcs appeared and expanded both poleward and equatorward at local midnight from ˜0308 UT on 11 September 2018 at Nain (magnetic latitude: 66o), Canada, during the expansion phase of a substorm, while diffuse auroras covered the whole sky after 0348 UT. The auroral arcs were characterized by purple and green emissions at the top and bottom parts, respectively. Bi-directional field-aligned electrons with structured energy-time spectra were observed in the source region of auroral arcs, while source electrons became isotropic and less structured in the diffuse auroral region afterwards. We suggest that structured electrons were caused by upward field-aligned potential differences reaching high altitudes (˜30,000 km) near Arase. The bi-directional electrons were probably caused by Fermi-type acceleration associated with the observed field dipolarization. Strong electric-field fluctuations and earthward Poynting flux were observed at the beginning of the arc crossing, and are probably also caused by the field dipolarization. The ions showed time-pitch-angle dispersion caused by reflection by mirror force. These results indicate a clear contrast between auroral arcs and diffuse auroras in terms of source plasma and fields and possible generation mechanism of auroral arcs in the inner magnetosphere.

# Estimation of the altitude of pulsating aurora emission by using five-wavelength photometer

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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 is known to show two characteristic temporal variations. One is so-called main pulsation whose period ranges from a few 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. In recent years, the altitude of ionization associated with PsA has been investigated in detail by incoherent scatter radars. Such studies indicated that the altitude of PsA ionization is slightly lower in the morning side that that in the post-midnight. However, the altitude of PsA emission has not been examined in the past. Scourfield et al. [1971] proposed a method for monitoring significant changes in the emission altitude of PsA by using the lifetime of excited state atoms O(1S) seen in the optical observations. This method is also is useful for estimating the energy of precipitating electrons causing PsA. In this study, we performed a statistical analysis of the altitude of PsA emission by applying this method to multi-wavelength optical observations of PsA.

We employed the five-channel photometer in Tromso, Norway (69.6N, 19.2E, 66.7MLAT), whose FOV is directed along the magnetic field line. The five-channel photometer measured the auroral emissions at five wavelengths (427.8 nm, 557.7 nm, 670.0 nm, 777.4 nm, and 844.6 nm) with a temporal resolution of 400 Hz. In the analysis, we extracted the time series of main pulsation at 427.8 nm and 557.7 nm and calculate the lifetime of O(1S) state by performing a cross correlation analysis between them. Then, we succeeded in deriving the distribution of lifetime showing a strong peak at 0.70 sec. This result is in good agreement with a previous study by Brekke and Henriksen [1972]. We also classified the events by magnetic local time and derived the distribution of lifetime for each MLT sector. There is a tendency that the lifetime becomes shorter as going to morning side. By using the model atmospheric density profile of O2, we derived the altitude of the 557.7 nm emission of PsA. The altitude of PsA becomes lower as going to morning side, which indicates that the energy of PsA electrons tends to be higher in the later MLT sector.

We will compare the temporal variations of the effective altitude of PsA estimated from the photometer and the altitude profile of ionization observed by the European Incoherent Scatter (EISCAT) radars at the same time. In the presentation, based on the current statistical analysis, we will discuss what controls the energy precipitating electrons of PsA.

# Computer simulations of pitch angle scattering process for pulsating aurora

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Whistler mode chorus waves cause scattering and acceleration of energetic electrons in the inner magnetosphere, and recent studies identified that chorus waves cause the pulsating aurora. The interaction processes have been modeled as diffusions in the velocity space, and the scattering rate depends on the wave amplitude. However, the recent studies indicate that the wave-particle interactions with chorus waves are non-linear process, so that it is expected that the scattering rate will not simply depend on the wave amplitude. In this study, we investigate chorus wave amplitude dependence of electron scattering using the GEMSIS-RBW simulation code. The GEMSIS-RBW simulation calculates variations of local pitch angle and energy by the imposed chorus waves. In this simulation, chorus bursts that consist of multi rising tone elements are imposed at the equatorial plane, and these bursts propagate along the field line with L= 4. We calculate the trajectory of a number of electrons with initial energy of 50 keV. At small wave amplitudes, time variations of pitch angle and energy of electrons are similar to diffusive process. At large wave amplitudes, both pitch angle and energy of electrons increase at the interaction with the first rising tone element, and then they decrease at interaction with the second rising tone element. We classify these variations due to wave-particle interaction into three categories; diffusion, phase-trapping and dislocation, by taking into consideration of the parameter rho. Here, the parameter rho indicates the ratio of the wave-induced and the background inhomogeneity effects for the momentum change of the resonant electron. When rho<< 1, variations of pitch angle and the energy of electrons are diffusive. When rho˜1, both pitch angle and the energy of electrons increase because of the phase trapping. When rho>> 1, both pitch angle and the energy of electrons decrease because of the dislocation. In the simulation, energy and pitch angles of some electrons with rho˜1 increase due to the phase-trapping, which cause increase of rho. During the second interaction, energy and pitch angles with large rho decreases due to dislocation, in which rho also decreases. During the third interactions, energy and pitch angles increase again due to the phase trapping. Therefore, variations of dislocation and phase trapping occur alternately due to variations of rho. We also calculated the number of precipitating electrons with various wave amplitudes. The number of precipitating electrons increase if the wave amplitude increases from 10 pT to 200 pT. However, as the wave amplitude increases more than 200 pT, the number of precipitating electrons decreases. From this simulation, the simple relationship between the wave amplitudes and precipitating flux is not always satisfied due to the non-linear wave particle interactions, and the depression of the precipitating flux is expected with the wave amplitude of more than a few hundred pT.

# Statistical study of EMIC wave-related electron precipitation at subauroral latitude

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Electromagnetic ion cyclotron (EMIC) waves are excited near the equatorial plane by anisotropic ring current ions. They mainly propagate along magnetic field lines and are observed on the ground as Pc1 geomagnetic pulsations. Pitch angle scattering of relativistic electrons by interaction with EMIC waves has been considered as one of the mechanisms to cause the loss of the outer radiation belt electrons. However, there are still questions left about the contribution of EMIC waves to the overall loss of radiation belt electrons and possible conditions favorable to pitch angle scattering. Here, we performed the statistical study about EMIC waves and associated electron precipitation from November 2016 to June 2018. We used a ground-based magnetometer and man-made VLF radio wave receiver installed at Athabasca, Canada. VLF radio waves propagate in the earth-ionosphere wave guide and are sensitive to ionization changes in lower ionosphere due to precipitating electrons with energies higher than 100 keV. We identified EMIC wave events with two different ways: manual inspection and an automatic detection algorithm based on Bortnik et al. (2007). At first, we manually detected EMIC wave events and electron precipitation that occurred simultaneously with the EMIC wave activity. In the period of analysis, simultaneous observation of the magnetometer and VLF radio waves were available for 286 days and we identified 162 EMIC wave events. We found that 19 of 162 EMIC wave events were clearly associated with electron precipitation (12%). Electron precipitation occurred more often on the duskside than dawnside. Also, we found that the preferential condition for electron precipitation is the main phase of geomagnetic storms.

In order to investigate which properties in EMIC waves correlate with electron precipitation, we used an automatic wave detection algorithm proposed by Bortnik et al. (2007). This technique allows us to remove incoherent noise signal from wave spectra, identify only polarized EMIC waves whose intensity is well above the background noise level, and derive quantitative spectrum information of the EMIC wave, such as wave frequency, bandwidth, and intensity. We applied this technique to the induction magnetometer data at Athabasca and confirmed that it worked successfully as designed. In addition, we found that this was also useful to distinguish broad band ELF wave events (e.g. Pi1B) from EMIC wave events. We will show statistical properties of EMIC waves derived from the automatic detection technique and their relation with the electron precipitation.

# Direct detection of nonlinear generation process of electromagnetic ion cyclotron emissions observed by the Arase spacecraft

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Electromagnetic ion cyclotron (EMIC) emissions with various frequency changes are observed by the Arase spacecraft. The EMIC rising tone wave has been previously studied by employing the wave-particle interaction analysis (WPIA) method to the spacecraft data. By the method, we obtain the phase angle between the particle and wave field to analyze the nonlinear resonant currents controlling the energy transfer and the wave frequency drift. We use the WPIA method with the Arase electromagnetic field and ion particle data to analyze the nonlinear mechanism of the EMIC emissions with different frequency evolutions. The WPIA on an EMIC falling tone emission, observed on 15th Nov, 2017, indicates that nonlinear resonant currents control the frequency decrease and the significant wave growth. The existence of the proton hill predicted by the nonlinear growth theory is shown in the phase angle distribution of the proton flux. The motion of the proton hill in phase space which forms the nonlinear resonant currents is also discussed. Concurrent generation of the rising tone emission with the falling tone emission in different frequencies with the same proton energy is also suggested by the WPIA result.

# 木星磁気圏での相対論的プロトンとEMIC波の相互作用に関するテスト粒子シミュレーション

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# Test particle simulation of relativistic protons interacting with EMIC waves in Jovian magnetosphere

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We perform a test particle simulation of interaction between relativistic protons and a coherent EMIC wave. The Earth's magnetic field cannot trap highly energetic protons above few GeV. On the other hand, in the Jovian magnetic field relativistic protons can be trapped. Assuming parameters of the Jovian magnetosphere, we find very efficient proton acceleration process by the EMIC wave. In the process of acceleration, the Lorenz factor is increased and changes the resonance condition. Hence, parallel motion of resonant protons changes from opposite direction to the same direction of wave propagation. This process results in longer resonance time than that in nonrelativistic case. We construct the nonlinear interaction theory between relativistic protons and coherent EMIC waves, and confirm that this process is the same as the Relativistic Turning Acceleration process of electrons interacting with whistler mode waves [1]. We also find that almost all protons can be trapped by EMIC waves regardless of their initial gyrophases. We analyze this phenomenon, and confirm it is due to the same scattering at low pitch angles as observed in electron-chorus interaction [2]. From these results, we find that a large portion of protons with low pitch angles can experience RTA and some of them can attain the maximum energy as large as 9 GeV.

# Arase observation of electron pitch angle scattering by Electrostatic Cyclotron Harmonic waves

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Electrostatic Cyclotron Harmonic (ECH) waves have been considered as one candidate to cause pitch angle scattering of electrons in the energy range from a few hundred eV to several tens of keV. Theoretical studies have suggested that electron pitch scattering by ECH waves is enhanced at lower pitch angle near the loss cone. Due to the insufficient angular resolution of particle detectors, it has been difficult to reveal the ECH-driven scattering based on electron measurements. This study reports on variation in electron pitch angle distributions associated with intense ECH wave activity observed by the Arase satellite. The variation is characterized by the decrease in fluxes at lower pitch angles near the loss cone, and energy and pitch angle dependence of the flux decrease is consistent with the region of enhanced pitch angle scattering rates predicted by the quasi-linear theory. This study gives the evidence for energy-pitch angle dependence of pitch angle scattering driven by ECH waves.

# 一次元、二次元および三次元磁場におけるホイッスラーモードコーラス波によって加速される高エネルギー電子のダイナミクス

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# Dynamics of energetic electrons accelerated by whistler-mode chorus waves in 1D, 2D, and 3D magnetic field models

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We evaluate the acceleration efficiencies of relativistic electrons under a 1D, 2D, and 3D model magnetic fields. We perform test-particle simulations and analyze nonlinear trapping motions of resonant electrons in each model. As a chorus wave model, we assume that a chorus wave packet generated at the magnetic equator propagates along the magnetic field to higher latitudes. When we perform simulations with the whistler mode wave, the cyclotron resonance with energetic electrons occurs at the similar timing in each model. Although we find relativistic turning acceleration (RTA) [1] to take place in each model, acceleration efficiencies of resonant electrons are different in these models. In terms of the numerical Green's function [2], we find a clear difference in time evolution of the distribution function in energy and equatorial pitch angle. The energy gap between resonant electrons and non-resonant electrons in the 1D model is slightly different from those in the 2D and 3D models. This difference is due to additional oscillations in the velocity phase space, which only occur in the 2D and 3D models. These oscillations occur because the magnitude of the magnetic field changes during one period of relativistic cyclotron motion, affecting the nonlinear trapping conditions of resonant electrons. These oscillations mainly affect number of trapped particles and we find obvious differences in the dynamics of trapped particles among simulations of different magnetic field models.

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# Pc4-5 帯 ULF 波動とのドリフト共鳴による高エネルギー電子の変動とコーラス放射の強度変調について

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# Drift resonance of energetic electrons with Pc 4-5 ULF waves and modulation of whistler-mode chorus

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Whistler-mode chorus emissions play significant roles in the acceleration and loss of energetic electrons in the magnetosphere. One of the important factors which control periodic enhancement of chorus emissions is ULF (Ultra Low Frequency) waves. Jaynes et al. (2015) reported that the periodic variations of chorus emissions associated with the toroidal and poloidal components of Pc4-5 ULF waves, while chorus emissions enhanced twice during one wave period of the ULF waves. Previous studies also suggested that enhancement of the temperature anisotropy of energetic electrons in the wave generation region should be required for the generation of chorus emissions. In order to investigate the correspondence between ULF waves and the intensity variation of chorus emissions, in addition to the wave observation, we examine variations of the flux and the pitch angle distribution of energetic electrons, which are simultaneously observed with these waves.

In the present study, we investigate the relationship between chorus emissions and ULF waves using particle and electromagnetic field observations made by the Arase satellite. We focus on the event observed by the Arase satellite from 2130 to 2200 UT on March 27, 2017. The Arase satellite was located at the magnetic local time about 04:00, the magnetic latitude about -10 degrees, and the L-value about 6 during the event. From the observation of the Onboard Frequency Analyzer (OFA) of the Plasma Wave Experiment (PWE), the Magnetic Field Experiment (MGF), the Medium-energy particle experiments - electron analyzer (MEP-e) and the High-energy electron experiments (HEP), we found one-to-one correspondence among chorus emissions, toroidal mode ULF waves and energetic electrons; chorus emissions enhanced at the timings when the toroidal component of magnetic field oscillation had a peak in the westward direction, and then the flux and the temperature anisotropy enhanced in the 40-60 keV energy range. The one-to-one correspondence is inconsistent with Jaynes et al. (2015). In addition, we evaluate the resonance energy of the observed chorus emissions using the data observed by MGF and the High Frequency Analyzer (HFA) of PWE. We estimated the resonance energy at about 20-400 keV, so it is suggested that the intensity variations of chorus emissions are caused by variations of energetic electrons.

We consider that the modulation of energetic electrons is caused by the drift resonance with the ULF wave. From the drift resonance condition of electrons with 50 keV, the azimuthal wavenumber (m-number) can be estimated as 56-81 for the equatorial pitch angle range from 0 to 90 degrees (c.f. Southwood et al., 1969). Then, the guiding center motion of electrons which resonates with the ULF wave assuming that the ULF oscillations in the electric field is 90 degrees late from those in the magnetic field, namely that the observed ULF wave is standing wave (c.f. Takahashi et al., 1996). Based on the assumed phase difference, the electric field component of the ULF wave oscillates radially outward at the timings when the fluxes of energetic electrons increase. Then the electric drift velocity is directed westward, and make the drift velocity of energetic electrons smaller. Similarly, when the electric field component oscillates radially inward, the fluxes of energetic electrons decrease, the electric drift velocity is directed eastward and the drift velocity of energetic electrons becomes larger. We suggest that the azimuthal inhomogeneity of energetic electrons due to the modulation of the drift velocity can be responsible for the observed flux fluctuations of energetic electrons and resultant intensity modulation of whistler-mode chorus.

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高エネルギー電子の大気への降り込みや放射線帯粒子の内部加速過程に関与していると考えられている。そのため、地球電磁圏の変動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。Jaynes et al. (2015) では、コーラス放射の周期的な発生はトロイダルモードならびに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が 2 回発生することが指摘されている。コーラス放射の発生には波動励起領域での高エネルギー電子の温度異方性が大きく関わっていると考えられており、周期的発生の要因を理解するためには高エネルギー電子のピッチ角分布がどのように変化するかを併せて考慮する必要がある。

本研究では、コーラス放射の周期的発生と 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

の波動・粒子観測結果を解析する。本発表では、ULF 波動とコーラス放射の同時発生が観測された 2017 年 3 月 27 日 21:30-22:00 UT のイベントに着目する。解析対象とした時間帯には、あらせ衛星は磁気地方時 04:00 程度、磁気緯度-10 度程度、L 値 6 程度の磁気赤道面付近の朝側領域に位置していた。プラズマ波動・電場観測器 (PWE) の Onboard Frequency Analyzer (OFA)、磁場観測器 (MGF)、高エネルギー電子分析器 (HEP) および中間エネルギー電子分析器 (MEP-e) の観測結果を解析した結果の観測結果を解析した結果、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、40-60keV のエネルギー帯の電子のフラックスおよび温度異方性が卓越し、さらにコーラス放射の強度が増大するという 1 対 1 の対応関係が確認された。これは Jaynes et al. (2015) で報告された対応関係とは異なるものである。また MGF と PWE の High Frequency Analyzer (HFA) の観測結果を用いて解析対象とする時間帯におけるコーラス放射の共鳴条件を検討したところ、共鳴エネルギーは 20-400 keV 程度と求められた。これらの結果から、本研究で観測された周期的なコーラス放射の発生は、ULF 波動によって引き起こされる 40-60keV の電子のフラックスおよびピッチ角分布の周期的な変動に起因することが示唆された。

さらに本研究では、高エネルギー電子のフラックスおよびピッチ角分布の変動は、高エネルギー粒子と ULF 波動とのドリフト共鳴に起因するものと仮定して、観測結果について考察する。本イベントで着目した時間帯に最も顕著な変動が観測された 50keV の電子が共鳴に寄与したと仮定して、磁気赤道面でのピッチ角が 0 度から 90 度の電子に対するドリフト共鳴条件 (Southwood et al., 1969) を検討すると、観測された ULF 波動の東西波数 (m-number) は 56-81 と見積もられる。次に、本イベント中に観測された ULF 波動を standing wave であると仮定して、ドリフト共鳴条件を満たす粒子の運動について考察する。Standing wave の ULF 波動は、電場成分の振動の位相が磁場成分の振動の位相より 90 度遅れることが知られている。(c.f. Takahashi et al., 1996) そのため本イベントで観測された高エネルギー電子のフラックスが増加している時間帯には、ULF 波動の電場成分が動径方向外向きに振動していたと推定される。このとき、ULF 波動の電場成分と背景磁場との間のドリフト速度は西向きであり、磁場勾配ドリフトする電子の速度を減少させる働きをすると考えられる。一方で、ULF 波動の電場成分が動径方向内向きに振動している時間帯には、電場ドリフトの速度は東向きであり、電子のドリフト速度を増大させる働きをすると考えられる。このように ULF 波動の電場成分の正負が東西方向に異なった構造が生じるによって電子のドリフト速度が東西方向に異方性を持ち、東西方向に電子の疎密が生じると考えられる。本イベントで観測された周期的な高エネルギー電子のフラックス変動はこのような電子の疎密の結果であると考えられ、コーラス放射の強度変動をもたらした可能性が指摘される。

# 磁気圏シース領域の磁場極小におけるホイッスラーモード波動の空間スケール

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# Spatial scale of whistler mode waves in magnetic dips in the magnetosheath

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In the terrestrial magnetosheath, intense whistler mode waves, called ’Lion roars’, are often detected around minima of semi-periodic fluctuations of magnetic field intensity. The whistler mode waves are efficiently generated near a local minimum of magnetic field intensity along a field line due to the smallest resonance velocity. If a spacecraft passes through the effective source region along the magnetic field direction, a reversal of the field-aligned component of Poynting flux is observed. One of the important but not well-understood characteristics of wave is the spatial scale of the wave. Especially, because a single plain wave approximation is one of the important assumptions for analyses of waves, it is important to understand the spatial scale for which the plain wave approximation is valid. In the present study, spatial scales of whistler mode waves in and around such Poynting flux reversals are studied using the data obtained by the four MMS (Magnetospheric Multiscale) spacecraft. Using the data during ˜7 km separation, which corresponds to ˜5-10 gyro radii of electrons with energies comparable to the temperature, the observed phase difference of the whistler mode waves among the four spacecraft were compared with the prediction by the dispersion relation of plasma waves under the cold plasma approximation using the direction of the Poynting flux and the minimum variance direction of the wave magnetic field, which corresponds to the direction of wave number vector and was calculated for each rotation of the right-hand polarized wave in the plain perpendicular to the background magnetic field. Although the agreement between the predictions and observed phase differences were good out of the Poynting flux reversal, the phase differences frequently deviated from the predictions in the Poynting flux reversal regions. This would be due to the co-existence of forward and backward propagating waves in the Poynting flux reversal regions. On the other hand, in 9 wave events with Poynting flux reversals during the interval of ˜40 km separation, the correlation of phase and amplitude among spacecraft were unclear and unstable. Thus, a few tens of electron gyro radii would be the upper limit of the spatial scale that the plain wave approximation is valid for the whistler mode waves in the magnetosheath even in the cases where the background magnetic field do not have significant small-scale structures in much larger ion-scale magnetic dips.

# MeV electrons observed at the plasma sheet boundary in the inner magnetosphere

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We report energetic electron bursts up to 1 MeV at the plasma sheet boundary observed by the Arase (ERG) satellite. Such higher energy electron bursts in the plasma sheet boundary layer have been rarely reported before. These events occur associated with substorm onsets, and they are observed when Arase enter the plasma sheet from the lobe region. The purpose of this study is to address where do the energetic electron bursts at higher latitude come from and what is the contribution of magnetotail reconnection and its associated acceleration process to the generation of the energetic electron bursts. The observed energetic electron bursts are different component from electron counter streams of 10-100 keV, which are usually observed in the plasma sheet boundary layer, and they look like substorm injections. If the observed electron bursts are due to the substorm injection, the observation cannot be explained by the standard understanding of the injection because (1) The injection occurs in downstream of the magnetotail reconnection jets (in deep inside of the plasma sheet), and (2) energetic electrons observed at the plasma sheet boundary are thought to be directly accelerated from magnetotail reconnection sites. In this presentation, we will present results of detailed analysis on the structure of the lobe-plasma sheet boundary and discuss the possible scenario of the MeV electron appearance in the plasma sheet boundary layer.

# Electric current evolution associated with the magnetic dipolarization observed by Arase (ERG) in the inner magnetosphere

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At the substorm the cross-tail current in the plasma sheet is disrupted and diverges to the field-aligned current. The current disruption is closely related to the change of the magnetic field configuration, i.e., magnetic dipolarization. Meanwhile the field-aligned current flows into the ionosphere and very possibly associated with the auroral illumination. The dynamic change of the magnetic field configuration associated with the dipolarization propagates toward the low altitudes by the magneto-hydrodynamic (MHD) waves, which are confined in flux tubes as we have showed in previous presentations. The same MHD waves should work to establish the field-aligned current flowing between the magnetic equator region and ionosphere.

The electric current configuration associated with the substorm has been studied mainly by the data from geosynchronous orbit satellites. We are studying the current evolution associated with substorm events at smaller L values observed by Arase (ERG) and its dismissal. The development of the field-aligned current is expected to affect not only the ionospheric plasma but also the energetic plasma in the inner magnetosphere. It could be most effective in the transient period of the magnetic dipolarization by the inductive effect. The plasma measurement data from Arase are examined to recognize the carrier of the field-aligned current.

In the presentation, we will show several events of the substorm and associated dipolarization events observed by Arase. We discuss the process to establish the field-aligned current closure, as well as its contribution to the energetic plasma in the inner magnetosphere.

# Longitudinal Structure of Oxygen Torus and Its Coincidence with EMIC Wave in the Inner Magnetosphere

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A recent study employing the Arase and Van Allen Probes A satellites at different MLT revealed that 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 [Nose et al., 2018]. In the reported event, Arase flying in the morning sector detected an enhancement of the average plasma mass up to ~3.5 amu around L=4.9-5.2, while Probe A flying in the afternoon sector observed no clear enhancements in the average plasma mass.

In the present study, we focus on simultaneous observations of the magnetic field and plasma waves made by the Arase and Van Allen Probe B satellites on September 12, 2017. Orbital configuration of the satellites is opposite to that in the study by Nose et al. [2018]; that is, Arase started from afternoon, traversed dusk with an apogee around MLT = 19 hr, and arrived at pre-midnight, while Probe B was flying from morning to afternoon through noon. It is found that (1) only Probe B observed a clear enhancement of the average plasma mass up to ~4 amu around L~3.6 and MLT~9.2 hr; and (2) a H+-band electromagnetic ion cyclotron (EMIC) wave appeared just outside the plasmapause where M is larger than approximately 2 amu. From the average plasma mass and the lower cutoff frequency of the EMIC wave, we can estimate that the oxygen torus for this event composes of 79.9% H+, 4.3% He+, and 15.8% O+. This result implies that the crescent-shaped torus or the pinched torus is a general feature of the O+ density enhancement in the inner magnetosphere. Using the linearized dispersion relation for EMIC waves, we calculated the growth rate of the H+-band EMIC wave, and found that cold O+ ions increase the growth rate of the H+-band EMIC waves. We suppose that the oxygen torus in the inner magnetosphere can lead to excitation of the H+-band EMIC waves, resulting in their simultaneous observations.

# Extremely collimated electron beams observed by the ERG satellite

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The ERG satellite occasionally observes extremely collimated field aligned electron beams in high latitude regions at L˜6 or farther. The electron beams are mainly flowing in the anti-parallel direction in the northern hemisphere and in the parallel direction in the southern hemisphere, i.e. in the direction away from the ionosphere. Observations also show that the beams are frequently counter-streaming along the field line. Phase space density distributions measured by the LEPe instrument reveal that the beams are collimated within several degrees in pitch angle, which indicates beam electrons of the ionospheric origin. According to a statistical study of beam events, the beams are seen more frequently when the AE index is larger. In addition, field lines of the beams can be traced back to the auroral oval on the ionosphere. The observational results suggest that the extremely collimated electron beams are most probably accelerated upward by a downward electric field in response to auroral activities and are streaming along the field line. Upward flowing electrons in low altitudes and also tailward electrons in the tail have been reported, and this beam observation at ERG locations can complete a global picture of electron beams.

# あらせ衛星によって観測された孤立静電ポテンシャル構造

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# Isolated electrostatic potential structures observed by the Arase satellite

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Plasma Wave Experiment (PWE) onboard the Arase satellite succeeded in observing several types of isolated potential structures. They are completely electrostatic. Since they move (possibly along the ambient magnetic field) in a specific velocity, the plasma wave receivers can observe their spatial potential variations as electric field waveforms in the time domain. The observed waveforms are classified into several types including electrostatic solitary waves (ESW) discovered by the Geotail spacecraft in the geomagnetic tail region in 1994. It is difficult to identify propagation velocities of electrostatic electric waves in general. However, the Arase PWE has the capability to identify the propagation velocities of electrostatic structures. The function is so-called "interferometry mode." This mode makes use of one set of the dipole antenna as two monopole antennas. The individual receiver is connected with each monopole antenna. The time lag of observed waveforms between two monopole antennas shows the propagation velocity. Once the propagation velocity is identified, it becomes possible to convert the observed electric field waveforms into the spatial potential structures. In the present paper, we pick up events in which isolated electrostatic potential structures are observed by the Arase satellite and estimate the special potential structures by applying the interferometry methods.

宇宙空間プラズマ中におけるポテンシャル構造の存在は、粒子の加速・減速を議論する上で非常に重要である。その構造が科学衛星と相対速度をもって移動している場合は、電界の変化として、衛星に搭載したプラズマ波動観測器で捉えることができる。本研究ではジオスペース探査衛星あらせ（ERG）により観測された電界波形から、軌道上に分布するポテンシャル構造の解析を目的としている。

宇宙空間に存在するポテンシャル構造については、すでにいくつかの衛星観測によってその存在が知られている。例えば、磁気圏尾部観測衛星 GEOTAIL により発見された静電孤立波（ESW: Electrostatic Solitary Waves）は、高速で流れる電子ホールによる正の孤立ポテンシャルであることがわかっている。また、ダブルレイヤーとなるポテンシャル構造などがあらせ衛星と同様の軌道をとる RBSP 衛星などでも観測されている。通常、ポテンシャル構造は、1 機の衛星による観測ではその空間スケールやポテンシャルの大きさを捉えることができないが、あらせ衛星ではインターフェロメトリモードをもっており、これを使用することにより、ポテンシャル構造が流れる速度を求めることができる。そして、その速度を利用して、観測される電界波形をポテンシャルの空間構造になおすことが可能となる。本研究では、あらせ衛星で観測されるポテンシャル構造をインターフェロメトリモードによる観測を中心に解析し、その特徴、種類、分布などを明らかにして、内部磁気圏におけるポテンシャル構造の役割を考察する。

# 衛星帯電緩和ビームによるプローブ電場計測干渉に関する粒子シミュレーション

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# Effects of Active Ion Emission on Double-probe Electric Field Measurements

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Spacecraft is subject to electrostatic charging due to plasma particle impact as well as photo- and secondary electron emission. Spacecraft has a positive potential in tenuous plasmas of the outer magnetosphere, because the photoemission should be a dominant current source. The spacecraft charging will interfere with in-situ measurements of low-energy particles and electric fields, and thus optimal designs to minimize the effects have been a long-standing issue. As one of such techniques, the Active Spacecraft POtential Control (ASPOC) uses active emission of heavy ions from the spacecraft to reduce a spacecraft potential, and is in practical use, e.g., in the Cluster and MMS missions. Although the technique has been proved to have a preferable effect on low-energy ion measurements, its side effects such as modification of potential structures and the associated spurious electric fields have been an unresolved issue.

A spacecraft with two pairs of probe extension booms is placed at the center of a simulation space that is filled with magnetospheric tenuous plasmas. Within the spacecraft spin plane, a heavy ion beam is emitted from the spacecraft in the directions of 45 and 225 degree with reference to a certain probe extension direction. The simulation model mimics ASPOC flown on the MMS satellite. The probe electric field measurement is numerically simulated by acquiring a potential difference between the probes attached at the boom tips. In this simulation, we consider the plasma convection to examine the effect of plasma wakes. Several considerations are performed on the angle between the flow and probe extension directions in order to consider the field measurements during a spacecraft spin. Consequently, the simulations predict that the probes will measure a complex electric field waveform in the spacecraft spin frame. The electric field waveform is influenced by the wake formed behind the charge relaxation beam, in addition to that behind solid structures of the spacecraft and booms. We will present the initial results on the significance of the wake formed behind the charge relaxation beam and its spin angle dependence.

人工衛星が宇宙環境に置かれると、プラズマ荷電粒子の流入、もしくは光電子および二次電子の放出によって、衛星表面は帯電する。地球外部磁気圏は比較的希薄なプラズマで満たされているため、光電子放出電流が支配的となり、衛星は正に帯電する。衛星帯電は、科学衛星による低エネルギーの粒子計測や、プローブを用いた電界計測に影響を与えることが知られており、観測機器開発の初期から様々な対策が考案されてきた。そうした対策の一つに、衛星からの能動的なプラズマ放出による帯電緩和 (Active Spacecraft Potential Control: ASPOC) が挙げられる。衛星が正に帯電している場合には、インジウムなどの重イオンを機外に放出することで、衛星電位を下げるのが基本的なアイデアである。こうした装置は Cluster や MMS 衛星で実用化され、希薄プラズマ環境下での低エネルギーイオン観測にとり好ましい結果が確認された。一方で、イオンビームの能動的放出は衛星周辺の電位構造を変化させることが予想され、プローブによる電位および電界計測に干渉する可能性があるが、その影響について定量的な評価はまだなされていない。

そこで我々は、3 次元のプラズマ粒子シミュレーションを用いて、帯電緩和ビーム放出下の衛星近傍の静電環境評価を開始した。磁気圏尾部を想定した希薄プラズマで満たされたシミュレーション空間内に、スピン面内に 2 対のプローブ伸展用ブームを備えた衛星を配置した。MMS 衛星を想定し、スピン面内において、あるプローブ伸展方向を基準に、45 度と 225 度の方向に帯電緩和ビームを射出した。ブーム先端に仮定したプローブ間の電位差を取得することで、現実のプローブ電界計測を模擬した。本シミュレーションではプラズマの対流を考慮し、プラズマウェイクの影響に着目した。流れの方向とプローブ伸展方向の間の角度を可変パラメータとして複数の計算を実施し、衛星のスピンに伴って、プローブで計測される電界を数値的に模擬した。シミュレーションの結果から、スピンに伴ってプローブ間に複雑な電界波形が生じることが確認された。この電界波形には、衛星やブームなどの構造体のウェイクに加えて、帯電緩和ビームの後方に形成されるウェイクが影響していることが判明した。発表では、帯電緩和ビームの後方に形成されるウェイクの強度とスピン角度依存性に関する初期計算結果を紹介する。

# Validation of High-energy electron detector simulator for the HEP instruments onboard Arase

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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 have developed a detector simulator using the Geant4 toolkit. Especially contamination due to high energy particles must be considered quantitatively. We have also been working on electron irradiation experiments using HEP detector modules which are almost the same as the flight model in order to compare detailed simulations and experimental data.

We will present a comparison between results from the electron irradiation experiments and those from the detector simulator. And we will discuss its influence on the interpretation of the observational data obtained in orbit.

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

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Inter-channel comparison of electron fluxes measured by the high-energy electron experiments (HEP) instrument onboard the Arase satellite has been conducted with a focus on the apparent non-uniformity in detection efficiency and relative offset of the background flux level between the channels. On the basis of the two-year data since the start of the prime mission, we have derived empirically relative efficiencies for all azimuthal channels of the HEP-L module. In the course of the inter-channel comparison, we also confirmed that a few channels are significantly blocked by some structures on the surfaces of the satellite and/or those extending from the satellite body. Considering all of those results, we have finally derived relative correction factors for azimuthal channels . The new set of correction factors significantly improves angular distribution spectra, such as pitch-angle spectra of particle flux. The efficiency correction will be incorporated into Level-2 version 2 data products and the new data set will be made available soon.

# あらせ衛星で取得した波形観測データのゲインと位相の較正法

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# Study on calibration method for the gain and phase of electric waveform data acquired by the Arase satellite

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The Plasma Wave Experiment (PWE) on board the Arase satellite measures electric field from DC to 10 MHz, and magnetic field from a few Hz to 100 kHz. The waveform capture (WFC) is one of subsystems of the PWE and is dedicated to measuring waveform for the two electric components and three magnetic field components. WFC aims at detailed observation of plasma waves in the VLF range such as chorus, hiss and lightning whistler in the Earth's inner magnetosphere, but it is necessary to be corrected for gain and phase using frequency responses of sensors and receivers. In particular, the electric field data needs to be corrected in consideration of the antenna impedance of the electric field sensor. Currently, this is corrected assuming a vacuum, but the characteristics of the impedance change depending on the electron density and temperature at the observation point. In the present paper, we introduce how to calibrate the gain and phase of electric waveform data using natural waves.

In this research, the effect of the impedance is estimated by calculating the refractive index value of the observed chorus by two different methods and comparing the difference between the two refractive indexes.

In the first method, we calculate the refractive index by using the observation data. First, we convert the five components of electric and magnetic waveforms into complex waveforms by Hilbert transform. Next, the refractive index is calculated using these complex waveforms and wave normal vector (k vector) of a chorus element estimated using only three magnetic field components. We calculate the refractive index using the frequency range in which the chorus wave is observed. It is noted that the obtained refractive index is a complex number. In another method, using the wave normal vector described above and the electron density at the observation point, we calculate the theoretical refractive index which satisfies dispersion relation of whistler mode wave. In the calculation, we select the frequency with the largest intensity in the chorus element. By obtaining the ratio of the absolute values of the two refractive indexes, it is possible to correct the gain of the electric field component. On the other hand, the phase of the electric field component can be corrected by calculating the argument of the complex refractive index obtained by the former method.

In this study, we evaluate the estimated results by comparing with the antenna impedance derived from the software calibration function implemented in the PWE.

あらせ衛星に搭載されているプラズマ波動・電場観測器 (PWE) では DC から 10MHz までの電界成分と数 Hz から 100kHz までの磁界成分を観測している。PWE の受信器の一つである波形捕捉受信器 (WFC) では 20kHz までの電界 2 成分、磁界 3 成分の波形データを取得する。WFC は、地球内部磁気圏内でコーラスやヒス、雷ホイスラ等の VLF 帯のプラズマ波動の詳細観測を目的とするが、取得データは、センサや受信器の周波数特性を使って、ゲイン・位相を補正しなければ正しい波形データを得ることができない。特に、電界データは、電界センサのアンテナインピーダンスを考慮して補正する必要がある。現在は真空中を仮定して補正を行っているが、実際は観測点における電子密度や温度によって、インピーダンスの特性は変化する。本研究ではこのインピーダンスを自然波動から推定する方法について検討を行う。

本研究では、観測されたコーラスについて、屈折率の値を二つの異なる方法で導出し、その差異を比較することで、アンテナインピーダンスの影響を推定する。一つ目は、観測データを用いて屈折率を導出する方法である。まず、電磁界 5 成分の波形データを複素波形に変換し、電磁界両方の複素波形と、磁界 3 成分のみを用いて求めたコーラスの伝搬ベクトル（k ベクトル）の推定値を用いて屈折率を導出する。その際、コーラス波動が見られる帯域のみを用いて計算を行う。また得られた屈折率は複素数になる。もう一つは、前述したコーラスの伝搬ベクトルと、観測点における電子密度を用いて、波動の分散関係から理論的に屈折率を求める方法である。導出においては、観測されたコーラスエレメント内の最大強度となる周波数を用いる。このようにして導出した二つの屈折率から、絶対値の比をとることで電界成分のゲイン補正が可能となる。また、前者の方法で求めた複素屈折率の偏角が、電界成分の位相値に相当する。本研究では推定された結果を PWE 内に実装されたソフトウェア較正機能から得られたインピーダンスの推定結果と比較することで評価を行う。

# あらせ衛星で観測されたコーラス波動の自動検出手法の検討

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# Development on auto detection of chorus elements observed by the Arase satellite

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Wave-particle interaction plays an important role in affecting the environment in geospace. Particularly chorus waves are closely correlated with the physics in the Van-Allen belt. Chorus consists of independent elements with their duration less than 0.5s, and is classified into several types such as rising tone and falling tone according to its frequency pattern. The frequency range of chorus measured by the Arase satellite is nominally around a few kHz. In the present study, we introduce an image processing algorithm in order to detect the elements of chorus and distinguish their spectrum patterns in a systematic way.

We processed the images of spectra transformed by FFT from continuous waveform data observed by the PWE (PWE; Plasma Wave Experiment) on board the Arase satellite. Regarding the image processing, we adopt image masking, smoothing, second derivative, erosion and dilation, labeling, and aspect map. The second derivative filter is designed optimizing the image data. Aspect map is used to identify the frequency pattern of the chorus element whether it is a rising tone chorus or a falling tone chorus. The others are used to identify the time and frequency of the chorus elements. The followings are the sequence for our automatic detection algorithm. (1) smoothing and masking the original spectrogram, (2) calculating the second derivative, (3) performing erosion and dilation to the binary data, and (4) masking the original data according to the result from the process (3). As a next step, we process the following sequence to determine the frequency pattern: (5) masking the smoothed data according to the result from the process (3), (6) labeling each chorus element, (7) applying the aspect map algorithm to each element. In the process (7), we make an aspect map calculating the gradient Hx along the x-axis (time) and Hy along the y-axis (frequency), respectively in the spectra image. Next we calculate $T = Hx * Hy$. In case T is positive, the tilt direction is upper left or lower right. While T is negative, the tilt direction is lower left or upper right. Finally we identify the chorus element as rising tone when the number of cell with positive T is larger than the negative one, and vice versa.

In the present paper, we demonstrated that we could successfully detect the chorus elements with sufficiently large intensity against the background noise level, and distinguish rising tone and falling tone.

地球周辺のプラズマ波動や粒子は、宇宙環境を左右する大きな因子であり、そのうちの一つであるコーラスは、放射線帯の物理に深く関与する重要な波動である。コーラスは、時間とともに周波数変化する特徴的なスペクトルを持ち、周波数が上昇するライジングトーン、下降するフォーリングトーン等に分類される。個々のエレメントは孤立しており、各エレメントの継続時間が 0.5 秒以下で、あらせの飛翔高度では数 kHz 帯に多く観測される。本研究では、コーラスのエレメントの特徴を画像処理のアルゴリズムを応用して同定し、エレメントの分離と周波数変動の傾きを自動判定することを試みる。

本研究では、あらせ衛星 PWE で観測した連続波形観測データを周波数解析したスペクトル画像を用いてコーラスエレメントの抽出を試みた。具体的には、スペクトル画像に、マスク処理・平滑化・二次微分・膨張と収縮・ラベリング・斜面方位図の 6 つの画像処理のアルゴリズムを適用した。斜面方位図はコーラスの周波数変動の方向の判別に使用し、他のアルゴリズムはコーラスの検出に使用する。なお、二次微分は使用データに合わせた独自のフィルタを使用する。コーラスの時刻・周波数を特定するために、(1) 平滑化とマスク処理、 (2) 二次微分、 (3) 二値化したデータの膨張・収縮処理、(4) 手順 (3) で作成したデータを用いて元データのマスク処理、という一連の処理を順次行った。また、周波数変動の方向を同定する処理として、 (5) 手順 (3) で作成したデータを用いて、平滑化後のデータをマスク、 (6) ラベリング処理によって、エレメントを一つづつ分離、(7) 斜面方位図のアルゴリズムを適用、という手順を行った。斜面方位図では、スペクトル画像における x 軸（時刻）方向の傾き Hx と y 軸（周波数）方向の傾き Hy を求めた。$Hx * Hy$ の値が正であれば左上から右下方向斜面、負であれば左下から右上方向の斜面であることを利用して、正のセルの数が多いエレメントはライジングトーン、逆に負のセルの数が多ければフォーリングトーンと判定した。

コーラスのエレメント抽出については、背景の雑音レベルより十分に強いコーラスについては良好な結果が得られた。また、斜面方位図を利用することで、ライジングトーンとフォーリングトーンの判別が可能であることを確認した。

# あらせ衛星搭載の PWE/WFC によって計測した波形データの較正手法の評価

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# Evaluation of the calibration method of waveform data measured by the PWE/WFC on board the Arase satellite

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The Waveform Capture (WFC) is a receiver of the Plasma Wave Experiment (PWE) on board the Arase satellite. The WFC measures the electric and magnetic field waveform in the frequency range from a few Hz to 20 kHz and aims to detect plasma waves related to the electron acceleration, such as whistler mode chorus emissions. A new type of instruments named Software-type Wave-Particle Interaction Analyzer (S-WPIA) is also installed in the Arase satellite to measure energy and momentum exchange between plasma waves and particles directly and quantitatively. The S-WPIA requires the high-accuracy calibration of both amplitude and phase of waveform data with a reasonable processing load so as to realize the onboard calibration. Generally, the signal passed through a receiver should be transformed into spectra in the frequency domain, be calibrated using a transfer function of the system, and be inverse-transformed into the time domain. In the case of actual data processing, raw data is filtered by a window function in the time domain before applying short time Fourier transform to reduce the side lobe effect. However, a non-negligible gradient of a transfer function causes the phase shift of a window function and thereby calibrated waveform data are distorted in the time domain. To eliminate the effect of the window function shift, we suggest several methods to calibrate waveform data accurately by performing simulation using simple sinusoidal signal and transfer function. In consequence, the following two methods can reduce error to less than several percent of the input wave amplitude; (1) a Tukey-type window function with a flat top region and (2) modification of the window function by estimating a phase shift at each frequency from the gradient of a transfer function. We also apply these methods to actual data of the wave electric field observed by the PWE/WFC and compare the calibrated data using the proposed methods with a limited data window to the data calibrated using a whole data points with a rectangular window function. We conclude that the difference is less than several percent of the amplitude at the frequency range of a few to ten kHz and that, on the contrary, the phase of waveform is slightly shifted in the lower frequency range due to the limited data window. We need to take account of the relation between the frequency range of the electromagnetic waveform and the window function in interpreting observation results.

# Development of ASIC-based fluxgate magnetometer (AFG) and its flight proof on RockSat-XN sounding rocket

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For the magnetometer for space missions, reduction of its size and weight results higher potential of installation into the satellite and leads renewed scientific achievement, for example multi-point observations. In order to achieve such an ultra-small and light magnetometer with power saving and low noise, we developed an ASIC-based Fluxgate magnetometer (AFG) which includes analog-ASIC in its circuit.

AFG is in the instrument package called PARM (Pulsating AuRora and Microburst) which is aimed to investigate the mechanism of microburst by in-situ observation. PARM joined one of the Ground Challenge Initiative, RockSat-XN program (or G-CHASER student rocket), in order to investigate the microburst and its dependence on pulsating auroras. AFG and other three instruments, HEP, MEP, and AIC of PARM were installed into the NASA's RockSat-XN sounding rocket at Wallops flight facility of NASA in August 2018. AFG is placed on the top deck of the rocket where is suitable for avoiding the noise from rocket systems itself. On 13 January 2019 at 09:13:00UT, the rocket was successfully launched from Andoya space center (69.29N, 16.01E) in Norway and reached its altitude of 174km. During this flight, AFG has successfully observed the geomagnetic field. In this presentation, we show the calibration and flight data of AFG to discuss its performance in the space environment.

# FACTORS 搭載可視・紫外カメラならびにオーロラロケット LAMP 可視カメラによる微細-広域オーロラダイナミクス

# 坂野井 健 [1]; 八木 直志 [2]; 平原 聖文 [3]; 浅村 和史 [4]; 三好 由純 [5]; 大山 伸一郎 [5]; 津田 卓雄 [6]; 斎藤 義文 [7]; 細川 敬祐 [6]; 渡邉 智彦 [8]; 山内 正敏 [9]; Park Inchun[10]; 小嶋 浩嗣 [11]; 北村 成寿 [12]; 松岡 彩子 [13]
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# Auroral dynamics revealed by new visible and ultraviolet imagers for a future satellite FACTORS and sounding rocket LAMP

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We report science subjects, instrumental design, development plan and identification of issues of the visible and ultraviolet imagers for a future satellite project called FACTORS that aims to understand the coupling processes in the terrestrial magnetosphere/ionosphere/thermosphere and the acceleration and transportation of the space plasma and neutral atmospheric particles. FACTORS stands for Frontiers of Formation, Acceleration, Coupling, and Transport Mechanisms Observed by Outer Space Research System that is proposed as a multi-satellite formation flight mission. This will be a community exploration mission in Japanese space research, and the working group was approved by ISAS/JAXA. In this presentation, we mainly focus on visible and ultraviolet remote imaging of auroral and airglow emissions. A visible imager (VISAI) on FACTORS will measure small-scale auroral structures at a wavelength of auroral prompt emission at N2 1st PG with high-time (˜0.1s) and high-spatial (˜1 km) resolutions using a science CMOS or EMCCD. The FOV of 8 x 8 deg.ˆ2 covers a 400 x 400 kmˆ2 area viewed from 3000 km altitude. Combined with particle and electric/magnetic field data by FACTORS, we will reveal the time and spatial variations of acceleration/scattering process in the complicated magnetosphere-ionosphere coupling system, and the high-spatial and high-time resolution imaging is essential to understand small-scale variations of Alfven aurora, pulsating aurora, etc. Currently, we design a wide (˜40 x 40 deg.ˆ2) FOV far-ultraviolet imager (FUVI) which covers ˜2500 x 2500 kmˆ2 area viewed from 3000 km altitude. We plan to adopt a filter wheel in FUV imager to change the wavelengths between O 135.6 nm and the N2 LBH band at 140-160 nm. Wide-field multi-wavelength FUV images enable us to examine large-scale auroral dynamics like westward-travelling surge during substorms, omega-bands, and provide us to understand the global thermospheric activity from the O/N2 airglow ratio. We examined precise orbit analysis for FACTORS, considering rocket launch conditions, inclination, locations of apogee and perigee, and feasibility of simultaneous image-particle measurement in the winter hemisphere. We also plan to perform specific studies for CMOS/EMCCD detectors suited for this mission, and carry out radiation tests of detectors.

Related to FACTORS, we are now carrying out the ongoing sounding rocket project LAMP which is scheduled to be launched at Poker Flat research range in winter of 2020 to clarify microburst; short-term relativistic electron precipitation probably associated with pulsating aurora. We are developing two CMOS cameras called AIC2 installed on a despun platform of the LAMP rocket to derotate rocket spin. One camera AIC2-S1 measures N2 1st PG emission with a narrow-FOV and fast lens (F-number=0.95, f=17 mm, FOV=28 x 28 deg.ˆ2), and another camera AIC-S2 measures OI 844.6nm emission with a wide-FOV (F-number=1.6, f=3.5 mm, FOV=106 x 106 deg.ˆ2). Both cameras used the ZWO ASI-180MM CMOS detector. AIC2-S1 will take fine structure of pulsating aurora in the region more than 100 x 100 kmˆ2 around the magnetic footprint with a few kilo-meter resolution, while AIC2-S2 will cover from the magnetic footprint to the limb slantly looking westward from the rocket to avoid dawn light contamination and obtain an altitude distribution of pulsating aurora in the both of E- and F-regions. Both cameras have a high frame rate with 10Hz sampling. The imaging data combined with precipitating electron data in the wide energy range enable us to investigate the relativistic electron precipitation microbursts that is probably caused by chorus waves in the magnetosphere, and relationship to pulsating auroral emission.

# 観測機器パッケージPARM-HEPによる脈動オーロラ現象に伴う高エネルギー降り込み電子の観測

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# PARM-HEP Observation of Precipitating High Energy Electrons over Pulsating Aurora

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The phenomenon called microburst that radiation belt particles precipitate to the Earth's atmosphere is thought to be largely related to the dissipation of high energy electrons in radiation belt. It is suggested that this phenomenon is caused by pitch angle scattering of the magnetospheric particles by plasma waves, which is a mechanism similar to the cause of the pulsating aurora observed in the Earth's polar region. There is a possibility that the origin of microburst can be clarified by proving simultaneous occurrence of microburst and pulsating aurora, but observational verification has not been made yet.

For that purpose, we have developed a high-energy electron detector (HEP) for the observation of sub-relativistic - relativistic energy electrons that make up the microburst. HEP is designed to measure electrons between 300 keV and 2 MeV with energy resolution of 20% or less and with signal processing time of ˜5 us. Energy analysis is performed by the detection part of this instrument using SSD (Solid State Detector). Performance tests of this instrument are carried out using a sealed radiation source and a high energy electron beam line. This instrument is installed as one of the core instruments of the PARM instrument package developed for the simultaneous observation of the pulsating aurora and microburst by the international student sounding rocket experiment RockSat-XN and LAMP (Loss through Auroral Microburst Pulsation) sounding rocket experiment. We have succeeded in obtaining the flight data on 13 January 2019 from RockSat-XN sounding rocket experiment. Since the rocket was unfortunately launched on the dayside under quiet condition, microbursts cannot be detected, and the data is considered to contain contamination of protons from galactic cosmic rays, but even if it is subtracted, several hundred keV electrons are detected. On the other hand, LAMP rocket experiments are prepared for launch in winter 2020. We load an anti-coincidence counter on HEP mounted on LAMP to eliminate the effects of penetrating particles such as galactic cosmic rays. In this presentation, we will show the outline and observation results of HEP as well as the current status of the preparation for the launch of LAMP.

マイクロバーストと呼ばれる放射線帯電子が地球大気に振り込む現象は、放射線帯の高エネルギー電子の散逸に大きく関連していると考えられている。この現象は地球極域で観測される脈動オーロラと類似したメカニズムである、磁気圏電子のプラズマ波動におけるピッチ角散乱によって発生することが示唆されている。マイクロバーストと脈動オーロラの同時発生を証明することでマイクロバーストの起源を明らかにできる可能性があるが、未だ観測的な検証はなされていない。

私たちは脈動オーロラと電子マイクロバースト降下の関係性を調べるため、高エネルギー電子観測器（HEP）を開発した。HEP はエネルギー分解能 20 %以下、信号処理時間約 5 μ s で 300 keV～2 MeV の電子を計測するように設計されている。本機器の検出部では SSD（Solid State Detector）を用いてエネルギー分析を行う。この機器の性能試験は、密封放射線源と高エネルギー電子ビームラインを使って行われた。本機器は国際学生観測ロケット RockSat-XN および LAMP（Loss through Auroral Microburst Pulsation）観測ロケット実験に、脈動オーロラ・マイクロバーストの同時観測を目的とする観測パッケージ PARM の中心的機器として搭載され、このうち RockSat-XN は 2019 年 1 月 13 日にノルウェー・アンドーヤより打ち上げられた。ロケットは静穏時の昼側で打ちあげられたためマイクロバーストは検出できず、データのうちの一部は銀河宇宙線のコンタミネーションと考えられるが、それを差し引いても数 100keV の電子が検出された。一方で LAMP 観測ロケット実験は来年冬期の打ち上げに向けて準備が進められている。LAMP に搭載する HEP には銀河宇宙線などの貫通粒子の影響を除くための反同時計数部を搭載する。本発表では、HEP の概要と観測結果、ならびに LAMP の打ち上げに向けた準備の現状について説明する。

# 地球磁気圏 X 線可視化計画 GEO-X の現状

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# Status of GEO-X (GEOspace X-ray imager) mission

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GEO-X aims first observations of the dayside boundaries of the Earth's magnetosphere in the vicinity of the Moon around the next solar maximum. Soft X-ray emission below 2 keV is generated via charge exchange between high charge state solar wind ions and neutrals in geocorona. Numerical simulations predict that this emission will allow us to image dayside structures of the Earth's magnetosphere such as magnetosheaths, cusps and shock front. For this purpose, we plan a small satellite carrying a miniaturized X-ray imaging spectrometer composed of a ultra light-weight X-ray telescope and a high speed readout X-ray detector. In this paper, we describe development status and application of the new technologies for future planetary explorations.

GEO-X (GEOspace X-ray imager) は世界初の地球磁気圏の X 線撮像を目指す衛星計画であり、次の太陽活動極大が期待される 2022-25 年頃の打ち上げを目指している。太陽から吹く高速のプラズマ流である太陽風には酸素や窒素などの多価イオンが含まれ、地球周辺の超高層大気である外圏と衝突して電荷交換反応による X 線を生じる。イオンの空間

分布は、地球磁気圏の太陽側境界面の構造を反映するため、X 線は目には見えない磁気圏構造を可視化する全く新しい手段になると期待できる。

地球磁気圏からの電荷交換 X 線放射は月付近から見た場合、~10x20 度に大きく広がっていると考えられ、多くの X 線天文衛星が投入されてきた近地球軌道よりも遠くから俯瞰的に観測する必要がある。我々は本目的に特化した GEO-X 衛星計画を発案し、昨年度より JAXA 宇宙理学委員会の Working Group として活動している。現状、12 U CubeSat 約 25 kg に月付近までの高度に投入するための推進系 約 25 kg を加え、約 50 kg の衛星となる予定である。搭載機器は、限られた重量・電力リソースの中で広がった天体への高感度を実現するため、マイクロマシン技術を用いた超軽量 X 線望遠鏡と pixel 毎に読み出しが可能な半導体ピクセルセンサーという新技術を採用する。本講演では開発の現状と将来の惑星探査への応用性について紹介する。

# Feasibility of Geomagnetic Observation by 2U-size CubeSat

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Geomagnetic observation by the satellite has been conducted by many institutes to understand the global structures of the ionospheric currents. Recently, nano-satellite named CubeSat whose dimension is less than 10∗20∗30 (cm) are developed in many universities. The features of CubeSat can be characterized as a short duration of development and in the extreme low-cost.

We started a development of CubeSat under collaboration with 10 colleges to observe the small perturbation of the geomagnetic field at the LEO. Focus of the observation is to understand the global distribution of the Sq (Solar quiet) currents flowing in the dayside ionosphere, and to try an in-situ observation of the InterHemispheric Field Aligned Current (IHFAC). In particular, the IHFAC was theoretically predicted by Maeda [1974] and Fukushima [1979, 1991] to interpret the north-south asymmetry in the potential pattern. However, the fine structures and natures of IHFAC have not been well understood, although there are several observations of IHFAC from the ground magnetic observation and satellite observations (e.g. Yamashita and Iyemori, 2002, and Park et al., 2002).

In this study, we propose the 2U-size CubeSat in which the fluxgate magnetometer is installed to observe the 3D fine structures of Sq current system. The fundamental feasibility studies depending on the electric power budget, orbital life time, the communication capacity, and specification of the magnetometer show that the observation of the Sq current by CubeSat is well feasible with a short duration of the development and quite low-cost.

# MI センサを用いた地磁気微小変動のテスト観測

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# Test Observation of the Geomagnetic Perturbations by using the MI sensor

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Observation of the ionospheric current is important to clarify the structure of the ionosphere. Fluxgate (FG) sensor is usually used to measure the ionospheric current. However, in case that the magnetometer onboard the CubeSat, it is difficult to install the FG sensor due to its size and cost. In order to solve these problems, we focused on Magneto-impedance (MI) sensor. MI sensor utilizes the magneto-impedance effect in which the impedance of an amorphous wire varies with an intensity of external magnetic field. MI sensor is small size and low-cost even while the sensitivity of MI sensor is almost equivalent to the sensor. The aim of this study is to consider whether MI sensor could apply to actual geomagnetic observations, which include the Pc5 type geomagnetic pulsation.

In this study, the MI sensor which we used has an analog output range of +/- 15[V] with measuring range of +/- 50000[nT]. The voltage from MI sensor is divided by 2/3 then input to the data logger with 24-bit ADC. In order to evaluate test data by the MI sensor, we also measured the geomagnetic field and temperature by MAGDAS magnetometer, which is a Fluxgate magnetometer made by Kyushu University.

As a result, it is indicated that the MI sensor used in this study has temperature drift of 10[nT/degreeC] and considerable noise level to observe the magnetic pulsations. In this paper, we will discuss the feasibility of the calibration of the temperature drift and reduce of the noise level.

Sq 電流を始めとする電離層電流の観測は磁気圏—電離圏結合を理解するために重要である．電離層電流の観測には一般に Fluxgate（FG）センサが用いられてきた．しかし，FG センサはサイズが大きく，高価であるため，特に超小型人工衛星 CubeSat に搭載する場合，大きな制約となる．この問題を解決するために，我々は磁気インピーダンス（MI）センサに着目した．MI センサは，高周波電流が流れているとき外部磁場によってアモルファスワイヤのインピーダンスが変化する磁気インピーダンス効果を利用している．また，MI センサは FG センサとほぼ同等の感度を持ち，小型で安価である．今回の研究では，この MI センサを用いた地磁気の地上観測で Pc5 型地磁気脈動のような微小変動の観測ができるかを検討した．

本研究ではアイチマイクロインテリジェント（株）の MI-CB-1DJ-M-FB を使用した．当該センサは± 50,000[nT] の磁場変動を± 15[V] の電圧信号として出力する．試験では，出力電圧信号を 2/3 倍に分圧し，サンプリング周波数 1[Hz] で 24-bit ADC 搭載のデータロガーに記録した．MI センサと比較するため，九州大学の MAGDAS 磁力計でも同条件下での地磁気計測を実施した．観測は 2019/02/13 から 2019/04/01 の間，九州大学篠栗演習林（MLAT. =24.71 ° , MLON. = 201.55 ° ）で行った．計測した MI センサのデータはダイナミックスペクトルの変動及び温度依存性について評価した．

その結果，約 10[nT/℃] 程度の温度ドリフトが確認され，また，計測時のノイズレベルは 3[nT] 程度であることが明らかになった．本稿では，温度ドリフトの線形性の特性及びノイズ源について粒査し，地磁気微小変動を実施するにあたって較正の可能性を議論する．

# CubeSat 用磁気センサの伸展機構の機械特性が磁気計測に与える影響

# 石田 篤弘 [1]; 北村 健太郎 [1]; 藤本 浩 [1]
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# Affection of mechanical characteristics of an extension boom to magnetic field measurement using magnetometer onboard CubeSat

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We have started to develop a 2U-CubeSat which is characterized as a small size in 10*10*20[cm]. The mission of the satellite is to observe the small perturbations of geomagnetic field in the altitude less than 400km. In case of an actual geomagnetic observation, the remaining magnetic field on the satellite body and magnetic noise emitted from the electric circuit on board the satellite often cause significant inaccuracy of the observation. In this study we made a test extension boom to reduce the these inaccuracies. We also tested mechanical characteristics of the test extension boom using an acceleration sensor to understand an affection to the measurement of the magnetic field. As a result, the eigen-oscillation with a period of 15[ms] and amplitude of 1.46 - 11.67[m/s$^2$] which depends on the direction of gravity. This indicates that mechanics-origin artificial magnetic perturbations imposed on the actual magnetic measurement might be decomposed using above results obtained in mechanical test.

本研究では高度 400km 以下での電離層電流の観測を目的とした超小型人工衛星 (CubeSat) に搭載する伸展機構先端の磁気センサ台座部の揺動が磁気計測に与える影響を検討する。衛星による電離層電流の観測においては、電流の空間分布によって生じる磁場を数十 nT の変動として計測する必要があり、磁場分解能としては 1〜0.1nT 以下の精密計測が要求されるため、通常フラックスゲート磁力計等が搭載される。一般に衛星に搭載されているバスシステムやミッションシステムの電子部品などからは磁気ノイズが発生し、また、衛星構体の帯磁による背景磁場の歪みが計測に影響を与えることが知られている。こうした磁気計測上の影響を抑えるために本研究では伸展機構の搭載を計画している。

伸展機構の伸展に際しては伸展長によるノイズ低減の効果や伸展物の固有振動等によるアライメントの不安定などが計測に与える影響を事前に精査する必要がある。本研究では試作した伸展機構の先端台座部に加速度センサを設置し伸展前後における 3 軸加速度の変動特性を計測した。伸展後の 3 軸すべての加速度の変動の周期は約 15[ms] で、振幅は重力方向に依存し最大振幅が 11.67[m/s$^2$]、最少振幅が 1.46[m/s$^2$] であった。こうしたセンサ台座の周期的揺動によって、背景磁場に対する磁気センサのアライメントが周期的に変動し計測データに重畳することが予想される。また、本衛星は能動的な姿勢制御装置を搭載しないため、衛星構体のタンブリングによる周期変化も磁気計測に重畳する。本解析で得られたデータを精査することにより、最終的に取得される磁場データの時間変動から伸展ブームの揺動および衛星構体のタンブリングによる周期変動をそれぞれ分離化のせいについて議論する。

# 低高度電離層電流計測用 CubeSat のミッション系の検討

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# A Mission System of a CubeSat to Observe the Ionospheric Current in the Low Altitude

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In recent year, development and launch of a miniaturized satellite CubeSat has become popular worldwide. In this study, we are planning to develop a CubeSat to observe the geomagnetic field in the altitude less than 400km. In general, the satellite system consists from two subsystems which are bus system and mission system. Mission system owns a role for achievement of the mission while bus system for a basic function of satellite flight. Bus system has many common elements regardless of satellites, so OPUSAT-KIT developed by Osaka Prefecture University is provided as standard bus system for CubeSat. With the development of CubeSat, we use OPUSAT-KIT for bus system of the satellite while mission system is needed to be newly developed. OPUSAT-KIT requests some processing from mission system. The purpose of this study is development of mission system that meets the requirements from OPUSAT-KIT and mounts the magnetometer to observe the geomagnetic field.

近年，CubeSat と呼ばれる 1 辺が 10cm，重量 1kg 程度の立方体で構成される非常に小型，軽量である超小型人工衛星の開発，打ち上げが世界的に盛んになっている．本研究では，2022 年度の打ち上げを目指して「高度 400km 以下での電離層電流の観測」を実施するための CubeSat の開発を行う．一般的に，人工衛星は地上との通信や電力供給など必要最低限の機能を持つバス系と地球の観測や衛星通信を行うなど各衛星のミッションを実行するためのミッション系から構成されている．バス系は衛星間で共通要素が多く，汎用モデルとして大阪府立大学が開発した運用実績のある CubeSat 用標準バス系「OPUSAT-KIT」が提供されている．本研究では OPUSAT-KIT をバス系とし，OPUSAT-KIT からの要求事項を満たしたうえで，電離層電流を観測するための磁気センサを搭載したミッション系 BBM(Bread Board Model) の開発を行った．

ミッション系の MOBC(Mission On-Board Computer) には ARM 社のワンボードマイコン Mbed を使用し，磁気センサの取得データは 3ch24bitADC を介して Mbed に送られる．電離層電流の観測では 1[nT] 以下の磁場変動分解能が要求される．そのため，使用したミッション機器での 1[nT] 以下での磁場変動の観測可否を検討する．磁気センサには Bartington 製 Spacemag-Lite を使用する．この磁気センサの測定レンジは-60000[nT] から+60000[nT] に対して，出力電圧は-3[V] から+3[V] の差動出力である．ADC はバイポーラ動作で使用するため ADC のビット数は 23[bit] となる．そのため出力電圧の分解能は $7.15 * 10^{-4}$[mV] となり，このミッション系では 1[nT] 以下の分解能での磁場の計測が可能であることが確認できる．

またミッション系動作時のミッション系と OPUSAT-KIT の合計消費電力を測定した結果 1.688[W] となった．衛星の電力収支を計算するために (1) 磁場計測は常に実施 (2) 常時 CW 通信で生存信号，ハウスキーピングデータを地上に送信 (3) 可視領域に入ったとき，FM 通信で観測データを地上にダウンリンク (4) 軌道周期は 90 分 (5) 日照時間は軌道周期の 50%(6)FM 通信時間は 10 分 (7) 太陽光パネル発電電力は 3[W](8) 無線機 CW 通信時消費電力は 0.5[W](9) 無線機 FM 通信時消費電力は 3[W]，と仮定する．上記の仮定より衛星の 1 周期の電力収支は-1.448[Wh] となり，現状では発電電力よりも消費電力が大きく衛星を運用できないことがわかる．そのため今後，ミッション系の省電力化，使用する太陽光パネルや無線機，運用計画の検討を行っていく必要がある．

# Antarctic large area network observation of auroral phenomena using unmanned system (3)

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Several conjugate auroral events observed at Syowa Station and Amundsen Bay (by the Unmanned Auroral Observation system (UAO)) in Antarctica, and observatories in Iceland during 2017 - 2018 are analyzed. We will also introduce our plan to install the UAO-2 at Belgium Princess Elisabeth Antarctic station and an all-sky imager system at Indian Maitri Station in January, 2020.