COMMISSION H:Waves in Plasmas(November 2007 – October 2010)

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Based on the papers published from November of 2007 to October of 2010, we compiled major achievements in the field of plasma waves and related studies made by Japanese scientists and their collaborators. We categorize the studies into four groups as shown in Contents. Each section provides a specific summary of important scientific achievements rather than a comprehensive report of the whole research activities of Japanese Commission H. On the other hand, the reference list attached at the end is intended to be used as a database of all papers we have collected from the Japanese Commission H members.

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H1. Space Observation and Experiment of Plasma Waves

H1.1 Magnetospheric Plasma Waves

<AKEBONO >

Twenty-two years have passed since Akebono was launched in 1989. The instruments onboard Akebono are still working successfully, and an enormous amount of data has been stored.

The mechanism for formation of the Earth's radiation belt has been an outstanding issue for utilization of the geospace environment. Kasahara et al. [2009] presented a typical magnetic storm event which occurred from 9 to 19 October, 1990. They studied the relationship among ~30 keV energetic electron fluxes measured by NOAA-10, relativistic ~2.5 MeV electron fluxes and intensity of 1-10kHz VLF waves observed by Akebono, respectively, the Dst index, and the AE index during the magnetic storm. It was found that there was a clear correlation among continuous injection of hot electrons, generation of chorus, geomagnetic AE activity (all for ~8 days) and the acceleration of electrons to relativistic energies. They also showed the frequency characteristics of chorus elements that are important for non-linear wave particle interactions. They proposed a scenario to explain the observations, that is, the continuous injection of hot electrons associated with the continuous AE activity. The hot electrons with $T_{perp}/T_{para} > 1$ temperature anisotropies excite whistler-mode chorus waves. The chorus interacts with energetic electrons accelerating them to MeV energies forming a flux of ''killer electrons'' in the outer radiation belt.

As the total amount of data measured by scientific spacecraft is drastically increasing, it is necessary for researchers to develop new computation methods for efficient analysis of these enormous datasets. Kasahara et al. [2010] proposed a new algorithm for similar data retrieval. The aim of their study is to develop a technique to discover interesting and/or epoch-making datasets from enormous datasets. Many types of computational methods have already been devised and tested for achieving this. Some of these were developed based on learning algorithms such as neural network and pattern recognition. These algorithms work very powerfully to retrieve the required datasets from enormous databases if the characteristics of the required datasets are well known.

However, it is also important for scientists in geophysics and space physics to discover new and unusual phenomena. In order to solve this problem, Kasahara et al. [2010] constructed a database system on VLF/ELF waves obtained by the MCA onboard Akebono and introduced several kinds of key descriptors, such as wave intensity, time variation of wave spectrum, and ratio between electric and magnetic wave components, in order to describe the distinctive wave spectrum features. Finally they applied a proposed algorithm for similar data retrieval by storing these key descriptors in the database and evaluated the performance of the system. It was demonstrated that the developed algorithm works well for the purpose of similar data retrieval, and its computation time is also small enough for practical use. It is especially notable that the generality of the system is taken into account so that the proposed method is applicable not only to MCA data but also to other kinds of datasets.

A general-purpose database (DB) system that manages and opens experimental and/or observational data was introduced by Takata et al. [2010]. This platform works as a web-DB management system in which databases can be easily managed without special skills and facilities. By defining a group manager and data manager, the proposed system defines a flexible access restriction for each user and each unit of datasets under the control of these managers. They applied this web-DB system to the datasets on plasma and radio wave measurements by the Akebono satellite and their ancillary data, and demonstrated how a variety of web-DBs are appropriately integrated under one management system in such situations in which each web-DB has a different user interface in its search and data distribution functions and is designed with a different language (or script) and connection method to its DB. In spite of the diversity of web-DBs, the proposed system is highly suitable for practical use.

<GEOTAIL and CLUSTER>

Verkhoglyadova et al. [2009] studied some wave properties of nonlinear rising tone chorus emissions in the outer regions of the dayside equatorial magnetosphere. They analyzed wave data obtained on GEOTAIL associated with a substorm on April 29, 1993. Fine structure of the chorus elements and inter-element spacings were shown, and directions of propagation of the chorus elements relative to the local magnetic field lines were analyzed. Wave polarizations, intensities and spectral properties of chorus in the equatorial Earth’s magnetosphere were discussed.

The dayside outer zone (DOZ) portion of the magnetosphere is a region where chorus intensities are statistically found to be the most intense. In Tsurutani et al. [2009], DOZ chorus have been examined using OGO-5 plasma wave and GEOTAIL plasma wave, magnetic field and energetic particle data. DOZ chorus were found to be consistent with generation via the loss cone instability of substorm-injected temperature-anisotropic 5 to 40 keV electrons drifting from the midnight sector to the DOZ region.

Shin et al. [2007] showed the existence of intense electrostatic quasi-monochromatic (EQM) waves in the downstream region of the Earth’s bow shock. They appear at frequencies between the electron plasma and ion plasma frequencies. Although these waves have been believed to be Doppler-shifted ion acoustic waves, the typical plasma parameters observed in the downstream region do not support the generation conditions for ion acoustic waves. Shin et al. [2007] showed the existence of cold electron beam-like components accompanying EQM waves based on waveform and statistical analyses. Furthermore, they conducted linear dispersion analyses using realistic plasma parameters and revealed that the cold electron beams cause destabilization of electron acoustic waves at frequencies consistent with those of observed EQM waves.

Shin et al. [2007] reported the electrostatic solitary waves (ESW) observed in the Earth's foreshock region by the Geotail spacecraft. The Geotail waveform observations showed the existence of ESW in both electron and ion foreshock regions. To understand the wave features of ESW, Shin et al. [2007] examined the waveform and performed statistical analyses on the spatial distribution of the ESW. The results show that the occurrence and amplitude of ESW decrease as the distance from the bow shock transition increases. Shin et al. [2007] found two types of ESW in the ion foreshock region based on the orientation of their bipolar waveforms. They examined the angle between the magnetic field and the shock normal dependence of the occurrences of ESW in the ion foreshock region. The results show that ESW observed in the quasiparallel shock have characteristics that differ from those observed in the quasiperpendicular shock. From waveform and statistical analyses, the most plausible generation mechanism of the first type of ESW is the Buneman instability based on the superthermal ions and background electrons. A possible mechanism of the second type of ESW is the positive potential ESW propagating from the upstream region to the bow shock due to the reflection by the negative potentials or the negative potential ESW generated by the reflected superthermal ions.

ULF waves in the terrestrial foreshock observed simultaneously by the four Cluster satellites were analyzed to identify the plasma wave modes and to study the effect of plasma beta on the intrinsic wave properties [Hobara et al., 2007a,b]. The wave properties in the spacecraft and solar wind frame are experimentally derived using the minimum variance analysis (MVA) for the case study and the phase differencing (MVA-free) technique for the statistical study. The obtained results are in good agreement with theoretical kinetic dispersion relation with a different plasma beta.

Hobara et al. [2008] studied the electrostatic solitary structures in the foot region of Earth's quasi-perpendicular bow shock by using Cluster Electric Field and Wave instrument. The four individual probe potential measurements are utilized to investigate the fundamental characteristics of the solitary wave structures such as wave propagation vector, propagation velocity, scale-size and potential amplitude. The two classes of observed solitary waves may greatly influence the ambient plasma dynamics around the shock. The bipolar solitary waves do not exhibit a large net potential difference but may still play an important role in plasma thermalisation by particle scattering. Unipolar/tripolar solitary waves exhibit a remarkable net potential difference that may be responsible for the plasma energisation along the ambient magnetic field.

Zhu et al. [2008] has applied the Nonlinear processes identification techniques based on multi-input nonlinear autoregressive moving average with exogenous inputs model to four-point Cluster measurements in order to study nonlinear processes that take place in the terrestrial foreshock. It is shown that both quadratic and cubic processes are involved in the evolution of shocklets in particular in the steepening of their leading edge and generation of whistler precursor.

Hobara et al. [2010] reported the width of the terrestrial collisionless shock front, which is one of the key shock parameters. Cluster and Themis measurements at the quasi-perpendicular shock are used to study the spatial scale of the magnetic ramp. It is shown that statistically the ramp spatial scale decreases with the increase of the shock Mach number. This decrease of the shock scale together with previously observed whistler packets in the foot of supercritical quasi□perpendicular shock indicates that it is the dispersion that determines the size of magnetic ramp even for supercritical shock.

H1.2 Ionospheric Waves

<Rocket Experiment>

S-310-37 rocket was launched at 11:20 (JST) on January 16, 2007 at Uchinoura Space Center (USC) by JAXA, on which a MF radio wave receiver and an electric field detector were installed in order to measure the intensity and the waveform of the radio wave 873 kHz from NHK Kumamoto broadcasting station and DC – 40 Hz electric field in the ionosphere. Ashihara et al. [2008] analyzed the waveform and identified the characteristic mode waves; left- and right-handed polarized waves, from which they estimated the electron density profile in the ionospheric D region with very low density.

S-520-23 sounding rocket experiments were carried out at 19:20 (JST) on September 2, 2007 at USC. Electric field detector and LF and MF radio wave receiver were installed on S-520-23 rocket in order to observe the electric field in the range from DC to 40 Hz and the intensities and the waveforms of 60 kHz radio wave from JJY and 873 kHz radio wave from NHK Kumamoto broadcasting station. In this rocket experiment, a DC electric field and radio waves were measured by the new type receiver which was the floating ground type pre-amplifier and the inflatable antenna [Kasaba et al., 2010]. Suzuki et al. [2010] described that the sheath capacitances obtained from impedance probe measurements were examined for application to plasma diagnoses. They compared analytical calculations of the sheath capacitance with measurements from impedance probes onboard the S-520-23 sounding rockets. This sounding rocket measurement demonstrated that the observed sheath capacitances agreed well with those of the calculations. They concluded that the sheath capacitance measurements allow for estimation of the electron temperature and the electron density of a Maxwellian plasma. Uemoto et al., [2010] showed direct observation of the impact of the lithium releases on the ionospheric electron density in this rocket experiment. The direct observation is unique in that the electron density enhancement was observed by using the NEI (number density of electrons by impedance probe) which can measure accurately the absolute value of the electron density, and the distance between the NEI and the LES (lithium ejection system) was very close (several tens of meters). Data analyses of the NEI on-board the S-520-23 sounding rocket clarifies that lithium releases performed in the descending phase increased the electron density up to approximately 7×10^5 cm^{-3}.

S-310-38 sounding rocket experiments have been carried out at USC on 6 February, 2008. The purpose of this experiment is the investigation of the sporadic E-region at mid latitudes during the evening twilight. Kurihara et al. [2010] observed the ultraviolet resonant scattering by magnesium ions (Mg+) in an Es layer with the Magnesium Ion Imager (MII) on the S-310-38 sounding rocket in order to study the spatial structure of midlatitude sporadic E (Es) layers. The in situ electron density measured by an onboard impedance probe showed that the Es layer was located at an altitude of 100 km during both the ascent and descent of the flight. Simultaneous observation with a ground-based ionosonde at Yamagawa identified the signature of horizontally “patchy” structures in the Es layer. The MII successfully scanned the horizontal Mg+ density perturbations in the Es layer and found that they had patchy and frontal structures. The horizontal scale and alignment of the observed frontal structure is generally consistent with a proposed theory. To our knowledge, this is the first observation of the two-dimensional horizontal structure of Mg+ in an Es layer. The LF/MF band receiver (LMR) is loaded on this sounding rocket in order to measure the propagation characteristics of LF/MF band radio waves from the ground to the lower ionosphere. The LMR measured the attenuations of radio waves about 100 km in the ionosphere. The Es layer with patchy structures influenced the attenuations of radio waves [Ishisaka et al., 2008].

<Sub-Ionopsheric Radio Waves including Seismic and lightning Emissions>

Todoroki et al. [2007] studied the effect of solar flares onto the lower ionosphere by means of a short-distance subionospheric VLF propagation, and tried to deduce the solar-flare-induced anomalous electron density profile of the lower ionosphere by means of a comparison with the FDTD computations. Tanaka et al. [2008] studied the ionospheric disturbances caused by a giant gamma ray burst from the SGR 1900+14, who estimated the constraints on the energy spectrum of the flare. A much larger gamma-ray burst from the magnetar SGRJ1550-5418 was found to induce more significant lower ionospheric perturbations and estimated the change of effective lower ionospheric height [Tanaka et al., 2010].

The subionospheric VLF/LF propagation has been extensively utilized in order to investigate the ionospheric perturbations associated with earthquakes [EQs]. Some statistical studies on the correlation of the presence of ionospheric perturbations and EQs with magnitude M larger than 6.0 and with shallow depth [Kasahara et al., 2008; Muto et al., 2008; Biagi et al., 2009; Hayakawa et al., 2009; Kasahara et al., 2010;. Hayakawa et al., 2010a, b, c; Hayakawa, 2010; Hayakawa and Hobara, 2010]. Additional case studies have also been performed for different huge EQs [Biagi et al. [2008] for an Italian EQ, Hayakawa et al. [2008] for the 2007 Niigata-Chuetsu-oki EQ, Muto et al. [2007]

for the 2005 Miyagi-oki EQ, Rozhnoi et al. [2009] for the 2009 Abrusso EQ in Italy]. The generation mechanism of those seismo-ionospheric perturbations has been investigated in terms of the atmospheric gravity wave [AGW] mechanism. A lot of indirect evidences on the important role of AGW have been obtained in terms of amplitude fluctuations, fractal analysis etc. [Korepanov et al., 2009; Blaunstein and Hayakawa, 2009; Muto et al., 2009; Rapoport et al., 2009; Imamura et al., 2010; Kasahara et al., 2010]. Furthermore, the satellite observations have also been succeeded in finding the lower ionospheric perturbation associated with EQs by means of the detection of such whistler-mode VLF/LF transmitter signals [Rozhnoi et al., 2008; Muto et al., 2009].

Hobara et al. [2010] have studied the subionospheric VLF/LF propagation anomalies [known as Trimpis] in association with the transient luminous events in the mesosphere originated from huge lightning discharges. They have compared the experimental Trimpis observed at multiple stations in Japan with the VLF/LF modeling by means of FDTD, who inferred the spatial plasma structure of those transient luminous events.

ELF wave propagation in the Earth-ionosphere cavity [known as Schumann resonances [Surkov and Hayakawa, 2010] and ELF transients [Nickolaenko et al., 2010]] has been investigated in order to monitor the lower ionosphere and global lightning activity. The experimental and computed ELF waveforms were compared by Nickolaenko et al. [2008], who have shown a satisfactory agreement between the two. Yamashita et al. [2009] have estimated the global distribution and characteristics of intense lightning discharges as deduced from ELF transients observed at Moshiri [Japan] during one year, and found a significant difference in characteristics [global distribution, charge moment change, etc.] between positive and negative discharges. Nakamura et al. [2010] have compared different direction finding methods for ELF transients inducing sprites whose positions were accurately located, and they have suggested the use of Lissajous method [in time domain] together with the wavelet analysis. The inverse problem for the multi-stationed ELF Schumann resonance data has been, for the first time, developed; the first step is the reconstruction of background lightning activity as a function of distance from each station, and the second step is the tomography in terms of those distance distribution from a few stations [Shvets et al., 2009]. This is applied to the real data [Shvets et al., 2009, 2010], and Shvets et al. [2010] have utilized a long-period [one year] data in order to monitor the seasonal variation of global lightning activity.

Anomalous effects in Schumann resonance phenomena have been observed in Japan [Moshiri] by Hayakawa et al. [2008], who have found abnormal behaviors in Schumann resonance [enhancement of third or fourth harmonic] in possible association with an EQ in Taiwan and who have interpreted those anomalies in terms of the interference between the direct wave from the lightning source and the wave reflected from the seismo-ionospheric perturbation above Taiwan. Izutsu et al. [2008] and Ohta et al. [2009] have found further anomalous effects such as the excitation of Schumann-resonance-like line emissions in possible association with the EQs in Japan, and Hayakawa et al. [2010] have interpreted these line emissions in terms of the gyrotropic waves excited by the ELF waves from below in association with EQs. The effects of a large-scale gamma-ray burst [SGRJ 1550-5418] on the ELF Schumann resonance has been studied theoretically by Nickolaenko and Hayakawa [2010], who have predicted a severe decrease of all parameters [intensity, resonance frequency, etc.] of Schumann resonance modes.

Nickolaenko and Hayakawa [2010] have reviewed the Q bursts: natural ELF radio transients, who have reviewed the previous observations and have compared them with the model computations. Then Kudintseva et al. [2010] have studied the transient electric field in the mesosphere above a gamma-shape lightning stroke, which would be of essential importance in triggering the transient luminous sprites in the mesosphere.

Yano et al. [2010] have studied the detailed characteristics [intensity, wave polarization, arrival direction] of signals transmitted from an ELF transmitter in Russia, which suggests a potential use of this ELF transmitter for the detailed ELF propagation characteristics in the Earth-ionosphere waveguide.

Ohta et al. [2008] reported the direction finding of below 0.1Hz occurred natural emission observed at Nakatsugawa in Japan on the Sumatra Earthquake. This direction angle, 30 degree shows the angle from Nakatsugawa to the epicenter.

Precursory phenomena of ULF/ELF frequency band occurred from the epicenter just before the earthquakes Mid-Niigata prefecture earthquakes, and Noto Hantou earthquake in Japan are reported by Ohta et al. [2009].

Ohta et al. [2009] investigated the direct electromagnetic waves [ULF/ELF] occurred form the epicenter and measuring the change in amplitude or phase of VLF subionospheric disturbed by the energy from the epicenter before the earthquakes observed at Nakatsugawa in Japan.

Ozaki et al. [2009] evaluated amplitude of a current moment [created by a seismic activity] in the conductive lithosphere from the viewpoint of possible detection of the radiated electromagnetic waves with sensitivity of an electromagnetic sensor. To detect the radiated waves in the ionosphere, the current moment over 2.5 MAm/Hz1/2 is required in the conductive medium of 10?3 S/m, which would not be a realistic value. They suggested that the direct observation of the seismic-related electromagnetic waves in the ionosphere would be quite difficult.

To extract information on lightning return strokes from sferics, Ozaki et al. [2010] have been investigating a technique for estimating return stroke currents. They have succeeded in obtaining information on discharge time of a return stroke from the sferic spectrum, which is given by a sinc function of discharge time. They reconstructed the return stroke current waveforms by using the least-square method with the estimated value of the discharge time. By the numerical simulation, they confirmed that the error in the estimation of the current moment is less than 10% for the lightning at the horizontal distances over 100 km from the observation point.

Kikuchi et al. [2010] reported the results from Japanese nano-satellite mission. Maido-1 satellite was launched on 23 January 2009. The satellite carries the radio-frequency payload, Broadband Measurement of Waveform for VHF Lightning Impulses, for research on lightning discharges. Through the operation/observation for 5 months, more than 10,000 VHF signals were recorded. The locations where VHF signals were detected and examples of the received waveforms are presented.

H1.3 Ground observation and Experiment of Plasma Waves

<ULF Wave>

The Solar-Terrestrial Environment Laboratory (STEL) induction magnetometer network has been developed to investigate the propagation characteristics of high-frequency geomagnetic pulsations in the Pc1 frequency range (0.2-5 Hz). Five induction magnetometers were installed in the period 2005-2008 at Athabasca in Canada, Magadan and Paratunka in Far East Russia, and Moshiri and Sata in Japan [Shiokawa et al., 2010]. Sakaguchi et al.[2008] found one-to-one correspondence between the Pc1 (EMIC) waves and isolated proton auroras. Moreover, Miyoshi et al.[2008] revealed that EMIC wave cause the rapid scattering of relativistic electrons of the outer belt, based on observations at subauroral latitudes at Athabasca. Nomura et al.[2011] found frequency dependence of Pc1 polarization parameters at middle latitudes. ULF magnetic responses to indivisual lightning were also investigated.

Sakaguchi et al. [2008] reported one-to-one correspondences between isolated proton aurora appearances at subauroral latitudes and occurrences of Pc1 geomagnetic pulsations using one-year data at Athabasca, Canada (62°MLAT, L=4.6). The observed Pc1 frequencies have almost corresponded to the frequencies of He^+ ion cyclotron waves at the magnetic equator traced from isolated proton auroras. The observations indicate that spatially-localized resonant interactions between ion cyclotron waves with ring current ions cause energetic proton precipitation and associated meso-scale isolated proton auroras at subauroral latitudes. These results imply that the dynamics and instabilities in the inner magnetosphere can be monitored by low-latitude auroral emissions.

Miyoshi et al. [2008] used a unique set of ground and satellite observations to show evidence that left-hand polarized electromagnetic ion cyclotron (EMIC) waves near the plasmapause can precipitate relativistic electrons and lower-energy ions (with energies of tens of keV) at the same time into an isolated proton aurora. This interpretation is confirmed by estimating the pitch angle diffusion coefficients for their event. It was clarified that ions with energies of tens of keV affect the evolution of relativistic electrons in the radiation belts via cyclotron resonance with EMIC waves.

Shiokawa et al. [2010] reported on the Solar-Terrestrial Environment Laboratory (STEL) induction magnetometer network which has been developed to investigate the propagation characteristics of high-frequency geomagnetic pulsations in the Pc1 frequency range (0.2-5 Hz). Five induction magnetometers were installed in the period 2005-2008 at Athabasca in Canada, Magadan and Paratunka in Far East Russia, and Moshiri and Sata in Japan. They showed examples of PiB/Pc1 magnetic pulsations observed at these five stations, as well as the harmonic structure of ionospheric Alfven resonators observed at Moshiri. They found that the Pc1 packets are slightly modulated as they propagate from high to low latitudes in the ionospheric duct.

Teramoto et al. [2008] identified Pi 2 pulsations observed by DE-1 (polar-orbiting satellite having the perigee of 500 km and the apogee of 3.6 Re) from February 1983 to January 1991. They examined simultaneously-observed ground H-component data (at Kakioka or Hermanus), and found 91 events with high coherence (>0.6) between the DE-1 and the ground data, including events in which DE-1 was located at L>5. The power ratio (phase difference) of Pi2 pulsations observed by DE-1 and the ground stations had a weak peak (a 180° jump) around L=5. Teramoto et al. suggested that these findings can be explained if the events were generated by the plasmaspheric virtual resonance (PVR) mode.

By using MHD simulations, Ugai [2009] showed how reconnection jets drive ionospheric electrojets and Pi 2 pulsations at substorms. When a large-scale plasmoid, directly generated by the reconnection jet, collides with the magnetic loop of the closed field lines in the inner magnetosphere, strong electrojets are impulsively driven in a finite extent of the ionospheric footpoint of the magnetic loop. On the other hand, Alfven waves, which were generated simultaneously with the plasmoid generation, reach the ionospheric electrojet layer and interact (or resonate) with the waves traveling toward the footpoint, leading to impulsive Pi 2 pulsations.

Uozumi et al. [2009] examined Pi 2 wave oscillations that showed a high correlation between high- and low-latitude MAGDAS/CPMN ground magnetometer stations. They found that the delay time from the low-latitude station to the high-latitude station in the H component showed a remarkable MLT dependence, especially in the premidnight sector. The high-latitude oscillation tends to delay from the low-latitude oscillation by ≤100s in the premidnight sector. On the other hand, the D-component delay time was not significant (<10s) in the entire nighttime sector. These observational results make it possible for the authors to propose a new Pi 2 propagation model.

Ikeda et al. [2010] examined nighttime Pi2 pulsations simultaneously observed by a Frequency Modulated Continuous Wave (FM-CW) HF radar and by a ground magnetometer, both located at a mid-latitude (L=2.05) station belonging to the Magnetic Data Acquisition System (MAGDAS). They observed 83 Pi2 events in 43 days. The geomagnetic field variations in the H component and the ionospheric Doppler velocity (V*) variations exhibited high coherence for 80% of the 83 events, and about half of the high-coherence events had the same dominant frequency in H and V*. For such events, V* led H by 90° in phase in the midnight sector of 2230−0300 LT. The phase relation of H and V* in the midnight sector may be explained in terms of the radial standing structure of compressional waves, i.e., the cavity mode oscillation.

Nosé [2010] intends to examine which of the cavity mode resonance or the bursty bulk flow (BBF) driven process is more plausible as the excitation mechanisms for low-latitude Pi2 pulsations. Multiple correlation analysis revealed that the Pi2 period was negatively correlated with the ∑Kp index and positively correlated with ion mass in the near-Earth plasma sheet or the F10.7 index. This statistical result indicates that the Pi2 period was proportional to both the size and mass density of the plasmasphere, strongly supporting the plasmaspheric cavity mode resonance as the excitation mechanism of low-latitude Pi2 pulsations.

Saka et al. [2010] examined the temporal variations of the nightside geomagnetic field and the geosynchronous energetic ion flux during substorms by using a superposed epoch analysis with zero epoch time of Pi2 onset. They reported that the first 10 min interval of Pi2 onset was a transitional state of substorms dominated by MHD processes associated with earthward flow and its bifurcation. Intervals following the first 10 min were associated with field line variations that were well organized by dipolarization due to the reduced cross-tail current. It was also reported that the energetic ions are dominant in a localized in 2000-0000 LT in the first 10 min intervals of Pi2 onset and then expand to the post-midnight sector. They concluded that the expansion of the energetic plasma dominant regions could be attributed to the inflation of the inner magnetosphere during dipolarization.

Takasaki et al. [2008] demonstrated that data from geomagnetic conjugate points are helpful in identifying field line resonances (FLRs) in cases that the magnetometers are located too close to each other. Once FLRs is identified, the amplitude phase gradient method (APGM) can be applied to the identified FLR, yielding the FLR frequency as a continuous function of ground latitudes. The mass density in the equatorial region at the L of the auroral zones is estimated from the obtained FLR frequency by numerically solving the standing Alfven wave equation. The mass density thus obtained is consistent with observational results from previous in situ measurements by spacecraft. Therefore, the magnetospheric equatorial mass density is readily estimated with high spatial resolution.

Maeda et al. [2009] selected 19 cases in which the Cluster spacecraft was located on the field line running through the midpoint of two ground magnetometer stations belonging to the CPMN (Circum-pan Pacific Magnetometer Network), Tixie (TIK) and Chokurdakh (CHD), when TIK and CHD observed ULF waves caused by field line resonance. Then, for the 19 cases, they compared the electron density (Ne) observed by the WHISPER instrument onboard the Cluster satellites with simultaneous plasma mass density (ρ) estimated from the resonance frequency observed by TIK and CHD. The ratio of Ne to ρ fell into a realistic range for 15 out of the 19 events. It was also suggested that the contribution of heavy ions tends to increase when the magnetosphere is disturbed.

Obana et al. [2010a] analyzed the data from a ground magnetometer array by the cross phase method, and determined the equatorial mass density during three moderate geomagnetic storms. In each case the field line eigenfrequency increased significantly, suggesting the depletion of flux tubes and the earthward motion of the plasmapause. The timescales of refilling of the flux tubes are estimated to be 2-3 days at L=2.3, 3 days at L=2.6, and >4 days at L>3.3. The daily-averaged refilling rate is found to be ~420 amu·cm^{-3}d^{-1} at L=2.9-3.1. By comparison with IMAGE-EUV and VLF whistler data, they also estimated that the estimated O^+ proportion was 3-7% at L=2.3 and 6-13% at L=3.0.

Obana et al. [2010b] compared the plasmapause location determined by using EUV images with that determined by using ground magnetometer data. In EUV images the plasmapause was identified as a sharp gradient in the brightness of the 30.4 nm He^+ emission. They examined EUV images obtained by the IMAGE and the Kaguya satellites, operated in a solar maximum and minimum periods, respectively. By using the ground magnetometer data, the plasmapause was identified as a sharp-drop point in the radial profile of the mass density, which was inferred from the field-line-resonance frequency. The two kinds of the plasmapause measurements were compared in the same meridian at the same time, and very good agreement was found in 18 out of the 19 cases, suggesting that the He^+-plasmapause and the mass density-plasmapause are usually detected at the same place (with the error range of ±0.4Re).

Tanaka et al. [2007] statistically studied the horizontal spatial structure of Pc 3 pulsations observed at low geomagnetic latitude (22°-46°MLAT) around dawn, using data from the Circum-pan Pacific Magnetometer Network (CPMN). It was found that while the phase of the H component of low-latitude Pc 3 pulsations remains largely unchanged with the passing of dawn, the D component undergoes a phase shift of ca. 180°. It was also shown that both the H and D components have higher amplitude after dawn than before dawn. This horizontal amplitude and phase structure is well explained by the response of a nonuniform ionosphere around dawn to incident Alfven waves, where the secondary electric field caused by charge accumulation at the dawn terminator plays an important role in deformation of the current system.

Quarter wave is a mode of standing MHD waves on geomagnetic field lines which is predicted to be excited when the ionosphere has strongly asymmetric conductances at conjugate points of a field line. Obana et al. [2008] examined the diurnal variation of the local field line eigenfrequency at L ~ 2.6 using cross-phase analysis and found that on the 6 of the 37 quiet days the eigenfrequency was remarkably low near the dawn terminator, when one end of the field line was sunlit and the other end was in darkness. Later in the morning the eigenfrequency gradually increased to the normal daytime value. These observation agree with their model simulation of quarter wave formation at L=2.6.

Kataoka and Pulkkinen [2008] studied geomagnetically induced currents (GIC) flowing in ground-based conductor systems during large geomagnetic storms. They found that Pc3-5 pulsation activity during CIR storms drives long-lasting GIC in the local prenoon sector.

Kataoka et al. [2009] applied the Hilbert-Huang Transform (HHT) to high-latitude search-coil ground-magnetometer data at an auroral expansion onset, which data was quite fluctuative (leading to no meaningful results when a regular FFT is applied) as in usual onsets. As a result, HHT could automatically extract Pi 1, Pi 2, and Pc 3. Thus, Kataoka et al. suggested that HHT is useful for understanding the onset mechanism of auroral substorms.

<Polar Region Experiment>

In order to estimate the dynamic structure of the ionospheric exit points, Ozaki et al. [2007] conducted ground-based observations of natural ELF/VLF waves at three unmanned sites around SYOWA station, Antarctica. For unmanned autonomous observations at the three sites, they developed three sets of new wave receivers having satellite communication equipments, which were stably running in whole of 2006. The observation included interesting differences in the wave intensity and the polarization at the three sites, which should give important information on localization of the ionospheric exit point.

Ozaki et al. [2008] estimated the ionospheric VLF exit point by using observation and full-wave calculation results. Their results showed that the direction of the exit point for auroral hiss, was found to be consistent with a bright aurora region, but the estimated exit point was located a few hundred kilometers equatorward of the associated aurora. They suggested that the ray paths for the auroral hiss could be different from the directions of the geomagnetic field lines for auroral particle precipitation.

Ozaki et al. [2009] suggested a new remote sensing technique for enhanced electron density in the lower ionosphere. This technique is based on the difference in the ionospheric attenuation between VLF whistler mode waves and 30 MHz CNA both observed on the ground. They found that their correlation has information on the vertical profile of the enhanced electron density in the lower ionosphere caused by electron precipitation.

H2. Theory and Computer Experiment on Plasma Waves

H2.1 Acceleration and Scattering of Particles

Summers and Omura [2007] presented a new particle acceleration mechanism called ultra-relativistic acceleration (URA). Under ideal conditions, at Earth (L = 4) several-hundred-keV electrons can be energized to several MeV within a few seconds, while at Jupiter (L = 8), several-hundred-keV electrons can be energized by tens of MeV in a few tens of seconds.

Furuya et al. [2008] performed test particle simulations and showed that a fraction of the higher-energy electrons from a few hundred keV to a few MeV are effectively accelerated by chorus due to a special nonlinear trapping process called relativistic turning acceleration (RTA) found by Omura et al. [2007]. They used a Green's function method to describe the evolution of the particle energy distribution function and showed that the RTA process creates a high-energy tail in the electron energy distribution function. They showed that RTA can accelerate electrons in a much shorter timescale than that estimated by quasi-linear diffusion theory, e.g., it typically takes tens of minutes to hours for seed electrons (<100 keV) to be accelerated to energies of a few MeV by RTA.

Katoh et al. [2008] showed that in the simulation of chorus generation, some resonant electrons are rapidly energized by the processes of relativistic turning acceleration (RTA) and ultra-relativistic acceleration (URA). RTA and URA are particular forms of nonlinear wave trapping of resonant electrons by coherent whistler-mode waves and constitute viable mechanisms for the generation of relativistic electrons in the radiation belts of magnetized planets.

Tadokoro et al. [2009] performed numerical calculations to investigate a possible mechanism explaining precipitations of energetic electrons in the inner radiation belt during small and moderate storms, and showed that it is caused not by radial transport processes but by pitch angle scattering through wave-particle interactions. The waves related to wave-particle interactions are attributed to be banded whistler mode waves around 30 kHz observed in the inner magnetosphere by the Akebono satellite.

Hikishima et al. [2009b] studied a coherent scattering process associated with generation of the rising chorus emissions. The simulation showed that coherent rising chorus emissions scatter energetic electrons very effectively through formation of an electromagnetic electron hole. The nonlinear interaction induces acceleration by trapped resonant electrons and deceleration of untrapped resonant electrons. They found the repeated scatterings make the distribution much sharper at 90 degree, leading to formation of a pancake distribution function.

Hikishima et al. [2010a] showed that microburst precipitation of electrons of energies 10 keV–100 keV accompanies the generation of discrete bursty chorus wave emissions in the simulation. They also showed a one-to-one correspondence between the electron microbursts and the generation of discrete chorus elements.

Miyoshi et al. [2010] proposed a model for the energy dispersion of electron precipitation associated with pulsating auroras, considering the wave-particle interactions with propagating whistler mode waves from the equator. They conducted a time-of-flight (TOF) analysis of precipitating electrons observed by the REIMEI satellite, assuming an interaction with the whistler mode chorus rising tone, and showed that the modulation region of the pitch angle scattering is near the magnetic equator.

Matsukiyo and Hada [2009] investigated a new particle acceleration process in a developing Alfven turbulence in the course of successive parametric instabilities of a relativistic pair plasma. A one-dimensional PIC simulation reveals that high-energy particles having large relativistic masses are preferentially accelerated and a power-law-like energy distribution function is formed. The main acceleration mechanism is simultaneous relativistic resonance between a particle and two different waves. An analytical expression of maximum attainable energy through the process is derived.

Otsuka and Hada [2009] discussed cross-field diffusion of energetic particles using compressional and non-compressional two-dimensional turbulence models by performing test particle simulations. For both models, the diffusion coefficient, defined in the classical way, exhibits a timescale dependence, suggesting that the underlining physical process should be described by Levy statistics. The diffusion coefficient for long timescales is classified in terms of the Kubo number, K = bL bottom/ρ, where b is the standard deviation of magnetic field fluctuation in units of the background field, ρ is the particle Larmor radius, and L bottom is the field turbulence scale length. While the well-known JKG theorem predicts that a particle cannot move more than about one gyroradius normal to the magnetic field in a system with two or less spatial dimensions, the cross-field diffusion does take place in their models since they are exceptions to the theorem: we argue that particle motion on the flux surface is not prohibited in general, and in particular, it is not bounded when the background magnetic field is exactly parallel to the ignorable coordinate.

Matsukiyo [2010] investigated the efficiency of electron heating through micro-instabilities generated in the transition region of a quasi-perpendicular shock for a wide range of Mach numbers by utilizing PIC simulation and model analyses. In the model analyses saturation levels of effective electron temperature as a result of micro-instabilities were estimated from an extended quasi-linear analysis and trapping theory. Both the model analyses and the PIC simulations predict that a critical Mach number, above which a steep rise in electron heating rate occurs, may arise at the Mach number of a few tens.

Saito et al.[2010a] developed a three-dimensional relativistic test particle code and investigate the particle distribution associated with the solar wind pressure enhancement. They found that the magnetopause shadowing process cause the loss of the outer belt and the split of the outer belt. This split depends on the geomagnetic tilt angle and tends to be observed in summer and winter, which is an evidence that the magnetopause shadowing causes the loss of the outer belt.

H2.1 Generation and Propagation of Waves

On the generation mechanism of chorus emissions, Omura et al. [2008, 2009] developed a nonlinear wave growth theory. Omura et al. [2008] derived the relativistic second-order resonance condition for a whistler-mode wave with a varying frequency and showed that wave trapping of resonant electrons near the equator results in the formation of an electromagnetic electron hole in the wave phase space. For a specific wave phase variation, corresponding to a rising frequency, the electron hole can form a resonant current that causes growth of a wave with a rising frequency. They clarified that the wave amplitude is amplified by the nonlinear resonant current, which is sustained by the increasing inhomogeneity of the dipole magnetic field over some distance from the equator.

Omura et al. [2009] presented theoretical expressions for the nonlinear growth rate and the amplitude threshold for the generation of self-sustaining chorus emissions. They showed that self-sustaining emissions become possible when the wave propagates away from the equator during which process the increasing gradients of the static magnetic field and electron density provide the conditions for nonlinear growth. They derived a pair of coupled differential equations for the wave amplitude and frequency reproducing a rising tone of chorus emissions. The gap at half the electron gyrofrequency separating upper and lower band chorus was also explained by means of the nonlinear damping of the longitudinal component of a slightly oblique whistler mode wave packet propagating along the inhomogeneous static magnetic field.

By full particle simulation, Hikishima et al. [2009a] studied the generation mechanism of VLF whistler-mode chorus emissions in the equatorial region of the magnetosphere. They showed that in the initial phase, the amplitude growth of the incoherent waves is determined by the linear growth rate. When the wave amplitude reaches a certain level, it begins to grow more rapidly with a series of rising tone emissions consisting of coherent phase structures. They found a threshold for a nonlinear wave growth generating the rising chorus. They also found that the relation between the wave amplitude and the frequency sweep rate of chorus element satisfies the nonlinear wave growth theory of chorus emissions by Omura et al. [2008].

Hikishima et al. [2010b] showed generation of triggered emissions in the magnetosphere. Triggering whistler mode waves injected at the magnetic equator induces a nonlinear absolute instability that results in rising tone emissions. The phase-organized resonant electrons released by the triggering waves generate coherent waves that undergo nonlinear growth with increasing frequencies. The simulation showed that the saturation of the nonlinear wave growth is caused by enhancement of resonant electrons at high pitch angles that have been trapped and guided along the resonance velocity by the triggered emissions.

Saito et al.[2010b] conducted two-dimensional particle-in-cell simulations of decaying whistler turbulence in which the energy cascade rate is greater than the dissipation rate demonstrate a cascade of magnetic fluctuation energy at short scales. Their simulations show that the energy cascade is forward and anisotropic with preferential transfer of energy to wavevectors quasi-perpendicular to the background magnetic field. The magnetic wavenumber spectrum has a power-low index which is about -4. This steep magnetic spectrum is consistent with recent solar wind observations. It is expected that whistler turbulence may explain solar wind turbulence at short scales.

Shoji et al., [2009] analyzed the competing process between the L-mode electromagnetic ion cyclotron (EMIC) instability and the mirror instability by three dimensional hybrid simulation. The mirror instability becomes dominant by two reasons: (1) the large volume of the mirror mode waves in the 3D wavenumber space, (2) the quick dissipation of the L-mode EMIC waves due to nonlinear evolution.

Omura et al. [2010] developed a nonlinear wave growth theory of electromagnetic ion cyclotron (EMIC) triggered emissions observed in the inner magnetosphere [Pickett et al., 2010]. Starting from Maxwell's equations and the momentum equations for electrons and ions, they obtained a set of ordinary differential equations that describe the nonlinear evolution of a rising tone emission generated at the magnetic equator. Using the physical parameters inferred from the wave, particle, and magnetic field data measured by the Cluster spacecraft, they determined the dispersion relation for the EMIC waves. Numerical integration of the differential equations gave a solution for the time variation of the amplitude and frequency of a rising tone emission at the equator. A good agreement is found between the numerical solutions and the wave spectrum of the EMIC triggered emissions.

Lee et al. [2009] studied the cyclotron maser instability (CMI) driven by an energetic ring-beam distribution by a particle simulation and found that electrostatic wave modes excited by the electron beam instability compete with the electromagnetic waves excited by the CMI. They showed that this competing process results in the redistribution of the energetic electrons and makes the CMI less effective than it is anticipated theoretically.

Ryu et al. [2007] performed Vlasov and particle-in-cell (PIC) simulations to verify the finding that the collisionality of a plasma is crucial for the acceleration of electrons by Langmuir turbulence to a superthermal energy level. They confirmed it in the weak beam regime. However, in the strong beam regime, both the Vlasov and PIC simulations were found to produce a high-energy tail population, which indicates that there may be other mechanisms in the high beam speed situation.

Generations of electromagnetic wave modes during electron beam-plasma interactions are studied by means of large-scale two-dimensional full particle simulations. When the relative bulk velocity between total electrons and background ions is faster than the Alfven velocity, electromagnetic ion cyclotron waves are excited [Umeda, 2008]. When there are two counter-directional Langmuir waves, electromagnetic light mode waves are excited by a three-wave interaction [Umeda, 2010]. It is also shown that induced back-scattering of Langmuir waves by thermal ions is stronger than the back-scattering of Langmuir waves by parametric decay.

The parametric instabilities of coherent/incoherent Alfven waves in a finite ion beta plasma are studied by Nariyuki et al [2007,2008a,2008b,2009]. Nariyuki et al [2010b] studied that nonlinear scattering of protons and alpha particles during the dissipation of the finite amplitude, low-frequency Alfvenic turbulence. The heating occurs both in the parallel and in the perpendicular directions, and the ion distribution function which is asymmetric with respect to the parallel velocity is produced. A novel scheme of plasma simulation, particularly suited for computing the one-dimensional non-linear evolution of parallel propagating solar wind Alfven waves is developed by Nariyuki et al [2011].

The nonlinearity of the Langmuir turbulence excited by the weak-beam interaction is discussed by Nariyuki and Umeda [2010a]. After the linear growth saturates, while the wave power of the primary mode is much larger than the other modes, linear and nonlinear interactions occurring in both lower harmonic and secondary higher harmonic modes are more active than those in the primary mode.

Narita et al. [2008] presented an estimator of the bi-spectrum, a measure of three-wave couplings. It was evaluated directly in the wave number domain using a limited number of detectors. The ability of the bispectrum estimator was examined numerically and then it was applied to fluctuations of magnetic field and electron density in the terrestrial foreshock region observed by the four Cluster spacecraft, which indicates the presence of a three-wave coupling in space plasma.

Kuramitsu et al. [2008] discussed interaction between a magnetohydrodynamic (MHD) pulse and a charged particle both numerically and theoretically. Charged particles can be accelerated efficiently in the presence of spatially correlated MHD waves, such as short large amplitude magnetic structures, by successive mirror reflection (Fermi process). In order to understand this process, they study the reflection probability of particles by the MHD pulses, focusing on the adiabaticity on the particle motion. When the particle velocity is small (adiabatic regime), the probability that the particle is reflected by the MHD pulse is essentially determined only by the pitch angle, independent from the velocity. On the other hand, in the non-adiabatic regime, the reflection probability is inversely proportional to the square root of the normalized velocity. They discussed numerical as well as analytical results of the interaction process with various pulse amplitude, pulse shape, and the pulse winding number. The reflection probability is universally represented as a power law function independent from above pulse properties.

Kalaee et al. [2009] investigated a linear mode conversion process among UHR-mode, Z-mode and LO-mode waves by a computer simulation solving Maxwell's equations and the motion of a cold electron fluid. They showed that efficient conversion processes take place under the specific condition of the wave normal angle of the incident UHR-mode waves in which the perpendicular component of the refractive index becomes zero at the site of mode conversion. Their simulation results clarified that, by considering the steepness of the density gradient, efficient mode conversion could be expected even in the case of the mismatch of refractive indexes preventing the close coupling of plasma waves.

Kalaee et al. [2010] performed numerical experiments of the linear mode conversion process by assuming the density gradient of background plasma and the wave normal angle of incident upper hybrid mode waves determined from observations by the Akebono satellite. They found that the characteristics of reproduced LO-mode waves in each simulation run are consistent with observations.

Matsuda et al. [2010] developed a static Vlasov code, applied it to the Io-Jupiter system, and investigated source structure in order to clarify the ways in which the characteristics of Io-DAM are affected by the plasma in the Jovian ionosphere. A solution with a smaller ionospheric density for Io-B than for Io-A indicates lower altitude of the LATL for Io-B, which is consistent with the observed high-frequency limit higher for Io-B than for Io-A.

Asenjo et al. [2009] obtained the dispersion relation for circularly polarized electromagnetic waves propagating in the direction of an external magnetic field in a relativistic electron-positron plasma with arbitrary constant drift velocities for constant temperature in the homentropic regime. This result was an exact solution of the nonlinear magnetofluid unification field formalism introduced by S. Mahajan [Phys. Rev. Lett. 90, 035001 (2003)], where the electromagnetic and fluid fields are coupled through the relativistic enthalpy density. The behavior of electromagnetic and

Alfven branches of the dispersion relation were discussed for different temperatures.

The derivative nonlinear Schrodinger (DNLS) equation is explored by Sanchez-Arriaga, G. et al. [2009a] using a truncation model with three resonant traveling waves. In the conservative case, the system derives from a time-independent Hamiltonian function with only one degree of freedom and the solutions can be written using elliptic functions. In spite of its low dimensional order, the truncation model preserves some features from the DNLS equation. In particular, the modulational instability criterion fits with the existence of two hyperbolic fixed points joined by a heteroclinic orbit that forces the exchange of energy between the three waves. On the other hand, numerical integrations of the DNLS equation show that the truncation model fails when wave energy is increased or left-hand polarized modulational unstable modes are present. When dissipative and growth terms are added the system exhibits a very complex dynamics including appearance of several attractors, period doubling bifurcations leading to chaos as well as other nonlinear phenomenon. In this case, the validity of the truncation model depends on the strength of the dissipation and the kind of attractor investigated.

In Sanchez-Arriaga et al. [2009b], the triple-degenerate derivative nonlinear Schrodinger (TDNLS) system modified with resistive wave damping and growth was truncated to study the coherent coupling of four waves, three Alfven and one acoustic, near resonance. In the conservative case, the truncation equations derive from a time independent Hamiltonian function with two degrees of freedom. Using a Poincare map analysis, two parameters regimes are explored. In the first regime they checked how the modulational instability of the TDNLS system affects to the dynamics of the truncation model, while in the second one the exact triple degenerated case was discussed. In the dissipative case, the truncation model gives rise to a six dimensional flow with five free parameters. Computing some bifurcation diagrams the dependence with the sound to Alfven velocity ratio as well as the Alfven modes involved in the truncation was analyzed. The system exhibits a wealth of dynamics including chaotic attractor, several kinds of bifurcations, and crises. The truncation model was compared to numerical integrations of the TDNLS system.

Kimura and Nakagawa [2008] carried out a 2-dimensional electromagnetic full particle simulation of the electric field structure around the moon, introducing absorption of the plasma particles at the lunar surface. A plasma wake is formed behind the moon in the solar wind flow, and an intense electric field is produced near the terminator due to the negative charging of the night side surface of the moon.

Motoba et al. [2007] showed, by using a global MHD simulation, that oscillations in the solar wind dynamic pressure (Psw) could induce magnetic pulsations in the entire magnetosphere with the same period as that of Psw. They further studied the generation mechanism the Psw-forced pulsations.

By using a global MHD simulation, Fujita et al. [2010] found that long-period MHD disturbances induced in the magnetosphere due to periodic variations of the solar wind dynamic pressure show the feature of a non-linear spring. In addition, the authors resolved contradiction about disturbances of the magnetopause - one report about the surface eigenmode and another about almost stationary nature of the long-period disturbances induced by the solar wind disturbances in the dayside magnetosphere - by showing that the inertia current appears around local noon where the surface eigenmodes are observed.

Matsumoto and Seki [2010a] examined formation of a broad plasma turbulent layer by forward and inverse energy cascades of the Kelvin-Helmholtz instability by both MHD and PIC simulations. They found that the forward cascade is triggered by growth of the secondary Rayleigh‐Taylor instability excited during the nonlinear evolution of the KHI. The inverse cascade is accomplished by nonlinear mode couplings between the fastest growing mode of the KHI and other KH unstable modes. They indicate that this process can make a large scale mixing layer which resembles characteristics of the Earth LLBL.

Matsumoto and Seki [2010b] conducted PIC simulations of the Kelvin-Helmholtz instability under various mass ratios (M/m) and the electron plasma to gyro frequency ratios (wpe/wge) in order to understand dissipation mechanisms of the Kelvin-Helmholtz turbulence. As results, they found that the KH instability decays into turbulence due to a electron-scale secondary instability and the wave power of the electric field turbulence is proportional to (M/m)^1.3 and (wpe/wge)^2.4.

Shinohara et al. [2009] reported on the development of unique, high-density helicon plasma sources and describe their applications. Characterization of one of the largest helicon plasma sources yet constructed was made. Scalings of the particle production efficiency were derived from various plasma production devices in open literature and our own data from long and short cylinder devices, i.e., high and low values of the aspect ratio A (the ratio of the axial length to the diameter), considering the power balance in the framework of a simple diffusion model. A high plasma production efficiency was demonstrated, and they clarified the structures of the excited waves in the low A region down to 0.075 (the large device diameter of 73.8 cm with the axial length as short as 5.5 cm). They described the application to plasma propulsion using a new concept that employs no electrodes. A very small diameter (2.5 cm) helicon plasma with 1013 cm-3 density was produced, and the preliminary results of electromagnetic plasma acceleration were briefly described..

H2.3 Development of Simulation Code

The basic techniques and important concepts of the one-dimensional electromagnetic particle code: KEMPO1 [Omura and Matsumoto, 1993] was reviewed by Omura [2007]. A modification of the KEMPO1/MATLAB code for the solution of the relativistic equations of motion was described.

A robust numerical interpolation scheme for Vlasov code simulations is developed by using a positive, non-oscillatory and conservative limiter [Umeda, 2008]. The new Vlasov code is applied for parametric decay of Langmuir wave packets in space plasmas. It is shown that Langmuir waves decay into back-scattered Langmuir waves and ion acoustic waves when the wave power of parent Langmuir waves is larger than the thermal energy of background plasmas [Umeda and Ito, 2008]. A new two-dimensional Vlasov code including fully electromagnetic fields is also developed. The two-dimensional Vlasov code is successfully applied to the GEM magnetic reconnection challenge problem [Umeda et al., 2009]. The conservative limiter is also extended for application to MHD simulations [Tanaka et al., 2009].

A new two-dimensional shock-rest-frame model for full particle simulations is developed by Umeda et al. [2008]. The new model allows us to follow full-kinetic dynamics of collisionless shocks in a long-time simulation run. It is shown that shock front ripples enhance nonthermal electrons, suggesting that ion dynamics plays important roles in electron acceleration [Umeda et al. 2009]. They also made a direct comparison between quasi- and exactly perpendicular shock, and found that the global shock structure is modified by strong ion-scale fluctuations at the shock front called “ripples” in both cases [Umeda et al., 2010].

Amano et al.[2011] have developed a new kinetic model for the dynamics of energetic ring current particles in the terrestrial inner magnetosphere. The model employs a five-dimensional drift-kinetic equation for the description of particle transport which is coupled with the Maxwell equations in a self-consistent manner. They have demonstrated that the developed model is capable of describing field reconfigurations in the inner magnetosphere accompanied by magnetohydrodynamic waves.

H3. Lunar and Planetary Plasma Wave Study

<KAGUYA (SELENE) >

KAGUYA was launched on September, 14, 2007 in order to explore the surface distribution of elements and minerals, surface and subsurface structures of the moon, the gravitational field, the magnetic field, and energy particles originating from the moon, as well as from solar/interplanetary space [Kato et al., 2007]. The Lunar Radar Sounder (LRS) is one of the scientific instruments onboard the KAGUYA main orbiter [Ono et al., 2008; 2010, Kasahara et al., 2008, Kumamoto et al. 2008]. The LRS consists of two orthogonal 30 m tip-to-tip antennas and three subsystems; the sounder observation (SDR), the natural plasma wave receiver (NPW), and the waveform capture (WFC).

A main objective of the SDR is to investigate the surface and subsurface structures of the moon using an HF radar technique, and the NPW and the WFC are designed to measure natural plasma waves around the moon and in interplanetary space originating from the sun, from the earth, and from other planets. The NPW covers the frequency range from 20 kHz to 30 MHz, and the WFC covers the lower frequency range from 100 Hz to 1 MHz. The operation of KAGUYA ended its scheduled nominal mission on October 31, 2008, and the mission was extended until KAGUYA was impacted to the south-east of near side of the moon on June 10, 2009. Nominal data acquisition of the LRS was performed until September 10, 2008. The operation of WFC was again restarted on February 19, 2008 and the operation was continuously performed until KAGUYA was impacted to the south-east of near side of the moon on June 10, 2009 [Ono et al., 2010].

Radar sounding by the SDR has revealed subsurface layers at an apparent depth of several hundred meters in nearside maria. Ono et al. [2009] discovered prominent reflectors lying at the apparent depths of a few hundred meters in the nearside maria of the Moon. The age of subsurface layer can be determined by crater chronology of outcrop region. The prominent echoes found in Mare Selenitatis are probably from buried regolith layers accumulated during the depositional hiatus of mare basalts between 3.55 and 3.44 billion years ago. The mare ridges in the southern part of Selenitatis basin were formed after 2.84 billion years ago, which suggests that global cooling probably dominated the tectonics after 2.84 billion years ago.

During the KAGUYA mission, like the Luna experiments, an electron density profile above the lunar surface was observed by the radio occultation technique using sub-satellite [Imamura et al., 2008]. Since density of the lunar ionosphere is obtained by subtracting effects of the earth's ionosphere, estimation accuracy of the lunar ionosphere is unfortunately restricted to that of the earth's ionosphere. On the other hand, the KAGUYA continuously observed natural waves with the LRS-NPW and WFC instruments. Spectrogram of auroral kilometric radiation (AKR) whose origin is the earth's polar region sometimes shows an interference pattern which is caused by phase differences between directly arrived waves and waves reflected on the lunar surface [Ono et al., 2010]. Because plasma frequencies of peak electron densities observed by the Luna correspond to a frequency band of the AKR waves, the waves are reflected on the lunar ionosphere in case it exists. Goto et al. [2008] proposed a new lunar ionosphere exploration method using such interference patterns of the AKR. In this method, they demonstrated that a theoretical interference pattern of the AKR for a given electron density profile can be constructed by calculating phase delays of reflected waves to direct waves. Comparing an observed interference pattern with the theoretical ones for candidate density profiles, the most reasonable profile is chosen. This is a new approach to examine the existence of the lunar ionosphere which is not based on the radio occultation technique.

Because the moon is basically non-magnetized, the solar wind particles directly hit the lunar surface and a plasma cavity called the “lunar wake” is created behind the moon. Hashimoto et al. [2010] presented observations of electrostatic solitary waves (ESWs) near the Moon in the solar wind and in the lunar wake. They demonstrated that ESWs are categorized into three types depending on different regions of observations: ESWs generated by electrons reflected and accelerated by an electric field in the wake boundary (Type A), strong ESWs generated by bi-streaming electrons mirror-reflected over the magnetic anomaly (Type B), and ESWs generated by reflected electrons when the local magnetic field is connected to the lunar surface (Type C).

Nishino et al. [2010] studied effect of the solar wind (SW) proton entry deep into the near-Moon wake that was recently discovered by the KAGUYA spacecraft. Because previous lunar-wake models are based on electron dominance, no effect of SW proton entry has been taken into account. They showed that the type-II entry of SW protons forms proton-governed region (PGR) to drastically change the electromagnetic environment of the lunar wake. Broadband electrostatic noise found in the PGR is manifestation of electron two-stream instability, which is attributed to the counter-streaming electrons attracted from the ambient SW to maintain the quasi-neutrality. Acceleration of the absorbed electrons up to ~1 keV means a superabundance of positive charges of 10^{-5}~$10^{-7}cm^{-3}$ in the near-Moon wake, which should be immediately canceled out by the incoming high-speed electrons. They demonstrated that this is a general phenomenon in the lunar wake, because PGR does not necessarily require peculiar SW conditions for its formation.

Associated with the solar wind protons reflected by the moon [Saito et al., 2008] and the magnetic anomaly on the lunar surface [Tsunakawa et al, 2010], various magnetic field fluctuations were detected by Kaguya on its orbit around the moon at an altitude of 100km above the lunar surface. Among them are large-amplitude, low-frequency waves of 0.01Hz, monochromatic whistler waves at around 1 Hz, and non-monochromatic fluctuations in the frequency range from 0.03 to 10 Hz. They are thought to be generated by the reflected protons through wave-particle interaction processes [Nakagawa et al., 2011].

<BepiColombo>

The BepiColombo is the science mission to Mercury. It is the first collaborative space program of JAXA and ESA. The BepiColombo mission consists of two individual spacecraft called MPO (Mercury Planetary Orbiter) and MMO (Mercury Magnetospheric Orbiter). Two spacecraft of the BepiColombo will be launched in 2014.

The PWI investigates plasma/radio waves and DC electric field in Mercury magnetosphere. The detailed science objectives of the PWI are described by Kasaba et al. [2008]. The PWI consists of two components of receivers (EWO: Electric Field Detector/Wave-Form Capture/Onboard Frequency Analyzer, and SORBET: Spectroscopie Ondes Radio & Bruit Electrostatique Thermique), two sets of electric field sensors (WPT: Wire-Probe antenna, and MEFISTO: Mercury Electric Field In-Situ Tool), two kinds of magnetic field sensors (LF-SC: Low Frequency Search Coil, and DB-SC: Dual-Band Search Coil), and the antenna impedance measurement system (AM2P: Active Measurement of Mercury's Plasma).

The Critical Design Review by JAXA was conducted in April, 2010. For about one week review meeting, the review panel for the PWI approved to proceed to manufacture the flight model of the PWI judging from the results of the design, tests, and evaluations in the engineering model. The first flight model integration test of the PWI at Kyoto University is scheduled in April, 2011.

H4. New instruments and sensors for plasma wave experiment>

Electric antenna behavior in space plasmas has received considerable attention in radio science community. Recently, the Particle-in-Cell (PIC) simulation approach is utilized to resolve the inherent complexity of electric antenna properties in space plasmas.

Miyake et al. [2008a] applied the three-dimensional electromagnetic particle simulations to impedance analysis of a short dipole surrounded by an ion sheath. They demonstrated the approach is so effective to include the effects of plasma inhomogeneity in the antenna analysis.

Miyake and Usui [2008] studied the effects of photoelectron emission on antenna impedance. It was revealed that the low-frequency contact resistance between the antenna and plasma is greatly affected by photoelectron dynamics near the antenna surface.

By taking advantage of self-consistency of the PIC approach, Miyake et al. [2008b] reproduced a double-probe antenna behavior of receiving various plasma waves in space. The effective length of the antenna was found to become shorter than the physical separation between probes, which is due to the presence of the conducting boom between the probes.

A strong demand should arise regarding the understanding of the spacecraft-plasma interactions in the context of rapidly increasing space development. This topic is also associated strongly with radio science, because such spacecraft-plasma interactions are often accompanied by various plasma wave processes.

Miyake and Usui [2009] developed a new particle simulation code for the analysis of spacecraft-plasma interactions on the electromagnetic basis. They proposed numerical treatments of current density and charged accumulation on internal boundaries describing spacecraft surfaces.

Usui et al. [2008] studied the mitigation process of absolute and differential charging of spacecraft in the polar environment by plasma release from the spacecraft surface. Their PIC analysis revealed that ion release in addition to electrons from the contactor is effective to neutralize the charges locally accumulated on the dielectric surface.

Magneto Plasma Sail (MPS) is proposed as one of the innovative interplanetary flight systems. To estimate the MPS thrust quantitatively, multi-scale kinetic interactions between the solar wind plasma and a small-scale artificial magnetosphere should be understood comprehensively. To this end, Usui et al. [2009] established the methodology of the multi-scale plasma particle simulations by combing Adaptive Mesh Refinement and PIC methods. In parallel to the code development, the detailed mechanism of magnetic inflation around MPS was studied intensively [Moritaka et al., 2010]. They revealed that the gyration motion of injected ions takes a key role in an effective inflation process of a magnetosphere with a scale comparable to the injected ion gyration radius.

Fukuhara et al. [2009] developed the new instrument dedicated to the direct observation of wave-particle interactions in space plasmas. They introduced the Wave-Particle Interaction Analyzer

(WPIA) to observe wave-particle interactions directly by calculating the inner product between the electric field of plasma waves and of plasma particles. The WPIA has four fundamental functions: waveform calibration, coordinate transformation, time correction, and interaction calculation. Fukuhara et al. [2009] also demonstrated the feasibility of One-chip WPIA (O-WPIA) using a Field Programmable Gate Array (FPGA) as a test model for future science missions.

Kasaba et al. [2010] developed three types of stiff and extendible electromagnetic sensors in rigid monopole antenna, loop antenna, and Yagi-Uda antenna for future space missions. They are based on carbon fiber reinforced plastic (CFRP) technologies, in order to fulfill severe requirements, i.e. enough stiffness, light mass, compact storage, safe extension, and reasonable test efforts. One of them, rigid monopole antennas, coupled with an inflatable actuator system, was successfully used in the JAXA S-520-23 sounding rocket experiment in September 2007. Applications of those antennas are expected in space plasma missions including the SCOPE program, sounding rocket experiments, planetary radar remote sensing, and landing radio measurements.

Kojima et al. [2010] achieved extreme miniaturization in plasma wave receivers for future space science missions. They described one-chip waveform type receivers that are developed using analogue ASIC technology. They succeeded in incorporating the necessary analogue components of the waveform receiver into a chip having dimensions of 3mm × 3mm and confirm the functionality and performance of the chip. Furthermore, they extended the application of the miniaturized plasma wave receivers to a sensor network system in space. The sensor network system consists of several small sensor nodes that are distributed randomly throughout the target area and monitor the spatial and time variation of electromagnetic environments in space. Kojima et al. [2010] introduced the concept of this sensor network system and presented results obtained during the development of the small sensor node for use in this sensor network in space.

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Acknowledgments

The editors thank Dr. H. Kojima, Dr. S. Yagitani, Dr. Y. Kasahara, Dr. Y. Katoh, Dr. Y. Hobara, Dr. T. Nakagawa, Dr. M. Nose, Dr. Y. Miyoshi, and K. Ishisaka for their collaboration in editing the report. As for the section of ULF, the editors thank Dr. S. Fujita, Dr. H. Kawano, Dr. Y. Obana, Dr. S. Saita, Dr. K. Sakaguchi ,and Y.-M. Tanaka.