Commission H (Waves in Plasmas) Activity Report (ver.1)

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Research Topics

<Akebono>

Akebono (EXOS-D) satellite has been observing electromagnetic waves in geomagnetized plasmas. It is necessary to know the antenna impedance of the VLF electric field antennas onboard Akebono to calibrate the electric field component data. Higashi et al. [2009] have researched the fluctuation of the antenna impedance in the short term.

In their study, a statistical analysis about the capacitance component of the antenna impedance was done. The capacitance components are expected to depend on the electron density because they are determined by the thickness of the plasma sheath formed around the antenna element. However, in the analysis of data observed by Akebono from 1989 through 1995, the effects on the capacitance components of the altitude of Akebono are small (Figure 1). The effects of the strength of the geomagnetic field and the satellite velocity are also small, and the capacitance components are almost constant as roughly 500 pF in Akebono's orbit.

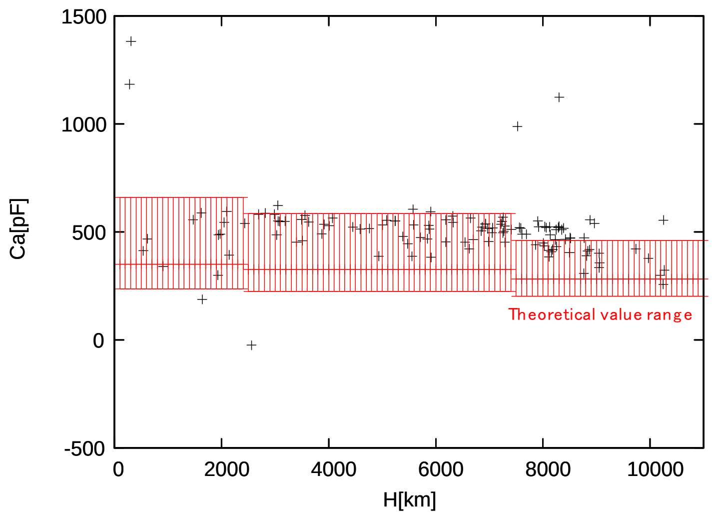

Figure 1: The dependence on altitude of the capacitance component of the antenna impedance of the electric field sensors onboard Akebono.

<GEOTAIL>

GEOTAIL spacecraft has been operated since 1992. The Plasma Wave Instrument (PWI) is continuously collecting spectrum data and high time-resolution waveform data. It is expected to be in a good condition at least until the next long eclipse in 2010. The 24 hour plots of the observed wave spectrum data have been opened in the PWI web site http://www.rish.kyoto-u.ac.jp/gtlpwi, and http://www.stp.isas.jaxa.jp/geotail. Furthermore, one can easily also access the PWI 2 hour plots with full time and frequency resolution through the above web page.

<Cluster>

Hobara et al. (2008) have used a period of internal burst mode data from the Cluster electric field and wave instrument, who have found a number of electrostatic solitary structures in the foot region of Earth’s quasi-perpendicular bow shock. The four individual probe potential measurements are utilized to study the fundamental characteristics of those solitary waves; propagation vector, propagation velocity, scale-size and potential amplitudes. Then, two classes of waves are observed; bipolar and unipolar/tripolar solitary waves. These waves are investigated in terms of BGK holes.

<BepiColombo>

The BepiColombo is the science mission to Mercury. It is the first collaborative science mission between JAXA and ESA. The BepiColombo mission consists of two individual spacecraft called MPO (Mercury Planetary Orbiter) and MMO (Mercury Magnetospheric Orbiter). Scientists in Japan and Europe jointly proposed the plasma wave observation system called PWI (Plasma Wave Investigation). The proposal was successfully accepted and the development of the PWI component started. The MMO launch is scheduled in 2014. The Principal Investigator of the PWI is Prof. Yasumasa Kasaba of Tohoku University.

The PWI investigates plasma/radio waves and DC electric field in Mercury magnetosphere. It consists of two components of receivers, two sets of electric field sensors, two kinds of magnetic field sensors, and the antenna impedance measurement system.

Photo1: Engineering model of the plasma wave instruments onboard BepiColombo.

The PWI consists of EWO, MEFISTO-E, SORBET, and AM2P receiver components as well as WPT-S, MEFISTO-S as electric field sensors and LF-SC and DB-SC as magnetic field sensors. The engineering models of these components have been established and tested in Kyoto University in April, 2009. The test results show the good features except for non-serious problems. Furthermore, in July, 2009, the engineering model tests with the spacecraft data handling system have been conducted in JAXA. All of the PWI components joined the tests and checked their function and the digital interface with spacecraft system.

<Sounding Rocket Experiments>

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. 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 measures the received radio wave intensities from two broadcast stations at frequencies of 60 kHz and 873 kHz. The LMR have been able to observe the relative attenuation of radio waves from ground up to the ionosphere. The electron density profile in the lower ionosphere is estimated by comparing these experimental results with the propagation characteristics calculate by the full wave method. Figure 2 show the electron density profile and propagation characteristics of radio waves for the ascent. Left panel are shown electron density profile measured by the impedance probe (NEI) (blue line) and estimated by the propagation characteristics of radio waves (red line), middle panel are propagation characteristics of 60 kHz radio waves measured by LMR (blue line) and calculated by the full wave method (red line), and right panel are propagation characteristics of 873 kHz radio waves. In the electron density profile, the *Es* layer has a single-layer structure at the altitude of 100 km. The peak electron density of the *Es* layer is 5×10^4 cm^{-3}. The second peak electron density is 2×10^4 cm^{-3} at the altitude of 133 km. Then electron density profile in the lowest ionosphere at the altitude less than 90 km is estimated from radio wave propagation characteristics. The altitude profiles of radio waves are similar for the calculated value using the estimated electron density profile and the measured value.

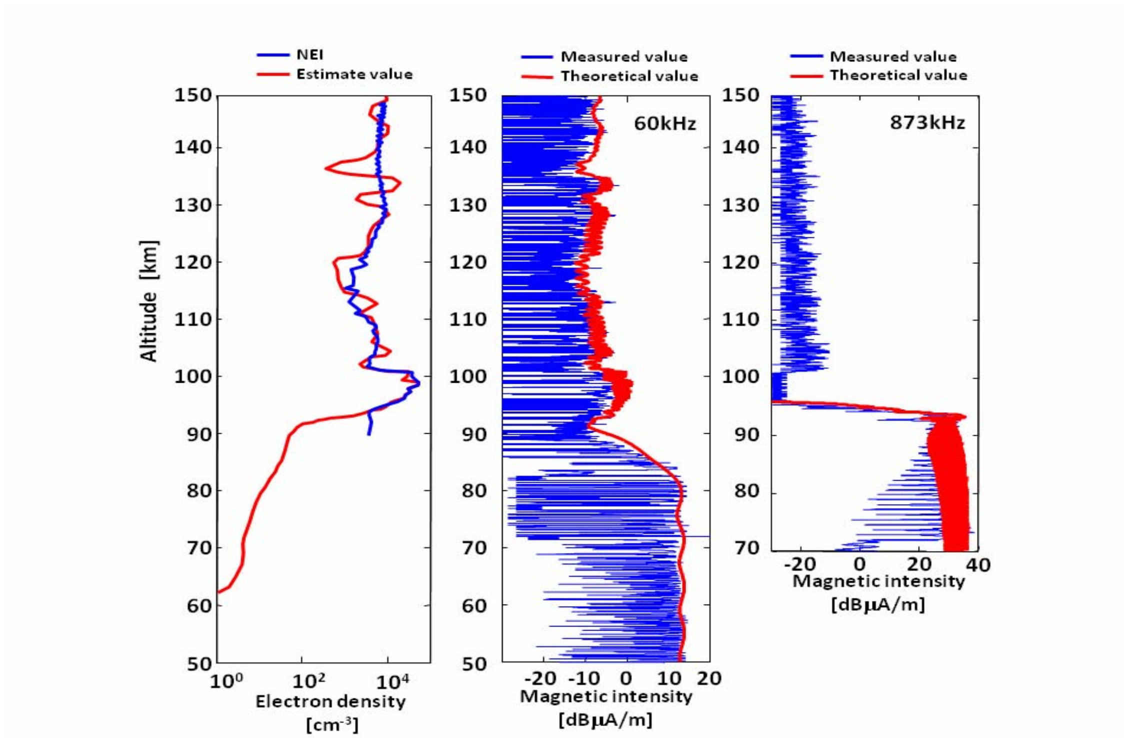

Figure 2: Estimation of electron density profile form the radio wave propagation characteristics observed by S-310-38 sounding rocket.

<Polar Region Experiments>

Ozaki et al. [2009] have investigated an interesting natural harmonic VLF/LF waves observed at Syowa station in Antarctica. The frequency components of harmonic spectrum exist in the frequency range of 10 kHz to 100 kHz [Okada et al., 2009].

Under an assumption that the origin of the harmonic spectrum is from the magnetosphere, they have calculated the spectrum of whistler mode waves on the ground, which are injected from the magnetosphere. The calculation results give 2 kHz and its harmonics, because the whistler mode waves resonate in the Earth-ionosphere waveguide. However, the harmonic spectrum does not extend over 10 kHz. Thus, the harmonic VLF/LF spectrum would not be generated inside the magnetosphere.

Also, they assumed that the origin of the harmonic spectrum is from the Earth such as sferics. They have theoretically calculated the frequency spectrum of a sferic as shown in Figure 3. The calculation results give the harmonic spectrum similar to the observation. Furthermore, their calculation results show that the harmonic spectrum almost do not depend on the horizontal distance. This suggests that the harmonic spectrum does not relate to wave propagation in the Earth-ionosphere waveguide. The harmonic spectrum would originate from the inherent spectrum of the sferic.

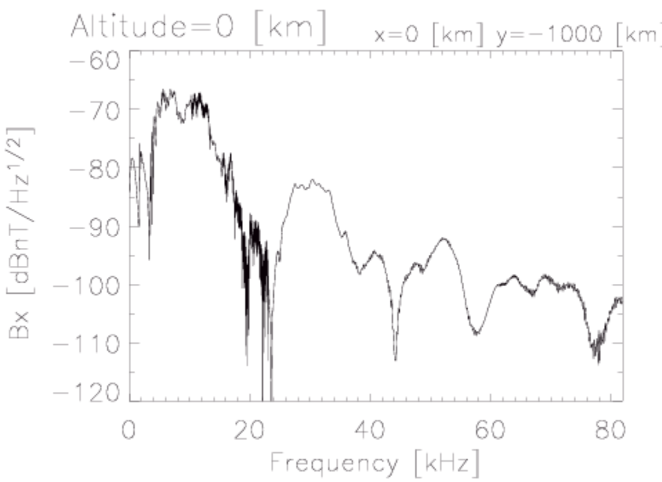

Figure 3: Calculated spectrum of a sferic propagated over a long distance in the Earth-ionosphere waveguide.

In order to observe more events of auroral roar and Medium Frequency (MF) burst, Sato et al. (2009) installed a receiver and loop antenna at Longyearbyen in Svalbard (CGM Lat.: 75.2 deg) in August 2008 in addition to the station at Husafell in Iceland (CGM Lat.: 65.3 deg), just in the auroral region where auroral emissions are difficult to reach the ground due to loss in auroral ionosphere. The instrument at Longyearbyen consists of two types of observation systems; one was designed for the continuous observation of spectrum in a frequency range below 6 MHz. The other was designed to obtain waveform data in a frequency range below 4 MHz, which makes it possible to determine the arrival direction of the auroral radio emissions. Some event studies suggests that MF burst is generated by high energy electrons in lower latitude while auroral roar is generated by low energy electrons just above the station.

< KAGUYA (SELENE)>

KAGUYA (SELENE) spacecraft Lunar radar sounder (LRS) onboard the Kaguya (SELENE) spacecraft successfully obtained 2362-hours worth of radar sounder data and 6523-hours worth of natural plasma wave data in the nominal operation period from October 29, 2007 to September 10, 2008 and 1714-hours worth of natural plasma wave data in the extended operation period until June 10, 2009. Those data will contribute the sciences of the lunar geology, physics of plasma around the moon, and radio waves from the earth and other planets.

Kumamoto et al. (2009) reported that LRS observed radio waves such as auroral kilometric radiation (AKR), Type III solar radio burst, Jovian hectometric radiation (HOM), and radio communication waves from the earth. It was found that the radio communication waves even around 5 MHz interfered with radar sounder observations when the earth’s nightside faced to the Moon. The phenomena are probably caused by the difference of shielding effects of the earth’s ionosphere in dayside and nightside.

Nakagawa et al. (2009) made global mapping of echo power based on Lunar Radar Sounder (LRS) data. It has been found that the echo power is mainly correlated with surface roughness and also with FeO abundance in the surface determined by Lunar Prospector (LP). Correlation with FeO abundance probably suggests the reflectivity of radio wave at the lunar surface depends not only on roughness but also the dielectric properties.

Lunar Ionosphere Exploration Method using Auroral Kilometric Radiation

The lunar ionosphere is known to be extremely tenuous compared with the earth's ionosphere. In theory, the peak density is less than or equal to the solar wind density. It was, nevertheless, reported that 500-1000 cm^{-3} electron densities were observed at altitudes of 5-10 km with a radio occultation technique from the Soviet Luna 19 and 22 in 1970s (Vyshlov and Savich, 1979). This report is, however, still controversial because the observed large density is difficult to explain theoretically without magnetic shielding from the solar wind. So that such high densities exist, there must be unknown maintainable or transfer mechanism of charged particles.

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 (Ono et al., 2008; Kasahara et al., 2008). 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. 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. (2009) presented a new lunar ionosphere exploration method using such interference patterns of the AKR. In this method, a theoretical interference pattern of the AKR for a given electron density profile is constructed by calculating phase delays of reflected waves to direct waves with ray tracing. 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. In Figure 4 as an example, they demonstrated that no dense layer existed for an observation in the nightside region.

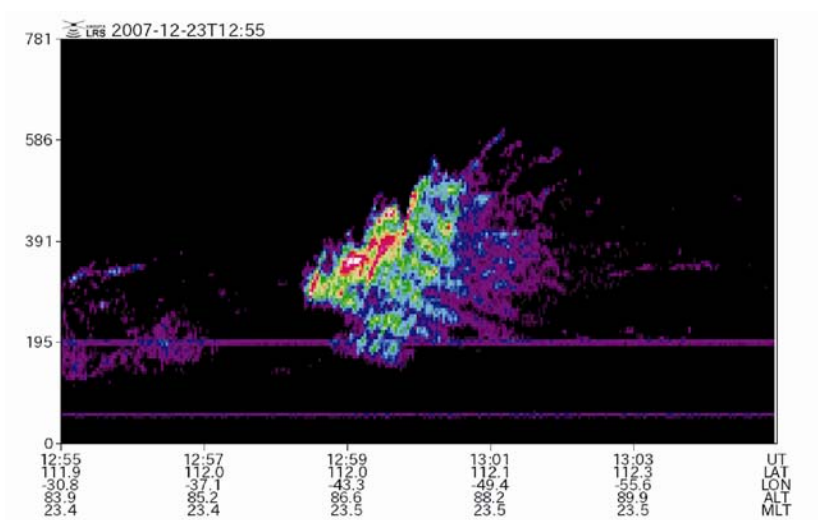

Figure.4: An example of interference pattern on AKR observed by LRS-NPW (2007-12-23 12:55). The horizontal axis indicates observation time (UT) and the vertical axis does frequency in kHz. Wave intensity at each frequency point is given by color.

Lunar ULF Waves

Various magnetic fluctuations associated with the solar wind interaction with the moon were detected by MAP-PACE/LMAG magnetometer onboard Kaguya. Most commonly observed around the moon are (1) large-amplitude, low frequency waves with the period around 100 seconds, and (2) non-monochromatic fluctuations whose frequencies range from 0.03 to 5 Hz.

The low frequency waves (0.01 Hz) detected by Kaguya, whose occurrence is often associated with the crustal magnetic field, is supposed to be generated by the ions that are reflected by the local intense field associated with the crustal magnetic field back into the upstream solar wind and then convected down the solar wind stream to be detected, just like the upstream waves generated by the ions reflected by the earth's bow shock. On the other hand, the 0.03-5 Hz fluctuations are detected by Kaguya on the solar side surface of the moon, regardless of the crustal magnetic field. They were not observed deep in the wake.

Such waves were also reported by Lunar Explorer as sporadic broadband (0-2Hz) magnetic turbulence in the solar wind or wake boundary region when the spacecraft was magnetically connected to the surface of the moon. Analogous to the whistler waves upstream of the earth's bow shock, the non-monochromatic magnetic fluctuations are supposed to be whistler waves, mainly because of their frequency and the upstream propagation against the solar wind. On the other hand, it is expected that the generation mechanism is quite different from the monochromatic whistler waves which are often related with beams of ions or electrons.

<Jupiter Observations>

By using Iitate Planetary Radio Telescope (IPRT), Tsuchiya et al. (2009) performed observation of absolute total flux of Jupiter's synchrotron radiation (JSR) at several frequencies below 1 GHz, which are not often observed by other research groups. The short-term variation of total power flux of JSR at 325 MHz shows clear correlation with the solar UV/EUV indices with a few days delay (Figure 5), which suggest that an enhanced radial diffusion, which is driven by the neutral wind in the upper atmosphere, is responsible for the time variation of JSR in the low frequency range.

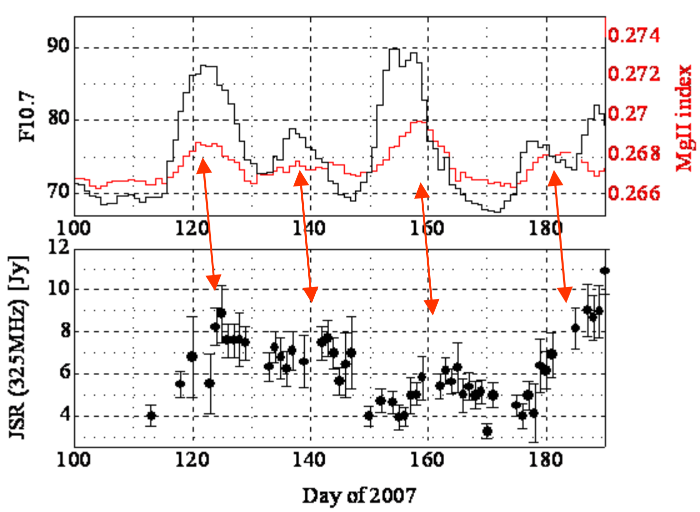

Figure 5: Comparison between JSR observed at 325MHz and the solar EV/EUV indices from DOY 100 to 190 in 2007.

Koshida et al. (2009) investigated millisecond timescale phenomena in L-burst of Jovina decametric radiation (DAM) based on the observation of Wave Form Receiver (WFR) at Iitate Planetary radio wave observatory. New absorption phenomena with slower drift rate than that of S-burst and Fast Drift Shadow (FDS) event, which are reported by previous studies, were found in the L-busts and named Slow Drift Shadow (SDS) event. The analysis results suggest that these phenomena are related with Alfven waves propagating in the Io flux tube.

<ULF Waves>

The Symposium on Electromagnetospheric Physics was held in Fukuoka, Japan, on March 4-5, 2009. This meeting, convened by H. Kawano and K. Shiokawa, was meant as a platform where scientists working on global observations and global simulations meet, discuss, and strengthen collaborations. Around forty people attended, and presentations and discussions were made along the line of the global observations and simulations, on various subjects, including ULFwaves; speakers talking on ULF-related subjects include the following (in alphabetical order, followed by the subjects of their talks).

H. Kawano (MAGDAS/CPMN, ULTIMA, and ground-based remote-sensing of the magnetospheric plasma density using ULF waves), R. Nomura (Polarizations of Pc 1 pulsations observed on the ground at mid-latitudes), M. Nose ("Substorm Swift Search" website, including Wp index based on Pi 2 wave powers), Y. Obana (Storm-time perturbations in the inner-magnetospheric plasma density, remote-sensed from the ground using ULF waves), V. Pilipenko (Nature of Pc 3 waves above the ionosphere), S. Saita (Nature of high-latitude Pc 5 waves observed by automatic ground magnetometers in Antarctica), K. Sakaguchi (Nature of EMIC waves in the inner magnetosphere, estimated from the nature of isolated proton aurorae), and M. Shinohara (Pc 5 index using low-latitude ground magnetometers).

JPGU (Japan Geoscience Union) meeting 2009 was held in Makuhari, Japan, May 16-21, 2009. This meeting covered a wide area of geosciences, including ULF waves, thus wide varieties of papers were presented related to ULF waves.

<Ionospheric effects on Radio Wave Propagation>

Hayakawa et al. (2008a) have found anomalous Schumann resonance effects as observed at Moshiri (Japan) in possible association with a large earthquake (named Pingtung earthquake) (M=7.8) in Taiwan. The anomaly is characterized by an increase in intensity at the frequencies from the 3rd to 4th resonance modes mainly on the B_{EW} component. Spectral modification takes place only in the UT internal of $21 \pm 1h$, corresponding to the American source. This phenomenon is interpreted in terms of the interference between the direct signal from the American lightning source and the signal scattered by the seismo-ionospheric disturbance located over Taiwan.

Hayakawa et al. (2008b) have investigated the precursory effect of ionospheric perturbations associated with the large 2007 Niigata Chuetsu-oki earthquake by making full use of the Japanese VLF/LF network. The ionospheric perturbation is identified from a comparison of different VLF/LF propagation paths; JJI transmitter (Ebino, Kyushu)-Moshiri, JJY (Fukushima)-Moshiri, JJY-Kochi and JJI-Tateyama (Chiba) and also the spatial scale of the seismo-ionospheric perturbation is estimated.

Nickolaenko et al. (2008) have compared the theoretical and experimental waveforms of ELF transients, so-called Q bursts. The experimental data are observed with a vertical antenna in a frequency range from 1Hz to 11kHz at Kochi, Japan. Experimental waveforms of several Q-bursts are compared with computations based on the analytical time domain solution (with the uniform Earth-ionosphere cavity with a linear frequency dependence of the propagation constant). The comparison gives us good coincidence between the data and theory, which confirms the validity of the model and the consistency of the source-observer distance.

Matsudo et al. (2009) have estimated the time delay of sprites behind their parent lightning discharges. The results are summarized as follows: (i) the predominance of column sprites in winter has been confirmed not only for the Hokuriku area but also in the Pacific Ocean, (ii)carrots are much more frequently observed in the Pacific Ocean (with a probability of ～28%) than in the Hokuriku area (～16%), (iii) a very unique property of Hokuriku sprites is the surprisingly long delay (average ～90ms) from their parent lightning flashes, and so on.

Myokei et al. (2009a,b) have examined the major effect in the appearance of sprites and in determining the morphology of sprites (columns or carrots), on the basis of continuous observations of sprites in the Hokuriku area of Japan from two sites (Chofu and Shimizu) during the three winter periods. Detailed analysis is performed based on the estimation of the height of -10° C at the time of sprite occurrence. When the height of -10° C is lower than 1800m, the occurrence of sprites is infrequent, and the dominant shape is column. Then when it is increased (1800-3000m), a new situation takes place, namely the occurrence of sprites is very enhanced and more spectacular shapes like carrots tend to be observed in addition to column sprites. These informations would be of essential importance in obtaining further understanding of generation mechanism of sprites.

<Computer simulations>

Luminous Events (like sprites)

Asano et al. (2009a) have tried to explain several unsolved questions related to transient luminous events (like sprites) such as the long-delay and lateral shift of a sprite against its parent lightning. Their use of electromagnetic (EM) code of computations has shown the potential importance of the high frequency components (like M components) in the lightning continuing current, and the simultaneous presence of the QE (quasi-electrostatic) field and electromagnetic effect is of essential importance in accounting for the long-delay effect of sprites. Asano et al. (2009b) have studied the effect of a horizontal channel of the lightning stroke, which is able to explain the occasional occurrence of lateral shift of a sprite against its parent lightning.

Antenna Characteristics in Space Plasma

Suzuki et al. (2009) have investigated characteristics of the cyclotron harmonic resonances found in the impedance probe observations in the thermal anisotropic plasma by laboratory experiment. The RF impedance of an antenna in a thermal plasma shows resonance around the electron cyclotron harmonic frequency. It was also found that the 2nd order of cyclotron harmonic series resonance sometimes became much clearer than the plasma sheath resonance (Figure 6). These resonances make it difficult to identify the upper hybrid resonance (UHR) measured by impedance probe. The results will help us to understand the impedance probe data affected by thermal plasma.

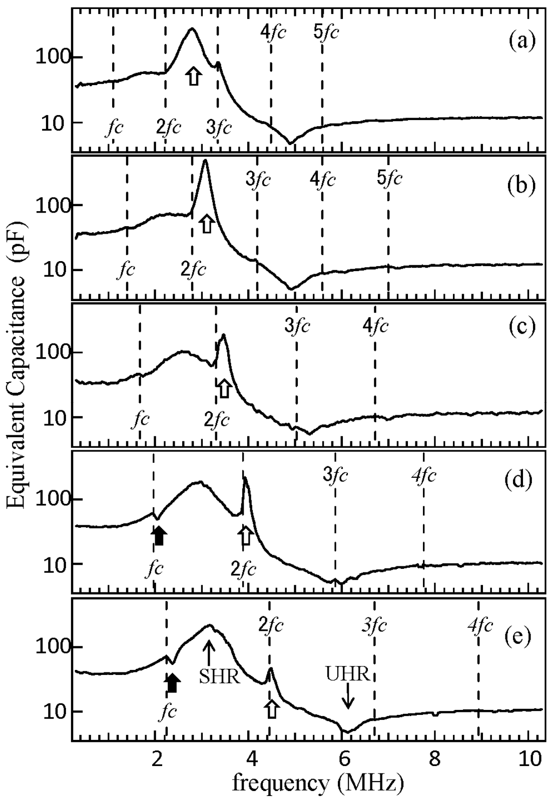

Figure 6: Variation of the probe equivalent capacitance depending on the magnetic field intensity. Large peaks are found at 2fc.

Hikishima et al. (2009) examined distribution functions of energetic electrons by resonant interactions with whistler-mode rising chorus waves near the magnetospheric equator in a self-consistent electromagnetic full-particle simulation. Figure 7 shows the time evolution of the phase space density of energetic electrons as a function of pitch angle in the presence of chorus emissions. The shapes of pith angle distribution aregradually deformed through a nonlinear scattering by rising chorus elements. A large number of resonant electrons with K = 50, 100 keV are scattered inside the loss cone angle (< 20 degrees). On the other hand, trapped resonant electrons are nonlinearly scattered toward higher pitch angles. The nonlinear trappings form distribution functions of electrons with peaked at higher pitch angles, which is called pancake distribution.

Omura et al. (2009) developed a nonlinear wave growth theory of chorus emissions, taking into account the spatial inhomogeneity of the static magnetic field and the plasma density variation along the magnetic field line. They derived theoretical expressions for the nonlinear growth rate and the amplitude threshold for the generation of chorus emissions. The amplitude threshold is tested against both observational data and self-consistent particle simulations of the chorus emissions. They obtained equations for the wave amplitude and frequency, reproducing a rising chorus. Chorus emissions, however, occur in two distinct frequency ranges, a lower band and an upper band, separated at half the electron gyrofrequency. They explained the gap 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.

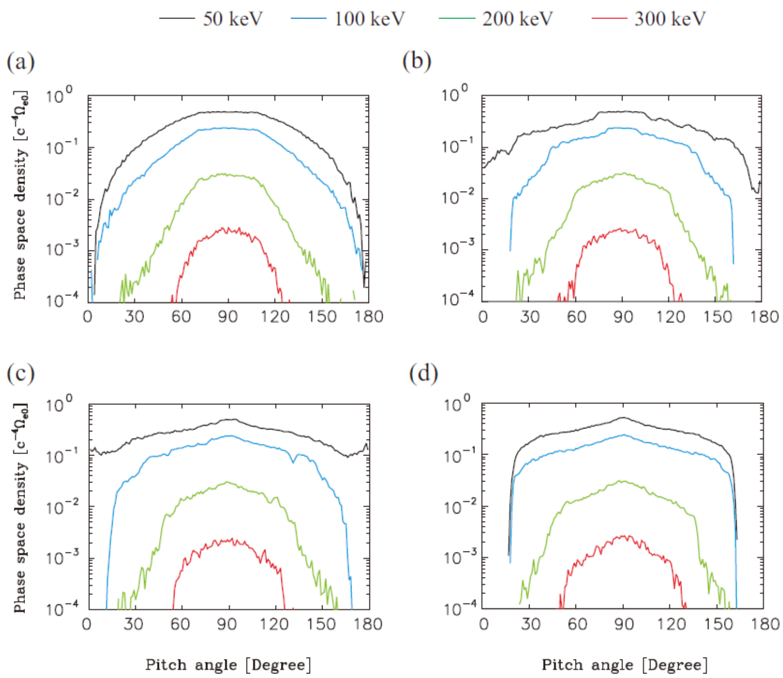

Figure.7: Pitch angle distributions of electron phase space density with different kinetic energies K = 50, 100, 200, 300 keV.

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Conferences and Meetings

1) Symposium on Electromagnetospheric Physics, Fukuoka, Japan, March 4-5, 2009.
2) 3rd European Conference on Antenna and Propagation (EuCAP) 2009, Berlin March 23-27, 2009
3) PGU (Japan Geoscience Union) meeting 2009, Makuhari, Japan, May 16-21, 2009.
4) IEEE MTT-S International Microwave Symposium 2009, Boston Massachusetts June 7-12, 2009
5) IEEE AP-S 2009, Charleston, South Carolina May 31-June 6, 2009
6) International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM) and the Canadian Radio Sciences Meeting (URSI/CNC), Banff, Canada July 27-30, 2009
7) The 11th Scientific Assembly of IAGA, Hungary Aug. 23-30, 2009
8) IEEE AP-S 2010, Toronto, Ontario, Canada July 10-17, 2010

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