COMMISSION H: Waves in Plasmas
(November 2016 – October 2020)

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1. Summary

1.1 Plasma wave observations in space and at ground stations

The most striking activity in this time period is the launch of two Japan's spacecraft. One is the Arase satellite investigating the terrestrial radiation belts and the other one is the BepiColombo spacecraft, the mission to Mercury. The Arase satellite was launched in December 2016. The onboard plasma wave receiver investigates wave-particle interactions that contribute to particle scattering and accelerations (Kasaba et al., 2017a; Hikishima et al., 2018; Y. Kasahara et al., 2018; Katoh et al., 2018a; Kumamoto et al., 2018; Matsuda et al., 2018b; Miyoshi et al., 2018a, 2018b; Ozaki et al., 2018c). The launch of the BepiColombo was in December 2018. The mission is designed under the collaboration of ESA and JAXA. The onboard plasma wave receiver proceeds the first observation of plasma waves in Mercury (Kasaba et al., 2020a).

The BepiColombo will arrive at Mercury in 2025, while the Arase has got its extensive observations started in March 2017. One of the crucial targets in the Arase mission is to investigate the nonlinear interactions of electrons and whistler mode chorus emissions. S. Kasahara et al. (2018) demonstrated that the Arase satellite found the direct evidence of the pitch angle scattering by whistler mode chorus waves. The satellite clearly showed the flux modulations inside the loss cone that are correlated with the lower-band chorus bursts. Both the flux modulations and the chorus bursts have a good correlation with the pulsating aurora. Kurita et al. (2018a) found the deformation of electron pitch angle distributions associated with upper band chorus emissions. They showed tens of keV electrons were accelerated by upper-band chorus within 30 seconds. Another target of the Arase mission is the ElectroMagnetic Ion Cyclotron (EMIC) wave. Matsuda et al. (2018a) statistically showed the spatial distribution of EMIC waves depending on their types. Shoji et al. (2018) demonstrated that the observed EMIC waves with rising or falling frequencies agree with the nonlinear theory. In the further low frequency bands, Nose et al. (2018) found strong magnetic field fluctuations in the frequency close to the local gyrofrequency of O+ ions with the depolarization signatures in the deep inner magnetosphere.

The unique feature of the Arase satellite is that its designed orbits allow us to coordinate collaborative observations with other satellites and ground stations. Kurita et al. (2018b) found rapid loss of relativistic electrons by EMIC waves in the outer radiation belt observed by Arase, Van Allen Probes, and the PWING ground stations during the geomagnetic storm on March 21, 2017, associated with an arrival of CIR in the solar wind. Ozaki et al. (2019) succeeded a visualization of wave–particle interactions by the coordinated observations of chorus waveforms by the Arase satellite and transient auroral flashes from electron precipitation observed by a ground-based EMCCD camera of the PWING project. Miyoshi et al. (2019) revealed EMIC waves converted from equatorial noise due to M/Q=2 ions in the plasmasphere based on observations from Van Allen Probes and Arase satellites. Hosokawa et al. (2020) reported the first direct correspondence between the main/internal modulations of the pulsating aurora and chorus burst of rising tone elements from simultaneous satellite-ground based observations.

The Hisaki satellite has been continuing the mission to observe planets. Kimura et al. (2018) investigated the response of Jupiter's aurora to mass loading from Io with a newly developed model and data from the Hisaki satellite. They found that during volcanic eruptions at Io, impulsive variation of aurora responded to the mass loading rate rather than the solar wind.

The space around the moon has been studied under the cooperative observations by the Kaguya and Geotail spacecraft. Nakagawa et al. (2018) found the narrow band EMIC waves on the lunar orbit in the Earth's magnetotail. They discussed the generation mechanism and showed the cyclotron resonance with anisotropic ions in the plasma sheet.

1.2 Development of new plasma wave instruments and observation techniques

The effort to miniaturizations of plasma wave receivers and sensors have been made to meet limited resources for micro-satellite missions in future. Ozaki et al. (2016) and Zushi et al. (2019) succeeded in developing the small sensor preamplifier and small spectrum receiver by designing analog chips through the development of the ASIC (Application Specific Integrated Circuits).

The Wave-Particle Interaction Analyzer (WPIA) is the new method in the direct measurement of wave-particle interaction, which is implemented in the Arase satellite. Kitahara and Katoh (2016) devised the new method for the direct detection of pitch angle scattering by extending the WPIA. Shoji et al. (2017) applied the WPIA method to THEMIS data and succeeded in identifying quantitative wave-particle interactions on the observed EMIC waves. The result clearly indicated that the rising tone of EMIC waves are caused by non-linear wave-particle interactions with ring current ions.

Neural network is applied to a large amount of observation data. Santosa and Hobara (2017) Nighttime VLF amplitude transmitted from Hawaii in the path to Japan is predicted by using Nonlinear Autoregressive with Exogenous Input Neural Network (NARX NN) model.

1.3 Computer simulations, modeling and theories on plasma waves

Wave-particle interactions between energetic electrons and whistler-mode chorus have been intensively studied. Hsieh and Omura (2017) revealed the contribution of nonlinear wave trapping by obliquely propagating whistler-mode waves on the relativistic electron acceleration. Kubota and Omura (2018) developed a new numerical Green's function method originally proposed by Omura et al. (2015) for the nonlinear dynamics of radiation belt electrons interacting with chorus emissions and reproduced the rapid formation of radiation belt electron fluxes by chorus emissions propagating parallel to the dipole geomagnetic field line. Hsieh et al. (2020) applied the numerical Green's function method to obliquely propagating chorus emissions and showed that oblique chorus energizes keV electrons to about 2 MeV rapidly within several emissions. Omura et al. (2019) confirmed the efficient acceleration of relativistic electrons at Landau resonance with obliquely propagating whistler-mode chorus emissions by theory, simulation, and observation. Kitahara and Katoh (2019) studied the mechanism of anomalous trapping at low pitch angles caused by coherent whistler-mode waves and examined its contribution on energetic electron precipitation to the atmosphere. Katoh and Omura (2016) carried out simulation of whistler-mode chorus generation with real parameters in the Earth's inner magnetosphere and reproduced spectral fine structures as observed by the Cluster spacecraft (Santolik et al., 2003; Santolik, 2008). Katoh et al. (2018b) revealed the dependence of chorus generation process on the temperature anisotropy and density of energetic electrons by a series of self-consistent electron hybrid code simulations.

Wave-particle interactions around a collisionless shock have been actively studied by full particle simulations. Otsuka et al. (2019) performed a one-dimensional full particle-in-cell (PIC) simulation of a quasi-parallel collisionless shock with the Alfvén Mach number 6.6 and a shock angle of 20 degrees to investigate the interactions between self-consistently produced backstreaming ions and upstream waves. Matsukiyo et al. (2020) solved a shock tube problem by one-dimensional full particle-in-cell simulations under the condition that a relatively tenuous and weakly magnetized plasma is continuously pushed by a relatively dense and strongly magnetized plasma having supersonic relative velocity. The results are discussed in the context of the heliospheric boundary region or heliopause. Umeda et al. (2019) conducted a numerical experiment for laboratory experiments on the generation of magnetized collisionless shocks with high-power lasers by using one-dimensional particle-in-cell simulation.

Darian et al. (2019) studied the effect of an external magnetic field on the formation of the wake in the potential distribution behind a dust grain with self-consistent Particle-In-Cell numerical simulations. The topology of the wake field is significantly affected by the magnetization degree of plasma and by the ion flow speed. The external magnetic field acts to reduce the potential enhancements in the wake and leads to the splitting of the wake pattern.

Usui et al. (2019) and Miyake et al. (2020) investigated the plasma-spacecraft interactions by using the PIC simulations. Usui et al. (2019) found the existence of a distorted plasma depetion region in a satellite wake, while Miyake et al. (2020) identified wing-like density structures formed by electrons reflected at a negatively-charged moving spacecraft in a magnetized plasma. Such structures are characterized by the trail of field-aligned propagation of Langmuir waves. Reflected electrons cause spurious electric fields that can be measured by double probes on a satellite.

2. Activity Report

Status of projects related with plasma wave observation

1. BepiColombo/MMO

http://global.jaxa.jp/projects/sat/bepi/

http://www.stp.isas.jaxa.jp/mercury/p_mmo.html

BepiColombo is a Mercury exploration project jointly planned by JAXA and the European Space Agency (ESA). It consists of two orbiters; the Mercury Planetary Orbiter (MPO) and the Mercury Magnetosphere Orbiter (MMO). JAXA is responsible for development of the MMO. MMO is at ESA/ESTEC (European Space Research and Technology Centre, Netherlands) from April 2015. For the plasma wave, Plasma Wave Investigation(PWI) (PI: Y. Kasaba [Tohoku Univ.]) is aboard this spacecraft. PWI will first observe electric field, plasma waves, and radio waves around Mercury, which were not covered by past spacecraft. The spacecraft was successfully launched om Oct. 2018 from Kourou (Arival at the Mercury in 2025). The PWI science team has shiftted to develop the telemetry data pipelines and operation planning for the real science execution which will be realized in 2020s. The spacecraft will experience flybys before the arrival of the Mercury. The first Venus flyby has succeeded in Oct. 2020.

2. JUICE

http://www.isas.jaxa.jp/en/missions/spacecraft/future/juice.html

JUICE (JUpiter ICy moons Explorer) is the L-class mission of ESA, planned for launch in 2022 and arrival at Jupiter in 2029. It will spend at least three years making detailed observations of the Jovian system including Ganymede, Calisto and Europa, and finally be on the orbit around Ganymede. For the plasma wave, Radio and Plasma Wave Investigation (PI: J.-E. Wahlund [IRF Uppsala, Sweden]) is aboard this spacecraft and covers the information of the exospheres, surfaces, and conducting subsurface oceans of icy satellites and their interactions with surrounding Jovian magnetosphere. For the access to the conductive subsurface ocean, RPWI will first observe cold plasma and electric fields, to separate the global conductivity and current from the ionospheres. As a byproduct, reflected Jovian radio emission can be expected from the boundary of crust (ice) and subsurface ocean (conductive water). From Japan, High Frequency part (RWI-Preamp and HF-Receiver) will be supplied (Co-PI: Y. Kasaba [Tohoku Univ.]) and provide the highly resolved information of Jovian radiation emitted from Jupiter and Ganymede by the first 3-axis E-field measurement. Our Flight Models was tested in Europe (Kasaba et al., 2016; Katoh et al., 2017; Kumamoto et al., 2017).

3. Arase (ERG)

http://www.isas.jaxa.jp/en/missions/spacecraft/current/erg.html http://ergsc.isee.nagoya-u.ac.jp/index.shtml.en

The Arase (ERG; Exploration of energization and Radiation in Geospace) project is a mission to study acceleration and loss mechanisms of relativistic electrons around the Earth. The Arase (ERG) was launched in Dec., 2016, and the prime mission started in March, 2017. The Plasma Wave Experiment (PWE, PI: Y. Kasahara [Kanazawa Univ.]) has measured DC electric field and plasma waves in the inner magnetosphere covering wide frequency range from DC to 10 MHz for electric field and from a few Hz to 100 kHz for magnetic field. The Software-Wave Particle Interaction Analyzer (SWPIA) (PI: H. Kojima, [Kyoto. Univ.]) is equipped to realize direct measurements of interactions between energetic electrons and whistler-mode chorus in the Earth's inner magnetosphere.

Varieties of wave phenomena such as chorus, EMIC, ULF pulsations and lightning whistlers have been successfully observed by the PWE. We have also conducted cooperative observations with the ground-based stations, Van Allen Probes and the other satellites in the magnetosphere. We intensively conducted the PWE burst mode operations, by which waveforms were continuously captured. During the prime mission, all science instruments have operated in good health and the JAXA has approved the mission extension of Arase until end of March, 2022(Kasaba et al., 2017a; Hikishima et al., 2018; Y. Kasahara et al., 2018; Katoh et al., 2018a; Kumamoto et al., 2018; Matsuda et al., 2018b; Miyoshi et al., 2018a, 2018b; Ozaki et al., 2018c).

4. Hisaki spacecraft

http://www.isas.jaxa.jp/en/missions/spacecraft/current/hisaki.html

Hisaki satellite with the EUV spectrometer (Extreme Ultraviolet Spectroscope for Exospheric Dynamics: EXCEED) is the UV/EUV space telescope dedicated to planetary sciences. Hisaki has provided continuous observations of Jovian system in UV aurora total flux and EUV Io torus plasma distributions and plasma diagnostics, which connected the solar wind information and ground-based radio (Decameter [aurora] - VHF [radiation belt]) and IR (aurora and airglows) observations. From July 2016, NASA Juno orbiter started the observation around Jupiter. Hisaki's priority is on the support observation for this mission. The Hisaki mission period has extended until the end of Mar. 2022.

5. GEOTAIL

http://www.isas.jaxa.jp/en/missions/spacecraft/current/geotail.html

GEOTAIL spacecraft has been operated since 1992. The Plasma Wave Instrument (PWI) is continuously collecting the high resolution waveform data as well as the spectrum data. The color plots of the observed wave spectrum data have been opened in the PWI web site http://space.rish.kyoto-u.ac.jp/gtlpwi, and http://www.stp.isas.jaxa.jp/geotail. One can easily also make the color spectrum plots in flexible time scales at https://geotail.nict.go.jp/.

6. Iceland - Syowa conjugate observation

A new VLF instrument has been installed at Husafell observatory in Iceland in September, 2016. Unique conjugate observations of auroral phenomena including the measurements of ULF and VLF waves have been carried out between Iceland and Syowa Station, Antarctica since 1983 by the National Institute of Polar Research in Japan in collaboration with University of Iceland.

7. Ground-based observation of solar and planetary radio waves

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

http://ariel.gp.tohoku.ac.jp/jupiter/

Ground-based observation of solar and planetary radio waves is performed using IPRT (Iitate Planetary Radio Telescope) and HF antenna array developed by Tohoku University. IPRT has been operated at the Iitate observatory in Fukushima Japan since 2000. IPRT measures meter to decimeter natural radio waves at fixed frequencies of 325 and 785 MHz using LNA and also from 150 to 500 MHz using wide-band receiver. Primary purposes of the telescope are to investigate the dynamic behavior of Jupiter's synchrotron radiation and solar radio emissions in the low-frequency range. In addition to this, IPRT has capability to observe weak radio sources in the low frequency range such as pulsars. HF antenna at Iitate observatory has been operated since 1996 for ground-based observation of Jovian decametric radiation (DAM; 15-40MHz). Wide-band spectrum monitor, and waveform receiver with single antenna, and long-baseline interferometer with 3 station's antenna (Kawatabi, Zao, and Yoneyama) are in operation. For observation of weaker non-Io Jovian DAM events, short-baseline interferometer with four antennas is also operated.

8. PWING Project

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

The PWING project investigates the process of dynamical variation of the particles and waves in the Earth’s inner magnetosphere and clarify the mechanism of the dynamical variation quantitatively. This project has operated eight ground-based stations separately positioned in the longitudinal direction at subauroral latitudes in Canada, Alaska, Russia, Finland, and Iceland, using induction magnetometers, riometers, VLF/ELF receivers, and all-sky airglow/aurora imagers and EMCCD cameras since March 2017. Conjugate measurements of particles and waves with the new ERG (Arase) satellite and the Van Allen Probes has been made extensively in 2017-2020. The budget for PWING will be finished in March 2021. But the ground-based observation will be continued as possible as we can (Shiokawa et al., 2017).

9. Bilateral project between JSPS and CAS

This is the joint project between JSPS and CAS (PI: Y. Miyoshi/O. Santolik) for plasma waves as well as lightnings using multi-satellite and ground-based data. The project will be finished in

March 2021.

10. HpFP protocol

http://hpfp.nict.go.jp/

Due to rapid increase of network bandwidth, applications and systems working in long fat network (LFN) play more important roles. For effective development of them, precise measurements of network conditions are significant. Transmission Control Protocol (TCP) is the most commonly used protocol, but is essentially unable to achieve high throughput in LFNs with packet losses. For this reason, it is hard for conventional network measurement tools to show the maximum or available bandwidth in LFN, especially in high packet loss environments. To overcome this issue, we introduced a novel data transfer protocol on TCP/IP transport layer, namely high-performance and flexible protocol (HpFP). For high-precision pace control and retransmission control, the HpFP intermittently monitors network conditions such as packet loss and latency. We develop an application via the HpFP, named hperf, which measures end-to-end throughput as well as status of packet loss and latency in LFNs. We carried out experiments to examine the abilities of the hperf in high-throughput data transfer and measurement of network qualities in terms of packet loss and latency(Figure 1). The hperf achieves almost wire-rate throughput, 10 Gbps, on the international link between Japan and the USA with even 0.5\% packet loss ratio (PLR). The measurements of packet loss and latency show good correspondence with the conventional methods via iperf and ping. These results are verified in our laboratory experiments on 10 Gbps link using a network simulator as well. We conclude that the HpFP has significant potential for a variety of network applications and the hperf is a good network quality measurement tool in LFNs, compared to the conventional TCPs.

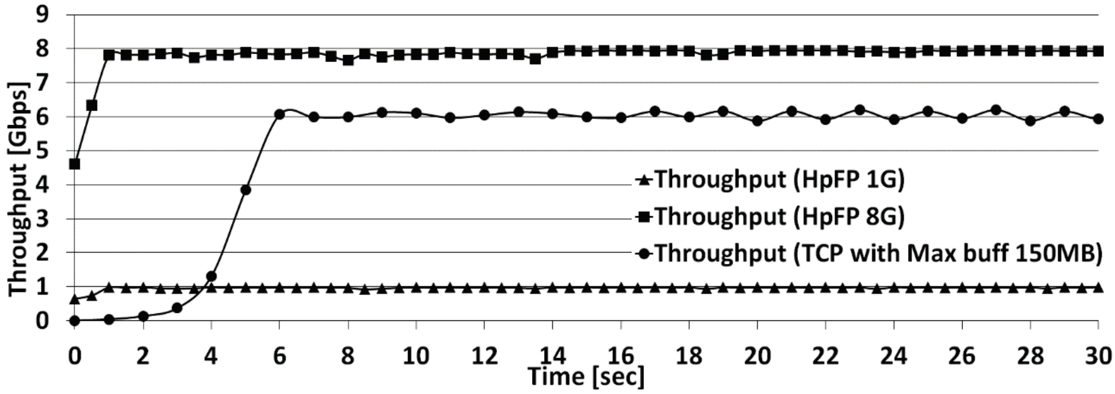

Figure1: Laboratory experiment result of HpFP and TCP on LNF.

11. Development of Real-Time Monitoring System via Visual IoT

Visual Internet of Things (IoT) is a class of IoT that collects rich visual data. In general, the visual IoT device is equipped with a video transmission equipment such as a camera. The involved technologies are advanced video transmission techniques and information extraction from images by image recognition techniques. However, since the video data size is larger than the sensor data size, one of the issues of visual IoT is high-performance video transmission in networks in which the bandwidths are limited. In this project[2017], we designed and developed a real-time monitoring system using visual IoT device. Our system is based on a novel protocol, named high-performance video transmission (HpVT), for field monitoring via 4G LTE mobile networks(Figure 2). The performance of our system is evaluated in real fields to conclude that we can achieve full high-definition (full-HD) resolution video transmission with as high frame rate as 30 fps.

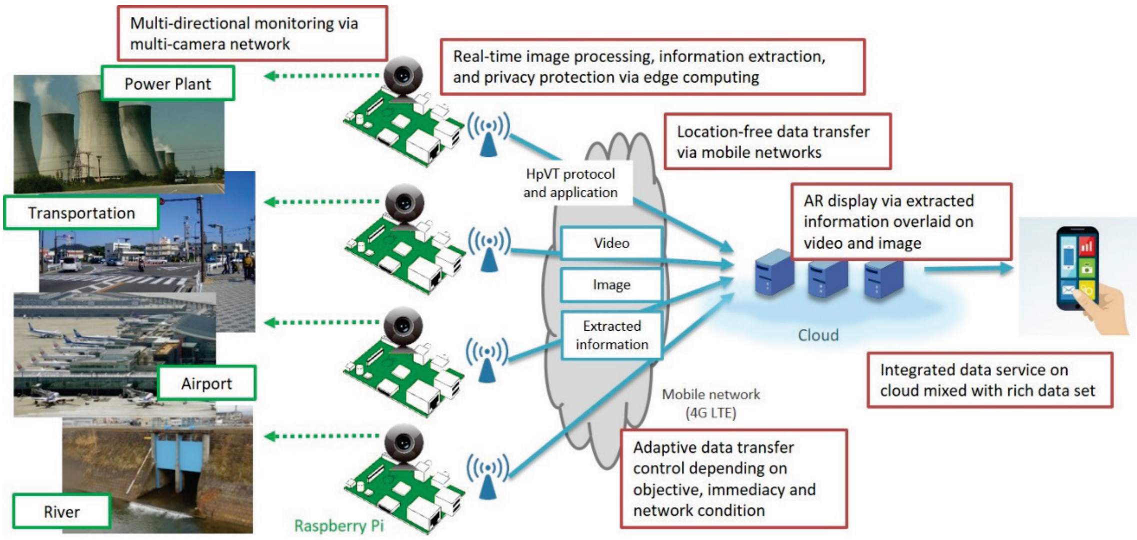

Figure 2: A schematic concept of Visual IoT.

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