P2-102

ERG/PWE: Plasma Wave Experiment

~ from Mercury (BepiColombo/MMO-PWI) to Earth's Radiation Belt ~

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The Plasma Wave Experiment (PWE) aboard the ERG mission, just in the EM phase, will observe the electric field (from DC to 10 MHz) and magnetic field (from few to 100 kHz) for the clarification of global plasma dynamics, energetic processes, and wave-particle interactions in the radiation belt.

It is based on the Plasma Wave Investigation (PWI) aboard BepiColombo Mercury Magnetospheric Orbiter (MMO), which FM is now tested at ISAS. The key issues are:

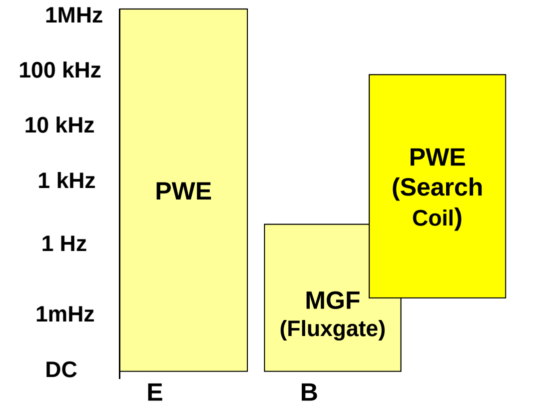
(a) Examination of the high-energy particle acceleration by plasma waves,

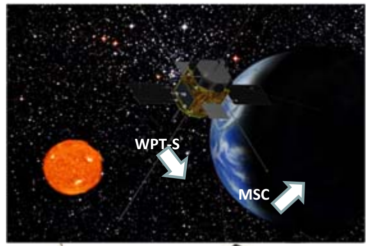
(b) Diagnosis of plasma density and temperature, and

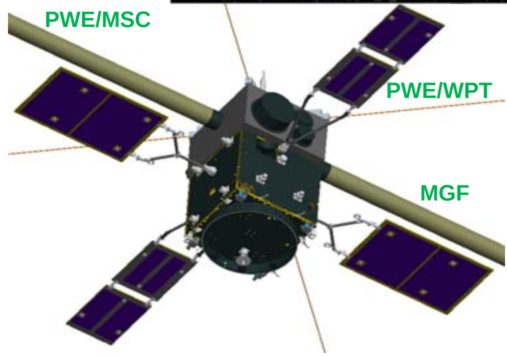
(c) Investigation of wave-particle interaction and mode conversion processes.

Some key development will also be the basis for the JUICE mission.

PWE : Plasma waves & Electric field
MGF : Magnetic field







- background E/B field,
- MHD waves,
- Ion-cyclotron / Whistler / UHR waves

→ Plasma waves related to electrons 'transportation / acceleration / loss'
Diagnostics of background plasma (electrons)

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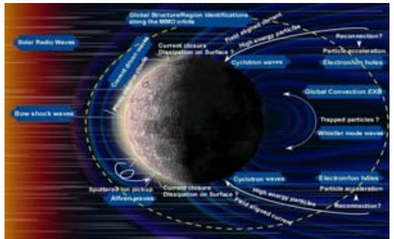
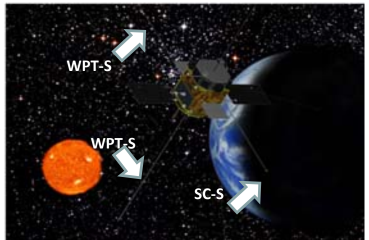
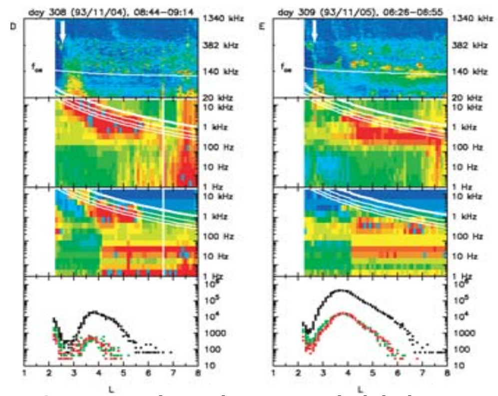
Electric Field Sensors (32m tip-to-tip dipoles)		
WPT (Wire-Probe anTenna)	DC-10MHz	[Tohoku U et al.]
Magnetic Field Sensors (search-coils)		
SC (3-axis Search-Coils)	0.1 Hz – 100kHz	[Kanazawa U et al.]

DC/Low frequency Electric field (E: DC – 128Hz [256Hz waveform])	
EWO-EFD (Electric Field Detector)	[Toyama Pref. U et al.]
Low/medium frequency E/B field (E: 10Hz - 20kHz, B: few - 20kHz)	
EWO-WFC/OFA (WaveForm Capture/Onboard Frequency Analyzer)	[Kyoto U et al.]
High frequency E field (E: 10kHz - 10MHz, B: 10kHz - 100kHz)	
HFA (High-Frequency)	[Tohoku U et al.]

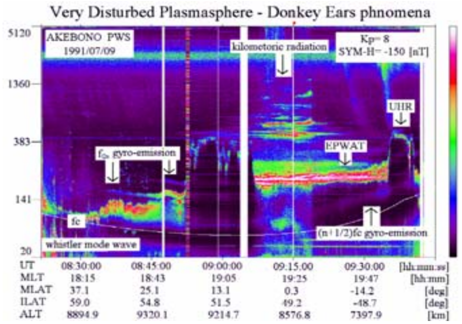




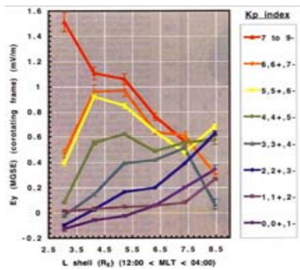
Plasma waves and E field in the inner magnetosphere during storm



Correspondence between relativistic electrons and intense whistler-mode chorus emissions during storm. [Miyoshi et al., 2003]



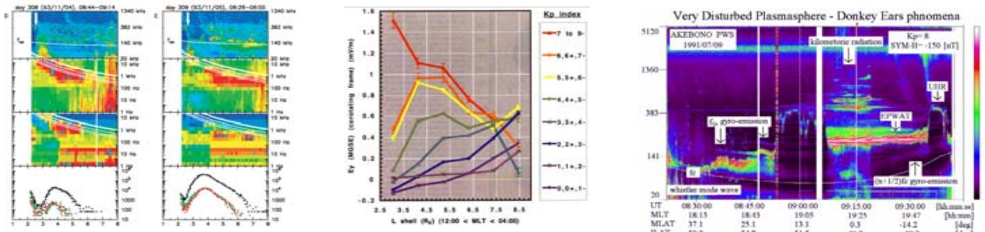
Spectrogram of plasma waves in the inner magnetosphere during geospace storm, which suggests large scale variation of plasmasphere structures and injections of energetic electrons



Unusual electric field structure during geospace storm [Rowland and Wygant, 1998]

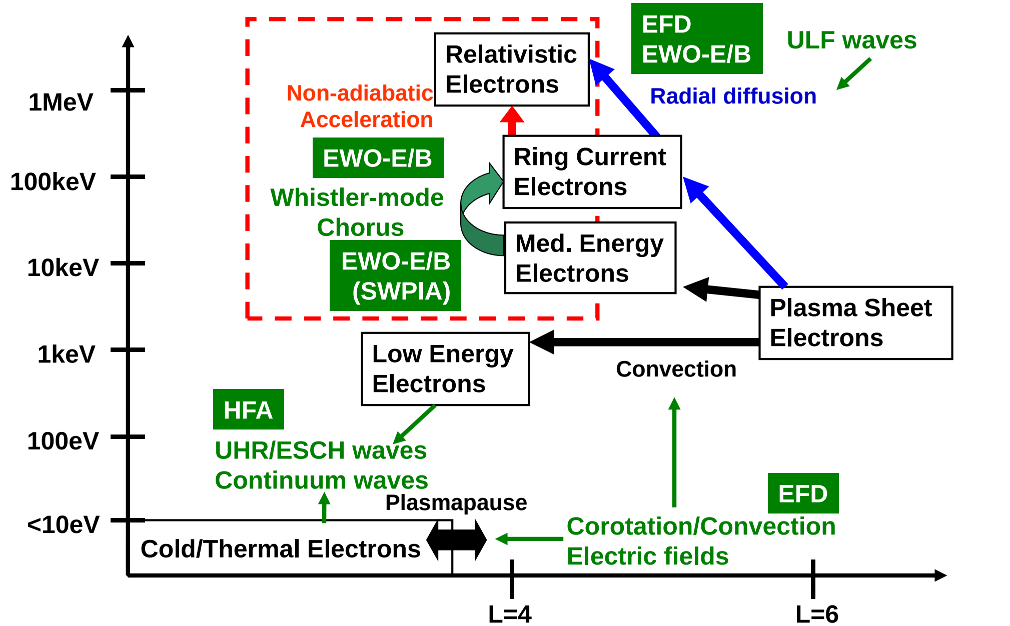
Scientific Objectives of ERG/PWE

Relativistic electron acceleration by plasma waves	E field in the inner magnetosphere	Plasma waves in the inner magnetosphere
･Verification of quasi-linear theory & Development of non-linear model of acceleration process by waves ･Direct detection of non-linear wave-particle interaction between whistler-mode chorus and medium energy electrons.	･Evolution of E field structure in the inner magnetosphere during storms ･Generation mechanism of intense E field during storms.	･Diagnosis of plasma density, temperature and composition in the plasmasphere by waves ･Wave-particle interaction and mode conversion inside and outside of the plasmasphere
EWO-E/B, HFA + WPT/MSC	EFD + WPT-S	EWO-E/B, HFA + WPT/MSC



[Miyoshi et al., 2003] [Rowland and Wygant, 1998]

Wave-particle interactions in the inner magnetosphere



Sensitivity & Dynamic range Issue

Wide coverage of both
eggs of Non-linear processes ~ weak waves
results of Non-linear processes ~ largest waves
in the Radiation belt's !

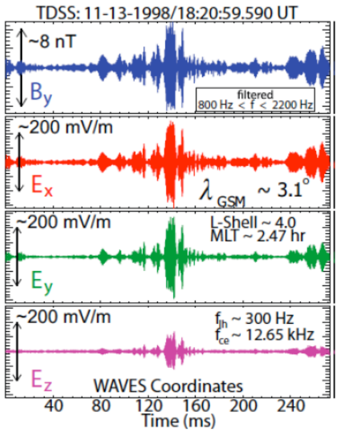
OK!

1. dE >100 mV/m (largest observed >300 mV/m)
2. dB >1 nT (largest observed >8 nT)
3. Amplitudes correlated with AE

OK!
Development in 2012FY support the feasibility.

MSC saturation levels
at several kHz
10 nT (for low gain)
1 nT (for high gain)

Poynting flux for this event was >300 μW/m², roughly four orders of magnitude above estimates from previous satellite measurements



school of physics & astronomy

Wilson et al. (2010; 2011)

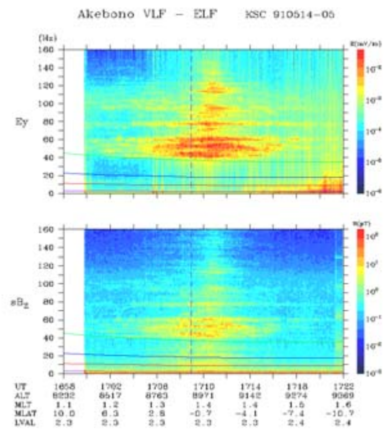
Chapman Conference on Radiation Belts

Strong waves found by Wind (Cattel et al. 2011)

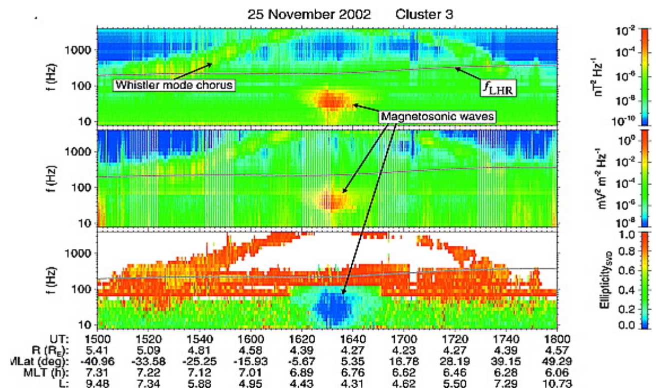
Low frequency wave issue

■ **Example: Magnetosonic Waves**

Horne et al. [2007, GRL]



(Kokubun et al., 1991, Kasahara et al., 1994)



Dawn side, with Chorus.
Magnetosonic wave is around the equator.

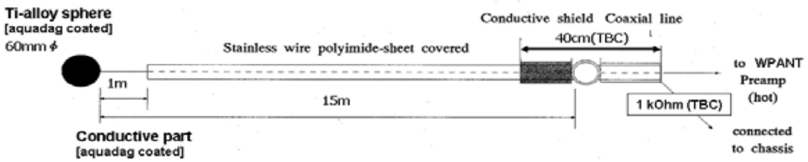
E: EFD (128Hz waveform in Bepi)
→ "256Hz waveform"
"Higher gain" by DPB [+-100mV/m, 16bit]
"Lower gain" by SPBx2 [+-6V/m, 16bit]

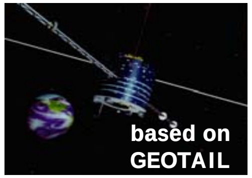
B(&E): CPU reduction in order to get 256Hz waveform from 60kHz-sample data

Electric field: Dipole wire antennas

~ First long wire antenna (32m tip-to-tip length) aboard a Planetary Orbiter ~

WPT-S [from Tohoku Univ. et al.]

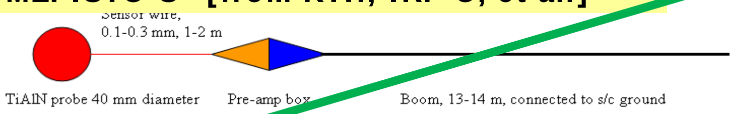




Optimized for plasma waves & radio waves

2 pairs. the same design with the MMO's.

MEFISTO-S [from KTH, IRF-U, et al.]



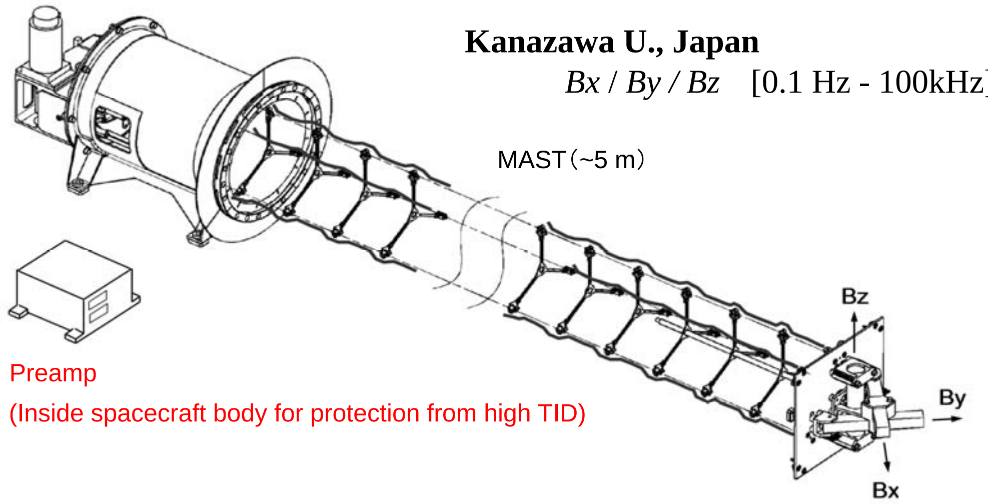
Optimized for dc & low frequency electric field

Provision is not possible.

Magnetic Field: Magnetic Search Coils (MSC)

Kanazawa U., Japan

Bx / By / Bz [0.1 Hz - 100kHz]



Preamp
(Inside spacecraft body for protection from high TID)

MSC [from Kanazawa Univ. et al.]

Search Coil (3-axis)
20x20x20 cm

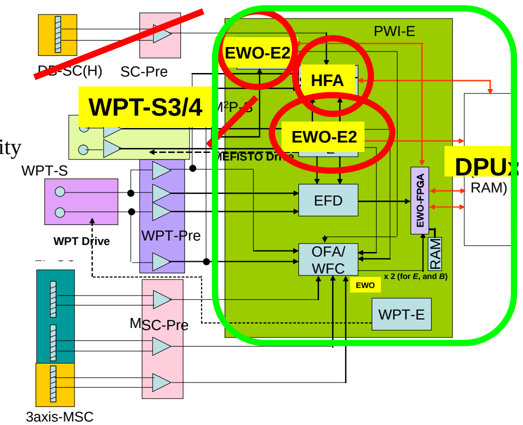
Receivers

[Receivers]

* **EWO-EFD** : DC – 80 Hz (512Hz waveform)
  - connected to WPT-S1/2 & WPT-S3/4 (E)
  - Double Probe Dynamic range 110 dB for Electric field
  - Single Probe Spacecraft potential (128Hz) for Electron density

* **EWO-WFC/OFA**: 10Hz – 20kHz (60kHz sample) for E
  few Hz – 20kHz (60kHz sample) for B
  - connected to WPT (E:2ch) & SC (B:3ch)
  - Waveform receiver with spectrum data (derived in DPU)

* **HF receiver** 10kHz – 10MHz for E
  10 – 100kHz for B
  - connected to the WPT (E-2ch) [or E-1ch + MSC (B-1ch)]



* **DPU(digital Processing Unit)** (x 2)
  - connected to EWO-E/B, HFA [MAST-WPT-E – from MDP outside of PWE
    - CMD/HK I/F
    - TLM calculations: FFT, Compression, Triggering, Packet

Raw data from PWE

Ring Buffer size in the DPU
320sec: WFCE/B, 1200sec: EFD, HFA

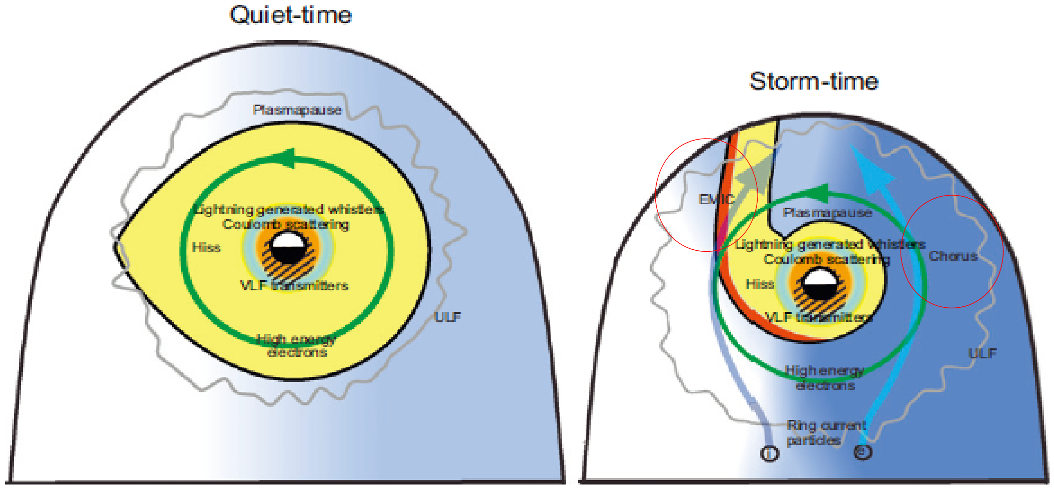
Receiver		Data	total (bps)
EWO-EFD	DPB [Sweep]	512Hz x 16bit x 2ch (sync) [1024Hz x 16bit x 2ch x 0.5/4sec] (sync)	16.4k
	SPB	128Hz x 16bit x 4ch (non-sync)	8.2k
EWO-OFA/WFC(E)	Nominal [for SWPIA]	65.536kHz x 14(16)bit x 2ch [262.144kHz x 14(16)bit x 2ch]	2097.1k or [8388.4k]
EWO-OFA/WFC(B)	Nominal [LF mode]	65.536Hz x 14(16)bit x 3ch [16.384Hz x 14(16)bit x 3ch]	3145.7k or [786.4k]
HFA	E-2ch	1Hz x 8bit x 1024ch [10k-10M] x 2	16.4k
	E/B	1Hz x 8bit x 1024ch [10k-10M] 1Hz x 8bit x 128ch [10k-100k]	<16.4k

Total of Raw Data: 3.0 – 11.6Mbps

Keynotes of the PWE data strategy

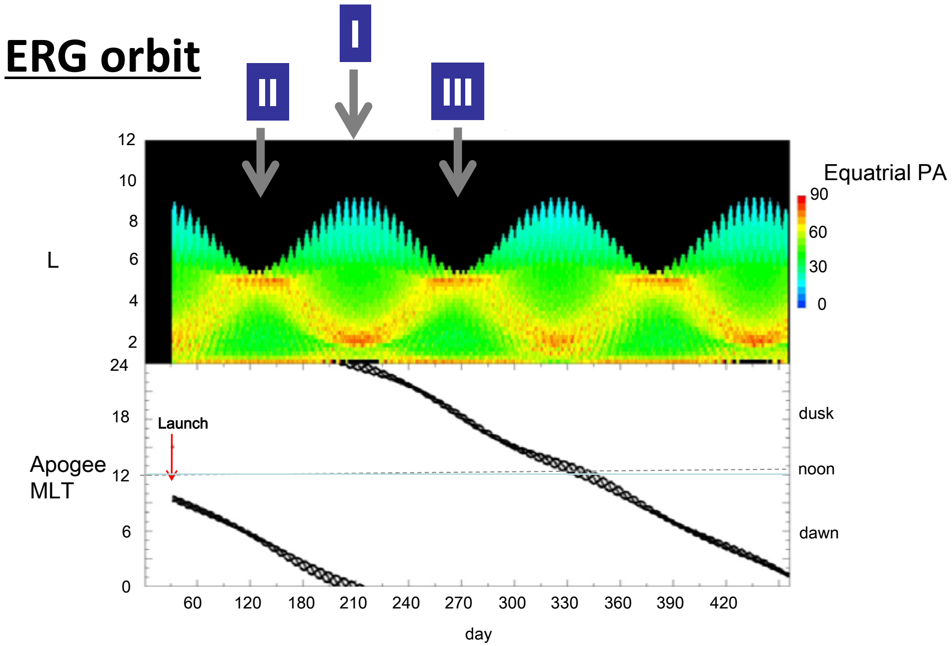
- How to cover the wide frequency range ?
  - PWE covers whole frequency range from DC to a few MHz
- Employment of Data compression
  - Would be necessary to obtain the mission data as much as possible
  - But should not loose the essence of the physics !
- Onboard data detection or selection
  - Should be carefully examined how to determine the index of important data
- Optimum design of onboard data processing
  - Optimization of CPU & Memory resources
  - Design of "special observation mode" is VERY important !
- Optimization of observation strategy in the operation plan
  - Optimized operation plan is needed binding with the other ground observatory & the other spacecraft

Typical Plasma Waves in the Inner Magnetosphere

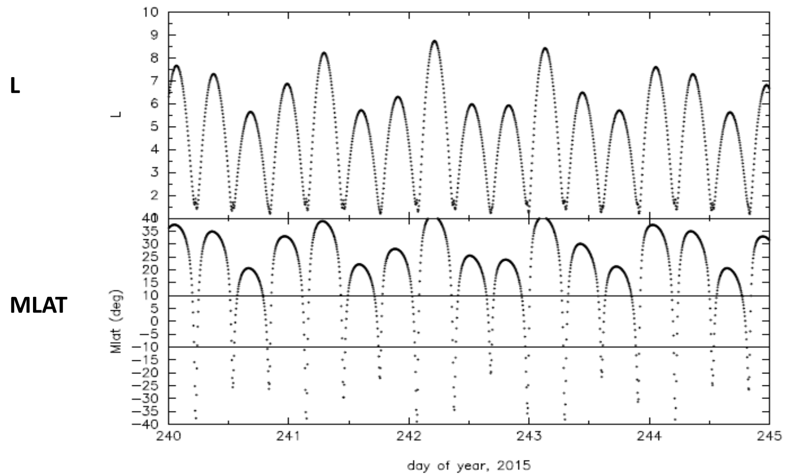


Shprits et al., 2008

ERG orbit



I. Apogee: Night, Magnetic equator: L ~ 2

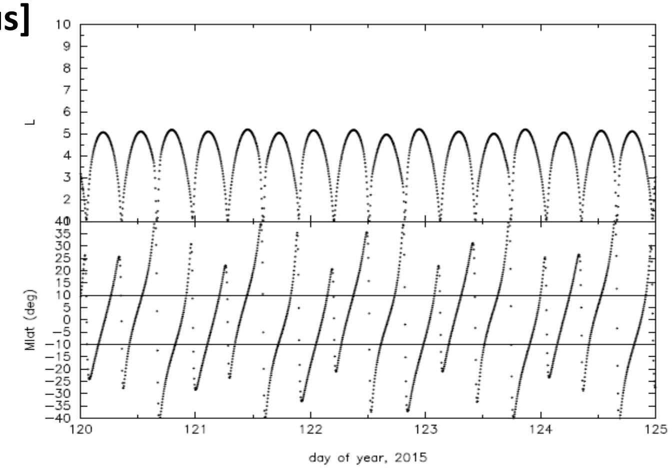


L>4,	|MLAT|	< 10deg	0 min/day
		< 5deg	0 min/day
		< 3deg	0 min/day

Ⅱ Apogee: DAWN, Magnetic equator: L~5 [for Chorus]

L

MLAT

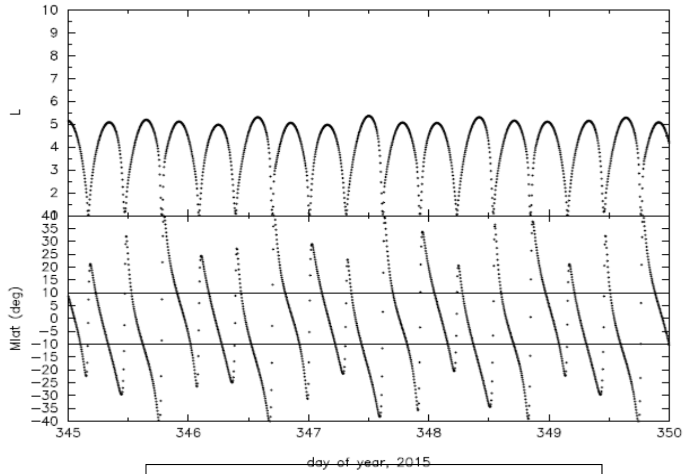


L>4,	|MLAT|	< 10deg	445 min/day
		< 5deg	243 min/day
		< 3deg	152 min/day

Ⅲ. Apogee: DUSK, Magnetic equator: L~5 [for EMIC]

L

MLAT



L>4,	|MLAT|	< 10deg	436 min/day
		< 5deg	235 min/day
		< 3deg	142 min/day

Team Structure

<HQ>

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Software	Yoshiya Kasahara	(Kanazawa U.)
Outreach+SWPIA-I/F	Yuto Katoh	(Kumamoto U.)
Data	Yoshizumi Miyoshi	(Nagoya U.)

DPU & Ground sotfware

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Yoshitaka Goto	(EWO-E/B)
Tomohiko Imachi	(EWO-E/B)
Yuki Ashihara	(EFD)
Keigo Ishisaka	(EFD)
Yasumasa Kasaba	(EFD)
Atsushi Kumamoto	(HFA)
Fuminori Tsuchiya	(HFA)
Yoshizumi Miyoshi	(Archive)

PWE & EWO: MHI

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Takayuki Ono
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Toshimi Okada
Isamu Nagano
Atsuki Shinbori
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