P2- 090

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 design phase, is introduced. It 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 FM design of Plasma Wave Investigation (PWI) aboard BepiColombo Mercury Magnetospheric Orbiter (MMO), whch FM is just now tested at ISAS. Some key parts are also related for the future Jovian mission studies with European and US colleagues. The key issues are:

(a) Examination of the theories of 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.

ERG/PWE: Plasma Wave Experiment

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<u>Electric Field Sensors (32m tip-to-tip dipoles)</u>

WPT (Wire-Probe anTenna) DC-10MHz [Tohoku U et al.]

<u>Magnetic Field Sensors (search-coils)</u>

SC (3-axis Search-Coils) 0.1 Hz – 100kHz [Kanazawa U et al.]

<u>DC/Low frequency Electric field (E: DC – 128Hz [256Hz waveform])</u>

EWO-EFD (Electric Field Detector) [Toyama Pref. U et al.]

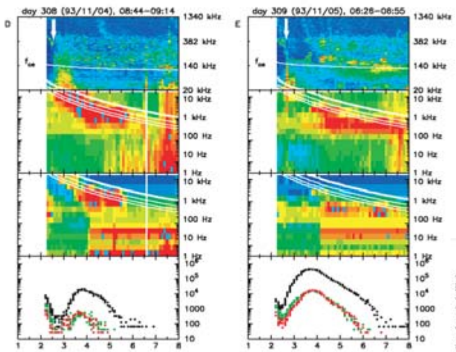
<u>Low/medium frequency E/B field (E: 10Hz - 20kHz, B: few - 20kHz)</u>

EWO-WFC/OFA (WaveForm Capture/Onboard Frequency Analyzer) [Kyoto U et al.]

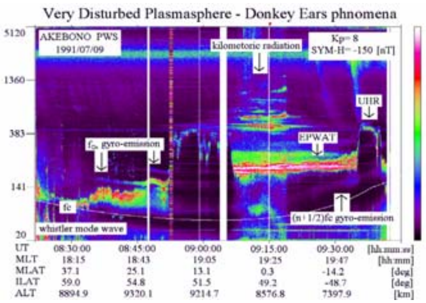
<u>High frequency E field (E: 10kHz - 10MHz, B: 10kHz - 100kHz)</u>

HFA (High-Frequency) [Tohoku U et al.]

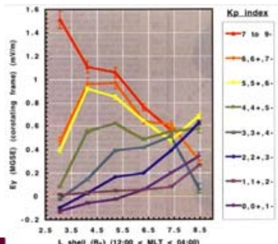
Plasma waves and E field in the inner magnetosphere during storm



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



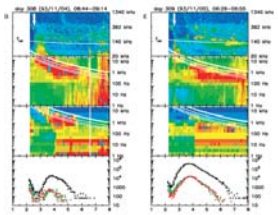
Spectrogram of plasma waves in the inner magnetosphere during geospace storm, which suggests large scale variation of plasmasphere structures and injections of energetic electrons



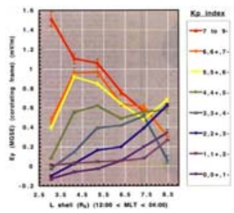
Unusual electric field structure during geospace storm [Rowland and Wygant, 1998]

Scientific Objectives of ERG/PWE

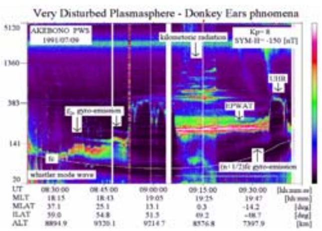
Relativistic electron acceleration by plasma waves	E field in the inner magnetosphere	Plasma waves in the inner magnetosphere
・Verification of <u>quasi-linear theory</u> & Development of <u>non-linear model</u> of acceleration process by waves ・<u>Direct detection of non-linear wave-particle interaction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



[Miyoshi et al., 2003]



[Rowland and Wygant, 1998]



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!

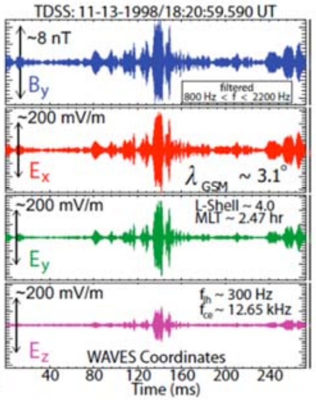
1. dE >100 mV/m (largest observed >300 mV/m)

OK!
Development in 2012FY support the feasibility.

2. dB >1 nT (largest observed >8 nT)
3. Amplitudes correlated with AE

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



Wilson et al. (2010; 2011)

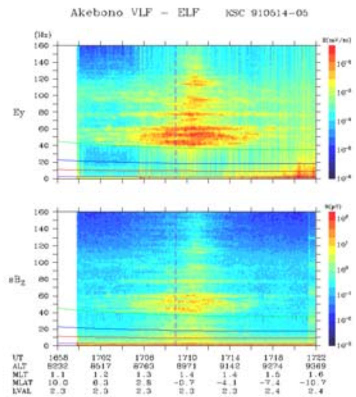
Chapman Conference on Radiation Belts

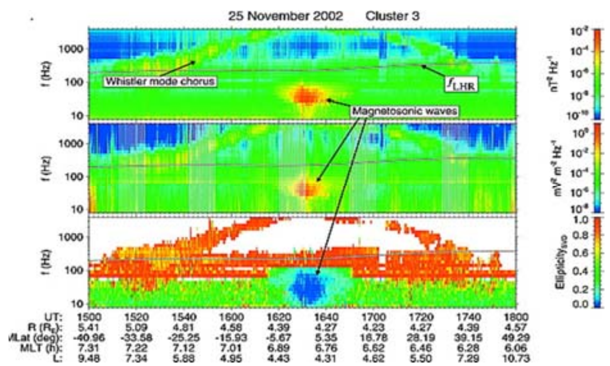
Strong waves found by Wind (Cattel et al. 2011)

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

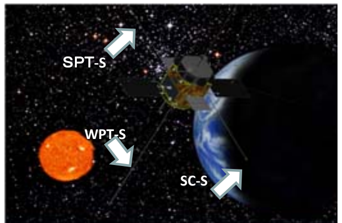
プラズマ波動・電場観測機器（PWE）の概要

(1) 電場センサー　* 電場アンテナ＋Preamp (2 pairs)：　WPT-S + WPT-Pre
(BepiColombo/MMO-WPT-Sと同一)　[東北大]
(BepiColombo/MMO-WPT-Preを一部改造)　[東北大、京大、富山県大]

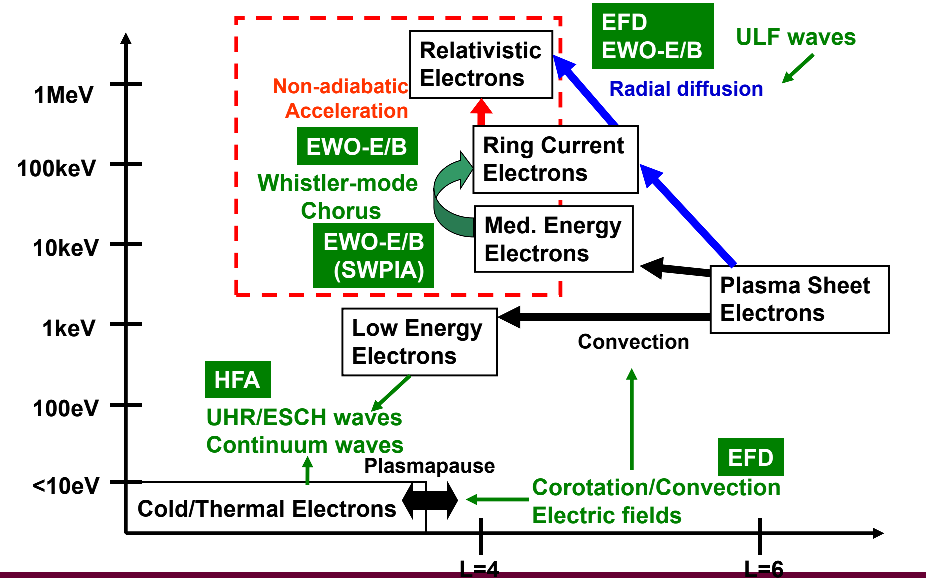
(2) 磁場センサー　* 磁場アンテナ+プリアンプ (3-axis)：　SC-S + SC-Pre
(BepiColombo/MMO-SC改造品)　[金沢大]

(3) 主電子回路部(PWE-E)：PWE-E共通シャーシに以下を収納
* DC電場、低周波電場・磁場受信機：　EWO (電場2成分、磁場3成分)
(BepiColombo/MMO-PWI相当品と同一)　[京大、富山県大、金沢大、東北大]
* 高周波電場・磁場受信機　：　HFA (電場2成分、磁場1成分)
(新規・ロケット実験にて実証済)　[東北大]

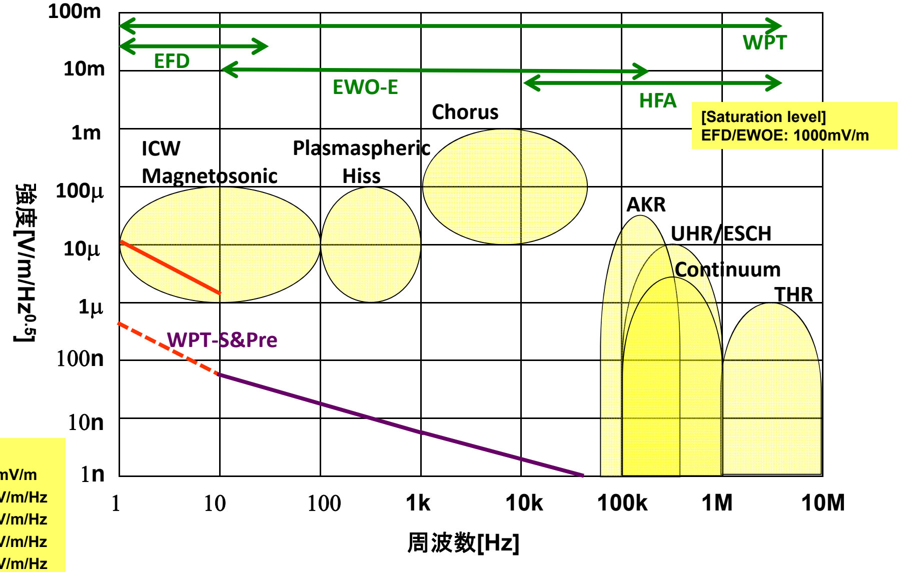
(4) WPT-S伸展制御: "MAST制御" と同梱
* 伸展エレキ　：MAST-WPT-E
(BepiColombo/MMO-PWI相当品と同一)　[JAXA, 東北大]



Wave-particle interactions in the inner magnetosphere

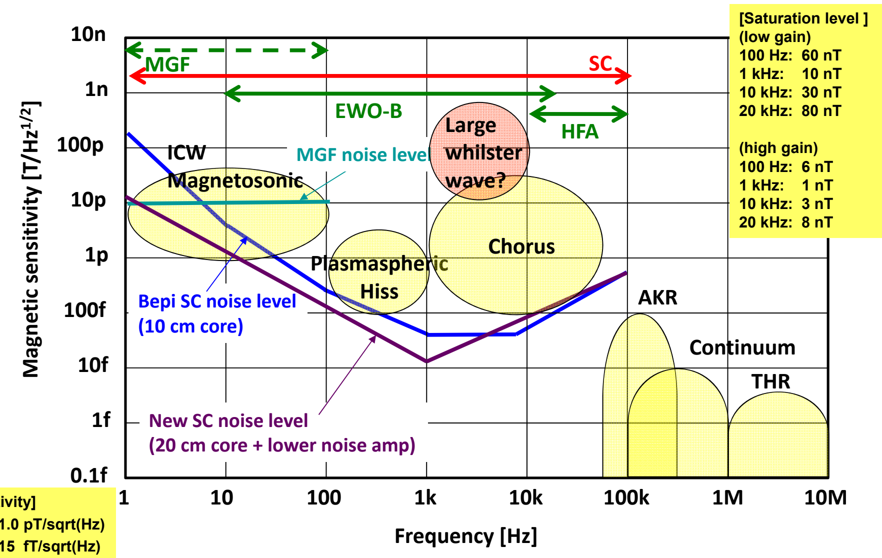


Target waves: Frequency & Strength ---- Electric Field



[Sensitivity]
dc < 1mV/m
1Hz 15uV/m/Hz
10Hz 80nV/m/Hz
100Hz 20nV/m/Hz
1kHz 8nV/m/Hz
10kHz 4nV/m/Hz

Target waves: Frequency & Strength ---- Magnetic Field

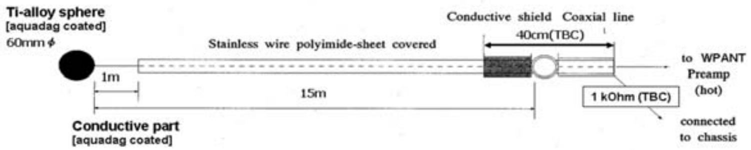


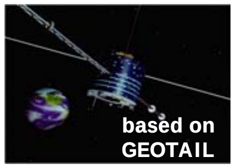
[Sensitivity]
10Hz 1.0 pT/sqrt(Hz)
1kHz 15 fT/sqrt(Hz)
10kHz 100 fT/sqrt(Hz)

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.]

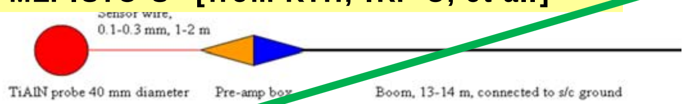




Optimized for plasma waves & radio waves

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.

If we have only 1 E-field antenna, following damage will be expected:
(1) Lost of time resolution of dc e-field.
(1-spin: 8(20) sec)
(2) Lost of polarization information for E-static waves
(Electromagnetic waves …. Covered by Ex1 + Bx3)

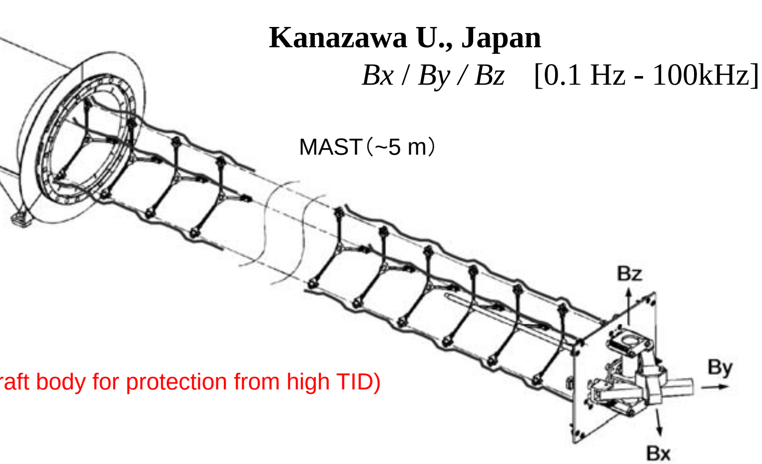
ERG 計画の目的　　期待される科学成果（成功基準）

	ミニマムサクセス	フルサクセス	エクストラサクセス
外部供給・内部加速の切り分け		規模の異なる宇宙環境変動下の内部磁気圏赤道面近傍において、粒子・磁場計測器による位相空間密度の動径方向分布の時間変化を計測し、放射線帯高エネルギー電子の外部供給・内部加速を切り分ける。	長期観測の実現により、宇宙嵐を多数観測し、ケースごとの外部供給・内部加速の違いを明らかにする。
相対論的電子の加速機構	内部磁気圏赤道面近傍でのプラズマ総合観測を実現し、波動粒子相互作用による相対論的高エネルギー電子の加速機構を同定する。	規模の異なる宇宙環境変動下でプラズマ総合観測を行い、地上観測・モデリングと組み合わせて、太陽風条件と発動する加速機構の関係を理解する。	長期観測の実現・海外ミッションとの協力により、異なるL値、地方時で同時観測を多数実施し、宇宙嵐時の加速域の空間分布や加速効率を含む定量的側面を明らかにする。
相対論的電子の消失機構	地上観測・モデリングと組み合わせて、波動粒子相互作用による消失過程を観測し、放射線帯変動への影響を推定する。	規模の異なる宇宙環境変動下において、リングカレント効果を含めた各種の消失機構を観測し、放射線帯変動への影響を検証する。	海外ミッションとの協力により、異なるL値、地方時で同時観測を実施し、宇宙嵐時の相対論的電子の生成と消失のバランスを定量的に検証する。

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

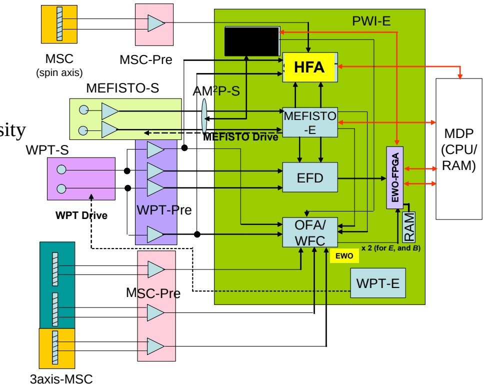
Receivers

[Receivers]

* **EWO-EFD** : DC – 80 Hz (512Hz waveform)
  - connected to WPT (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) & SC (B)
  - Waveform receiver with spectrum data (derived in MDP)

* **HF receiver** 10kHz – 5~10MHz for E; 10 – 100kHz for B
  - connected to the WPT / MEFISTO (E) [, SC (B)]



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

ERG PWE

INPUT

DPB: +-3.2V → +-100 mV/m dE = 3 μV/m

SPB: +-100V dV = 3 mV → +-6000 mV/m dE = 200 μV/m

Bias current : +- 300nA [2.3nA step]

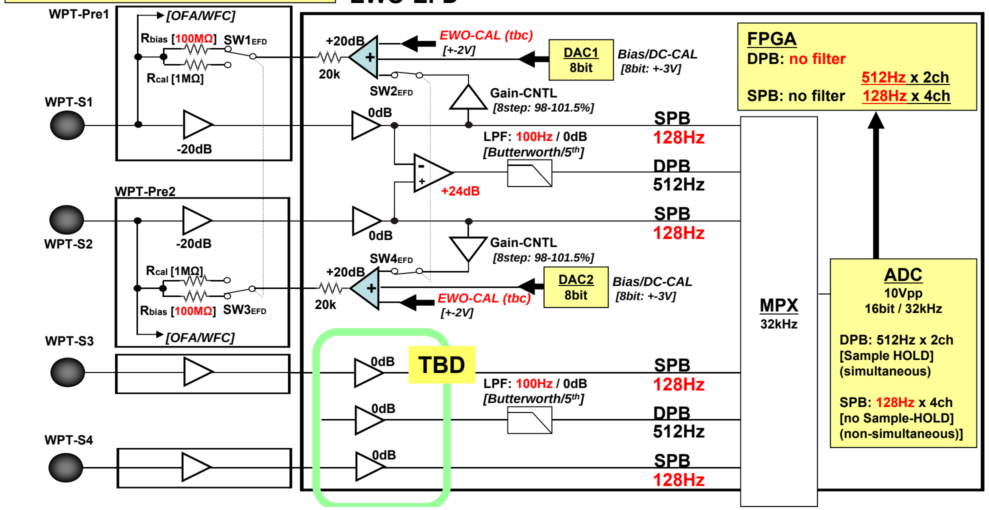
[SW1/3] at Power-on: R_{bias}
[SW2/4] at Power-on: OFF

: 100V-drive

: Digital parts

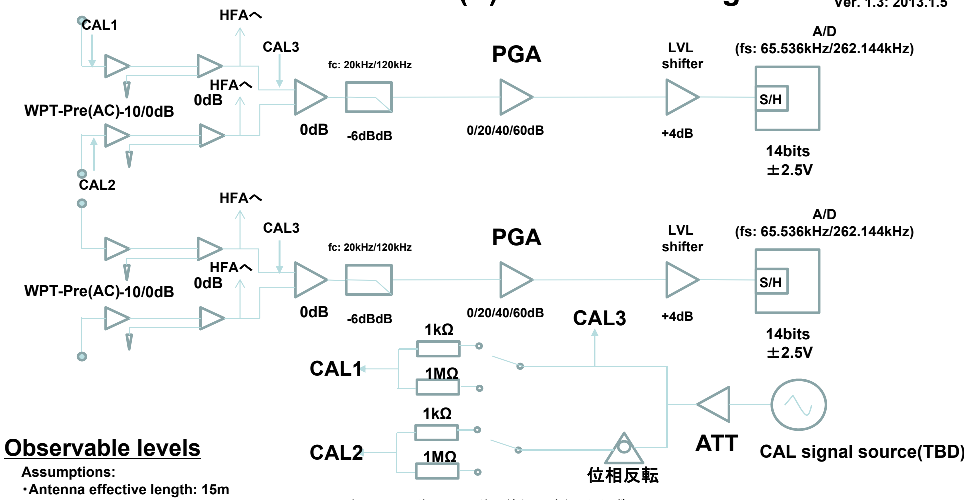
LPF condition: 512Hz: 71dB down, 1kHz -- 101dB down

EWO-EFD



ERG PWE-WFC(E) Block/level diagram

Ver. 1.3: 2013.1.5



Observable levels

Assumptions:

・Antenna effective length: 15m

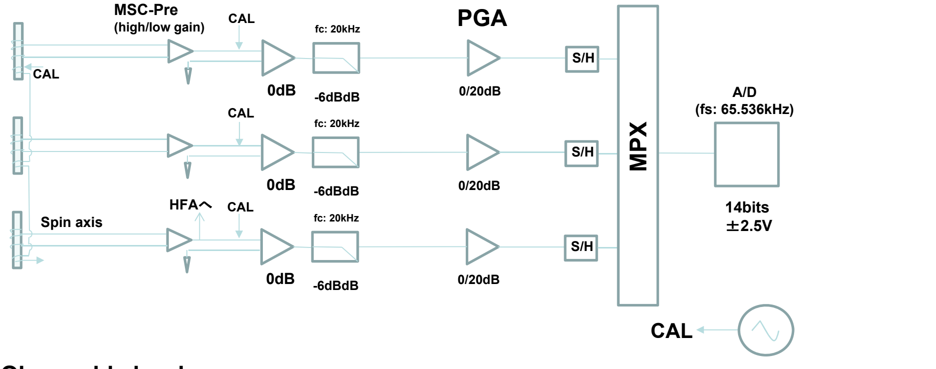
・Insertion loss at the WPT-Pre: 8dB (< 100kHz, これ以上は、徐々にCR並列等価回路なりたたず)

High gain mode: Total gain(50dB(=Insertion loss(-8dB)+Preamp(0dB)Receiver gain(58dB)))
2.5Vmax@A/D -> 3.15mVmax@WPT-pre-> 527uV/m @max
(1digit: 64nV/m)

Low gain mode: Total gain(-20dB(=Insertion loss(-8dB)+Preamp(-10dB))+Receiver gain(-2dB)))
2.5Vmax@A/D -> 3.15Vmax@WPT-pre -> 2.1V/m @max
(1digit: 256uV/m

ERG PWE-WFC(B) Block/level diagram

Ver. 1.3: 2013.1.5



Observable levels

High gain mode: MSC-Pre (high gain) – 6 dB (LPF) + 20 dB (PGA)
2.5Vmax@A/D -> 0.5Vmax@MSC-Pre-> 0.1 nT@max (1 kHz)
(1digit: 0.0122 pT)

Middle gain mode: MSC-Pre (high/low gain) – 6 dB (LPF) + 0/20 dB (PGA)
2.5Vmax@A/D -> 5/0.5Vmax@MSC-Pre-> 1 nT@max (1 kHz)
(1digit: 0.122 pT)

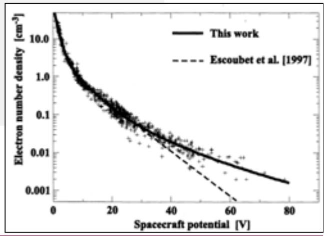
Low gain mode: MSC-Pre (low gain) – 6 dB (LPF) + 0 dB (PGA)
2.5Vmax@A/D -> 5Vmax@MSC-Pre -> 10 nT@max (1 kHz)
(1digit: 1.22 pT)

HFA issue

重量: 540g(PCB)+60g(Frame)
(SORBETと同等)
サイズ: A5 x1.5 (SORBETと同等)
FPGAロジック規模:納まる見込み
→引き続きPME筐体に収まるよう検討
消費電力: 約4W(SORBETの2倍)
→電源低減策を検討
周波数レンジ:10kHz～10MHz
→上限10MHzは下げる。

＜観測目標＞ 電子密度(<10⁶[cc]) を 10%精度で f_{UHR}[kHz] ～ 9 √ ρ [/cc]
・・・ f_{UHR} (< 1[MHz]) を 5%精度で ρ [/cc] ～ (f_{UHR}[kHz])^2/80

[Spacecraft potentialの場合（時間分解能: 高)]
精度: 100%程度
「相対値」は求まるが、周辺電子温度の影響大。
どのみち、Calibration情報は必要。



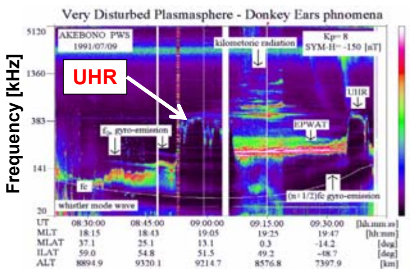
[Other bonus sciences] ～3MHz上限
- Auroral MF burst(THR)の微細構造探索
- Auroral Kilometric continuumの放射機構

Purpose of ERG/PWE/HFA

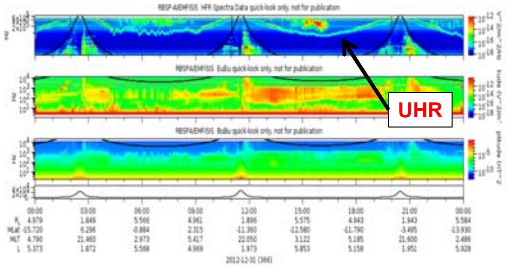
- Determination of electron number density by UHR for identification of plasmapause, and fp output to S-WPIA
- Observation of radio and plasma waves excited via wave-particle interactions and mode conversion processes in the storm-time magnetosphere

Specification of ERG/PWE/HFA

(1) RF input: Ex, Ey, and Bz
(2) Freq. Range: 0.01-10MHz
(3) Freq. Resolution: 1kHz (0.01-1MHz), 10kHz (1-10MHz)
(4) Time Resolution: 1 sec
(5) Sensitivity: -190dBW/m²Hz
(6) Dynamic Range: 84dB (14bit)
(7) PCB size: <A5×2
(8) Weight: <0.7kg
(9) Power Consumption: <2W

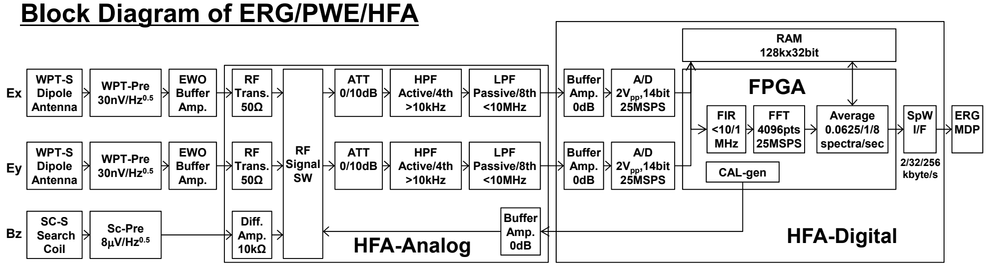


Example of Akebono Wave Data



Example of RBSP Wave Data

Block Diagram of ERG/PWE/HFA



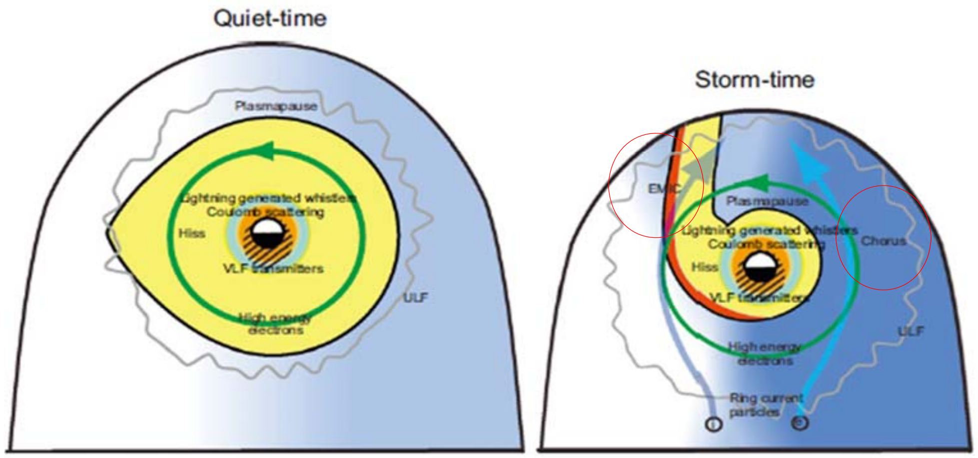
Weight & Power

	MMO SORBET	ERG-HFA (BBM#1)	ERG-HFA (BBM#2)
Mass	750g	600g	700g (*)
Power	1.7W	4W	1.9W(*)
(Analog)		1.6W	0.5W(*)
(Digital)		2.4W	1.4W(*)

(*) Designed value

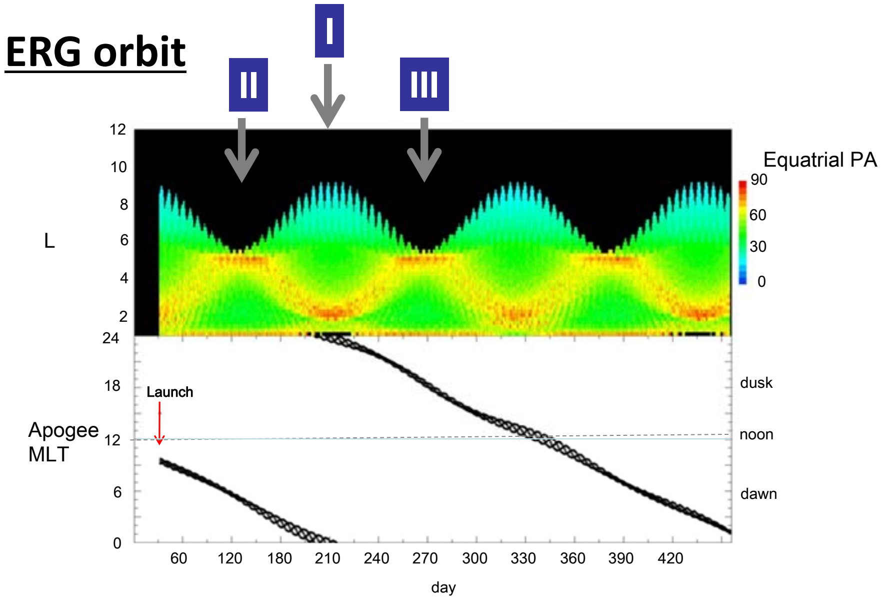
HFA BBM#1

Typical Plasma Waves in the Inner Magnetosphere

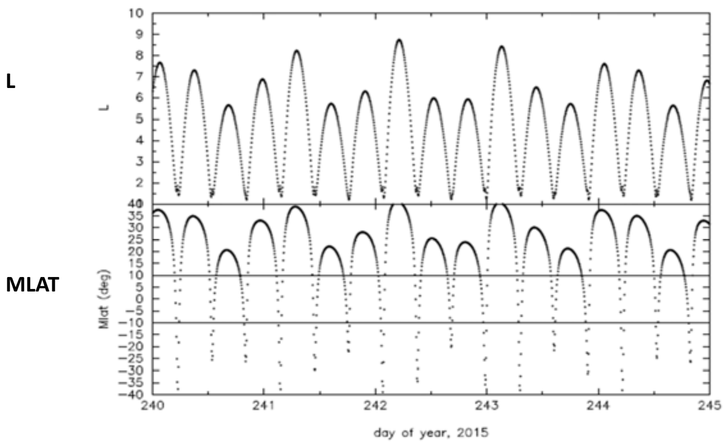


Shprits et al., 2008

ERG orbit



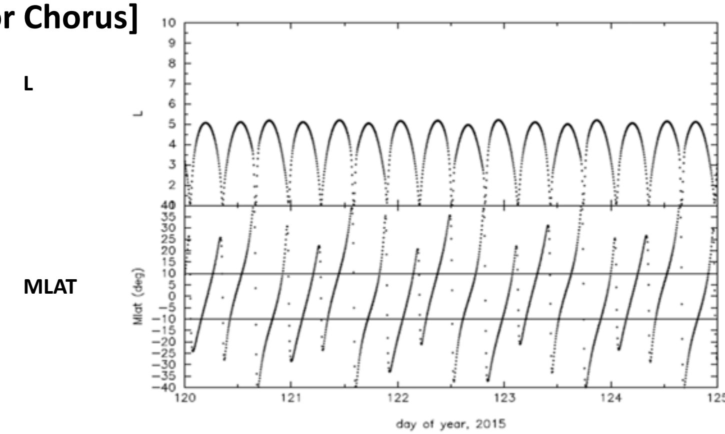
I. Apogee: Night, Magnetic equator: L ~ 2



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

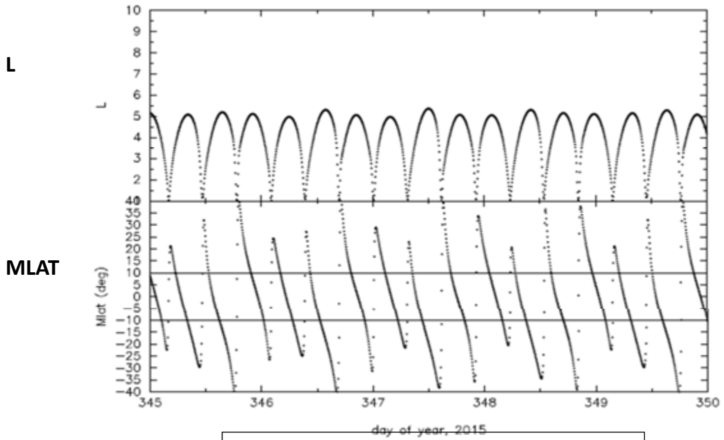
II Apogee: DAWN, Magnetic equator: L~5

[for Chorus]



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

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



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

Raw data from PWE

Receiver		Data	total (bps)
EWO-EFD	DPB [Sweep]	512Hz x 16bit x 2ch (sync) [1024Hz x 16bit x 2ch x 0.5/4sec] (sync)	16.3k
	SPB	128Hz x 16bit x 4ch (non-sync)	8.2k
EWO-OFA/WFC(E)	Nominal 1kHz [for S-WPIA]	65536Hz x 14(16)bit x 2ch 1024Hz x 14(16)bit x 2ch 349525Hz x 14(16)bit x 2ch x (0.117/0.8125)s	2097.1k 32.8k ----
EWO-OFA/WFC(B)	Nominal 1kHz	65536Hz x 14(16)bit x 3ch 1024Hz x 14(16)bit x 3ch	3145.7k 49.2k
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

Data Telemetry from PWE - Minimum (11840bps, 122MB/day)

Receiver		Data	total (bps)
EWO-EFD	DPB	spectrum(2Hz-80Hz) 1Hz x 8bit x 40point x 2ch waveform 8Hz x 16bit x 2ch	640 256
	SPB	waveform 4Hz x 16bit x 4ch	256
EWO-OFA/WFC(E)		spectrum(10Hz-20k) 2Hz x 8bit x 66point x 1ch waveform 1024Hz x 14(16)bit x 2ch / ~128 Waveform 65536Hz x 14(16)bit x 2ch / ~1800	1056 256 1165
EWO-OFA/WFC(B)		Spectrum(10Hz-20k) 2Hz x 8bit x 66point x 1ch waveform 1024Hz x 14(16)bit x 3ch / ~128 Waveform 65536Hz x 14(16)bit x 3ch / ~1800	1056 384 1748
S-Matrix (E & B)		S-Matrix 0.5Hz x 8bit x 66point x14component	3696
HFA	E-2ch	spectrum-E(10k-10M) 1Hz x 8bit x 60point x 2ch	960
	E/B	spectrum-E(10k-10M) 1Hz x 8bit x 60point x 1ch spectrum-B(10-100k) 1Hz x 8bit x 20point x 1ch	480 160

Data Telemetry from PWE - Maximum (40325bps, 415MB/day)

Receiver		Data	total (bps)
EWO-EFD	DPB	spectrum(2Hz-32Hz) 1Hz x 8bit x 40point x 2ch waveform 8Hz x 16bit x 2ch	640 256
	SPB	waveform 4Hz x 16bit x 4ch	256
EWO-OFA/WFC(E)		spectrum(10Hz-20k) 2Hz x 8bit x 66point x 1ch waveform 1024Hz x 14(16)bit x 2ch / ~128 Waveform 65536Hz x 14(16)bit x 2ch / ~160	1056 256 13107
EWO-OFA/WFC(B)		Spectrum(10Hz-20k) 2Hz x 8bit x 66point x 1ch waveform 1024Hz x 14(16)bit x 3ch / ~128 Waveform 65536Hz x 14(16)bit x 3ch / ~160	1056 384 19661
S-Matrix (E & B)		S-Matrix 0.5Hz x 8bit x 66point x14component	3696
HFA	E-2ch	spectrum-E(10k-10M) 1Hz x 8bit x 60point x 2ch	960
	E/B	spectrum-E(10k-10M) 1Hz x 8bit x 60point x 1ch spectrum-B(10-100k) 1Hz x 8bit x 20point x 1ch	480 160

波動観測計画のポイント

・バーストモード/S-WPIAの運用方針

MLT/L/MLATに依存する

・地上との連携観測： Pc5 (ERG+SuperDARN/GMAG)

Pc1 (ERG+G-SC)

・AKRなどの波動観測 （真夜中が遠地点の場合など）