

次期磁気圏観測衛星検討WG SCOPE計画 --プラズマ波動観測--

小嶋浩嗣¹, 笠羽康正², 八木谷聡³, 笠原禎也²,
石坂圭吾⁴, 熊本篤志², 樋口健⁵, 石村 康生⁶

SCOPE Plasma wave team

1. 京都大学
2. 東北大学
3. 金沢大学
4. 富山県立大学
5. 室蘭工業大学 もの創造系領域
6. JAXA

Plasma wave instruments onboard the SCOPE mission

Observation targets

- ✓ Macroscopic electric fields in the terrestrial magnetosphere
- ✓ Plasma waves destabilized due to wave-particle interactions in the terrestrial magnetosphere
- ✓ Plasma/Radio waves propagating from the inside or outside of the terrestrial magnetosphere
- ✓ Spacecraft potential

Outputs

- ✓ DC electric fields: vectors, magnitude  -Accelerations at shocks and reconnections
- ✓ Plasma waves(E and B):
Amplitude, frequency, phase, wavenumber  -Mode identification
-Identification of wave-particle interaction processes
- ✓ Local plasma density  -Macroscopic structure
- ✓ Solar/Terrestrial radio waves  -Monitor of solar and magnetosphere activities

SCOPE/PWI (Plasma Wave Instruments)

Electric Field Sensors – 3-axial

WPT	(Wire-Probe anTenna)	50-100m	DC - 10MHz
SPT	(Spin-Axis anTenna)	5-10m	few – several MHz

Magnetic Field Sensors (search-coils)

SC	(3-axis Search-Coils)	10 Hz – 100kHz
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DC/Low frequency Electric field (E: 0Hz ~ 32Hz)

EWO-EFD	(Electric Field Detector)
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Low/medium frequency E/B field (E: 10Hz ~ 100kHz, B: 0Hz ~ 20kHz)

EWO-WFC/OFA	(WaveForm Capture/Onboard Frequency Analyzer)
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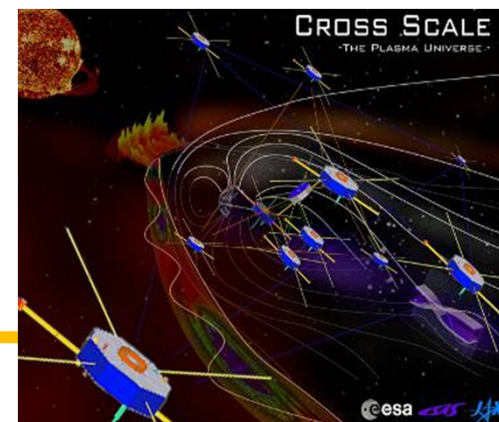
High frequency E/B field (E: 2.5kHz ~ 10MHz)

HFA	(High Frequency Analyzer)
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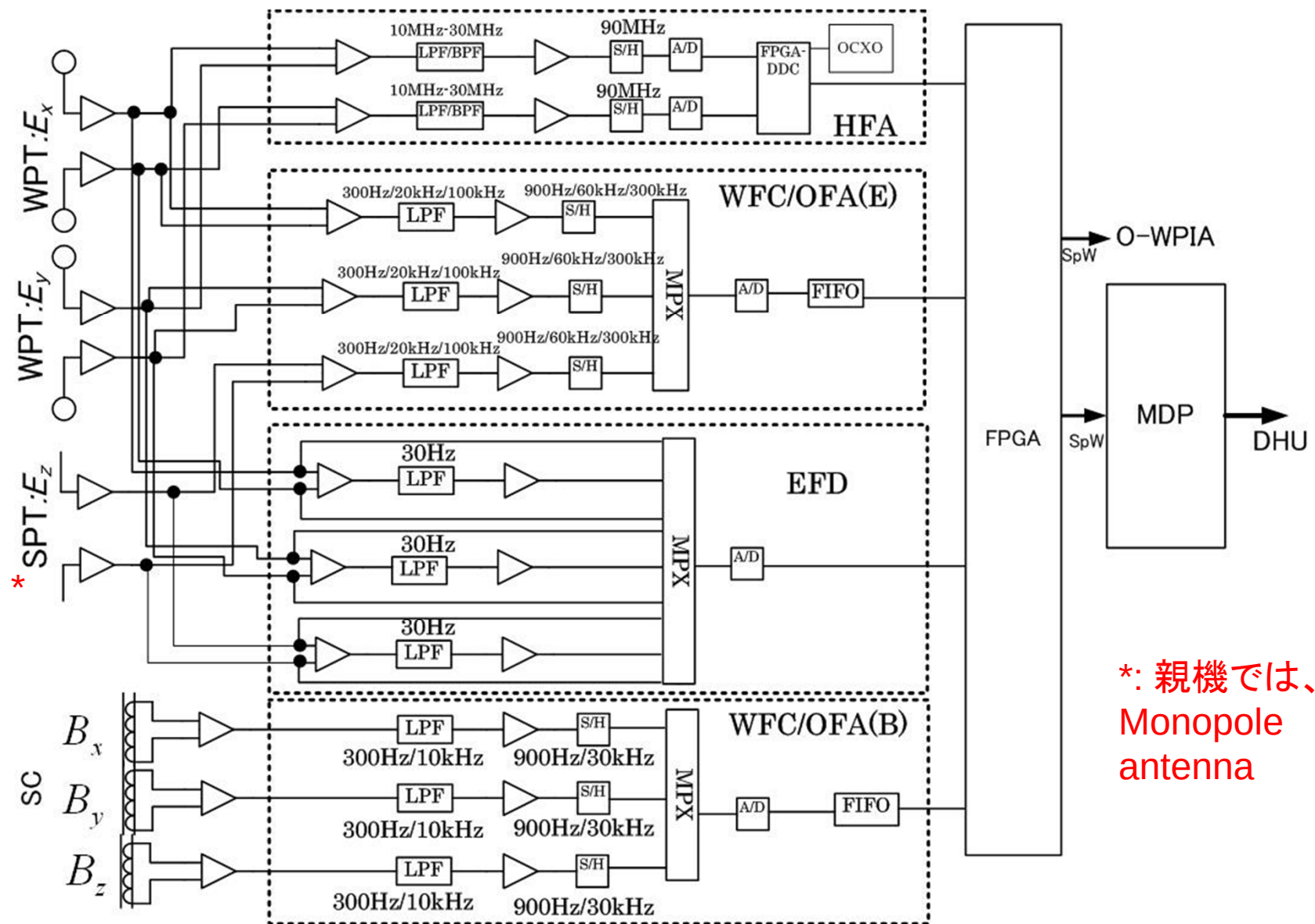
Wave-Particle Interaction Analyzer

S-WPIA	(Software Wave-Particle Interaction Analyzer)
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GEOTAIL
KAGUYA
BepiColombo
ERG



**Block diagram of the PWI onboard the SCOPE spacecraft (mother)
(almost the same design with the PWIs onboard the daughters)**



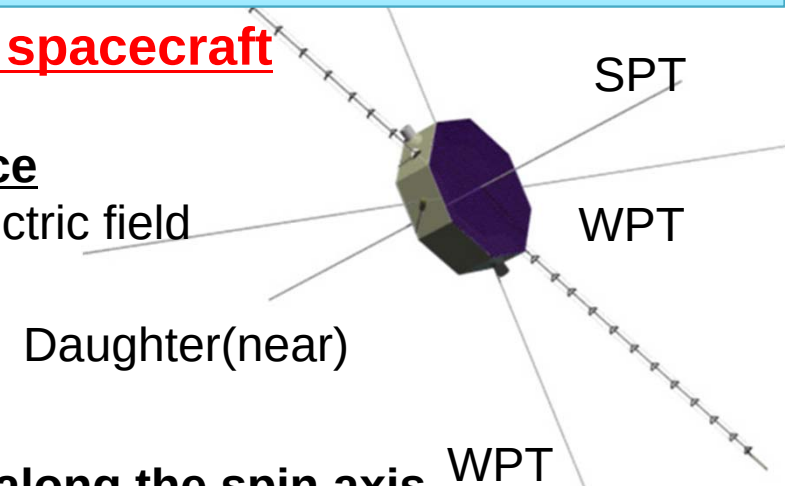
Sensors

Electric field sensors: WPT & SPT

Installed in the Mother and all of daughter spacecraft

*** Detection of electric field oscillations in space**

- Targets Macro-and micro-scopic electric field
- Frequency response DC ~ 10MHz



*** Two components on the spin plane and one along the spin axis**

Three pairs of dipole antennas

- Spin plane: WPT(Wire antenna) 25~50m(TBD) x 4elements
- Spin axis: SPT(Rigid antenna) 2.5~5m(TBD) x 2elements(*)

(*)親機では、通信アンテナの干渉を避けるため、Monopoleタイプになる予定

Heritage

<WPT>

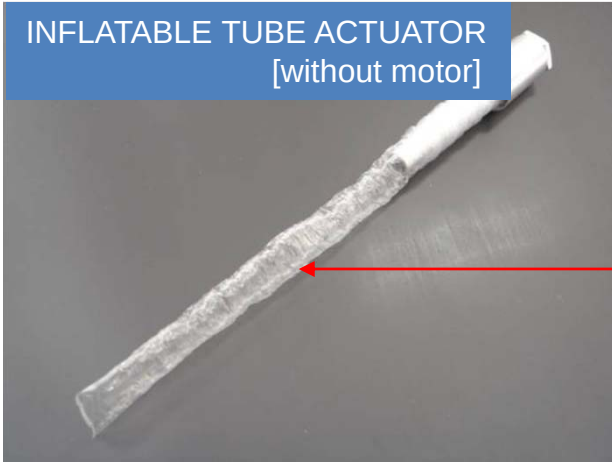
- BepiColombo/MMO [The same one is used in the ERG mission]
* EM design phase [Wire antenna : “15m” x 2elements]

<SPT>

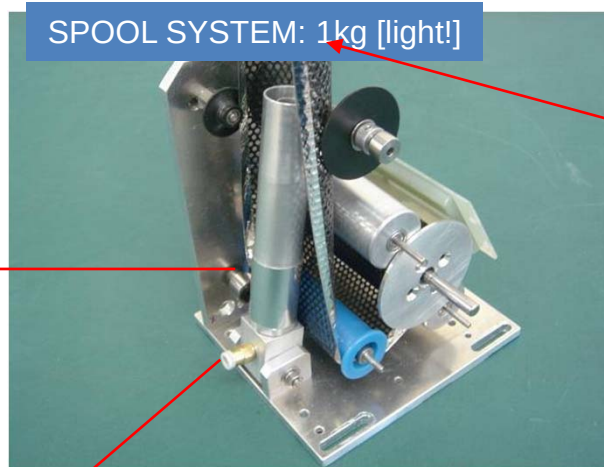
- S520-23 sounding rocket(2007) Successful extension of the same type of rigid antennas in 2.5m length

Rigid, Long, Light, and Safe antenna for the extension along Spin-axis electric field sensor(SPT)

INFLATABLE TUBE ACTUATOR
[without motor]



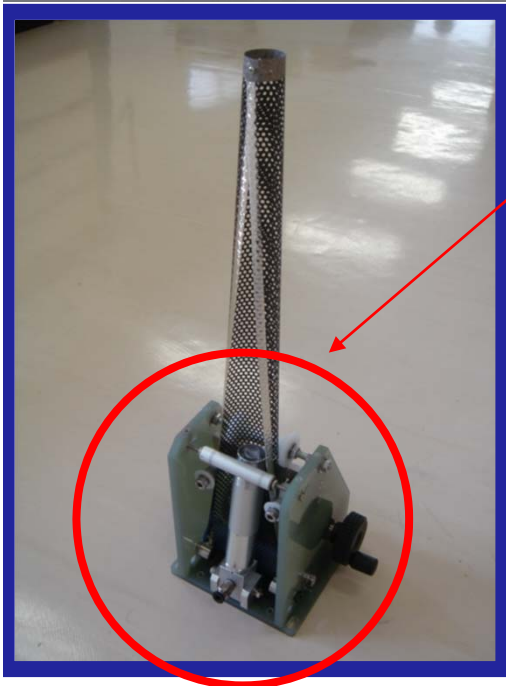
SPOOL SYSTEM: 1kg [light!]



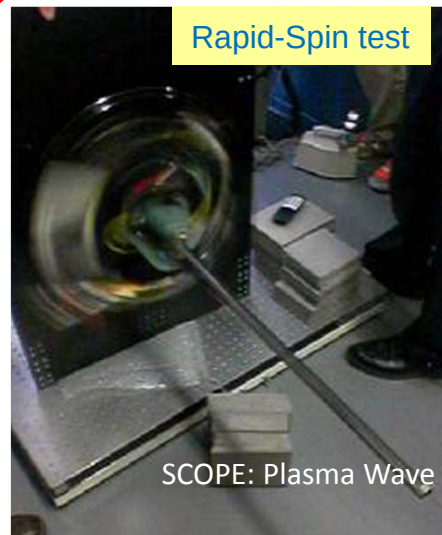
TWF (Tri-axially woven fabrics)
CFRP tubular member



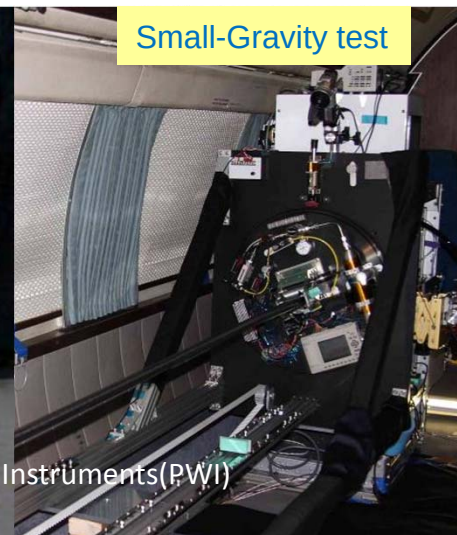
EVMR-ANT-1/3 [S-520-23 Sounding Rocket]



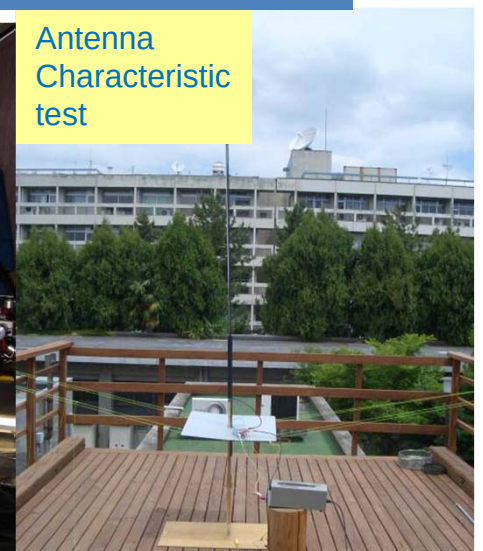
Rapid-Spin test



Small-Gravity test



Antenna
Characteristic
test



Magnetic field sensor: Search Coil(SC)

* Design:

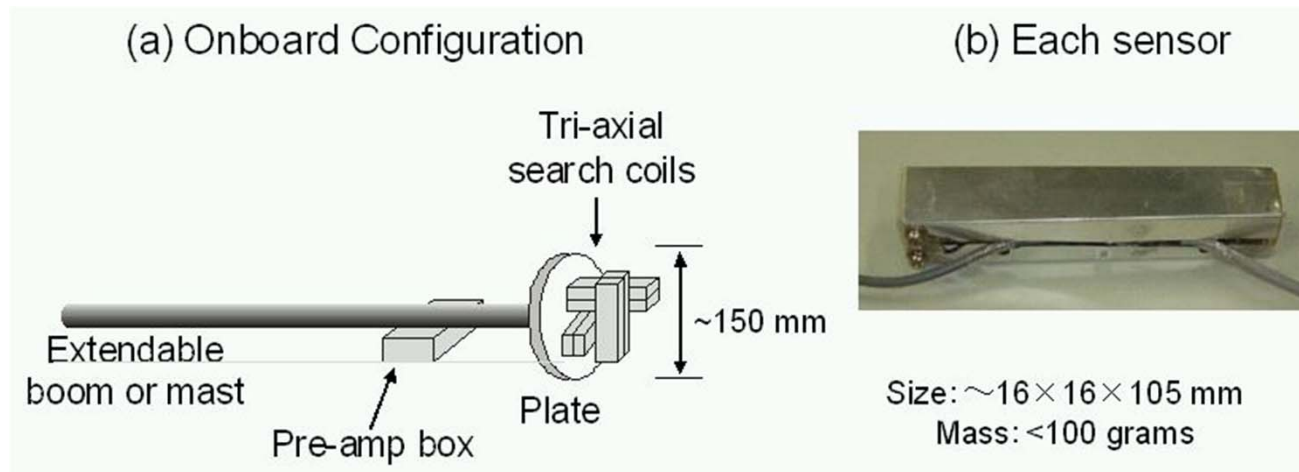
Tri-axis search coil magnetometer for the AC magnetic fields

The SC is mounted at the top of the mast in the length of a few meters in order to avoid the interference from the spacecraft

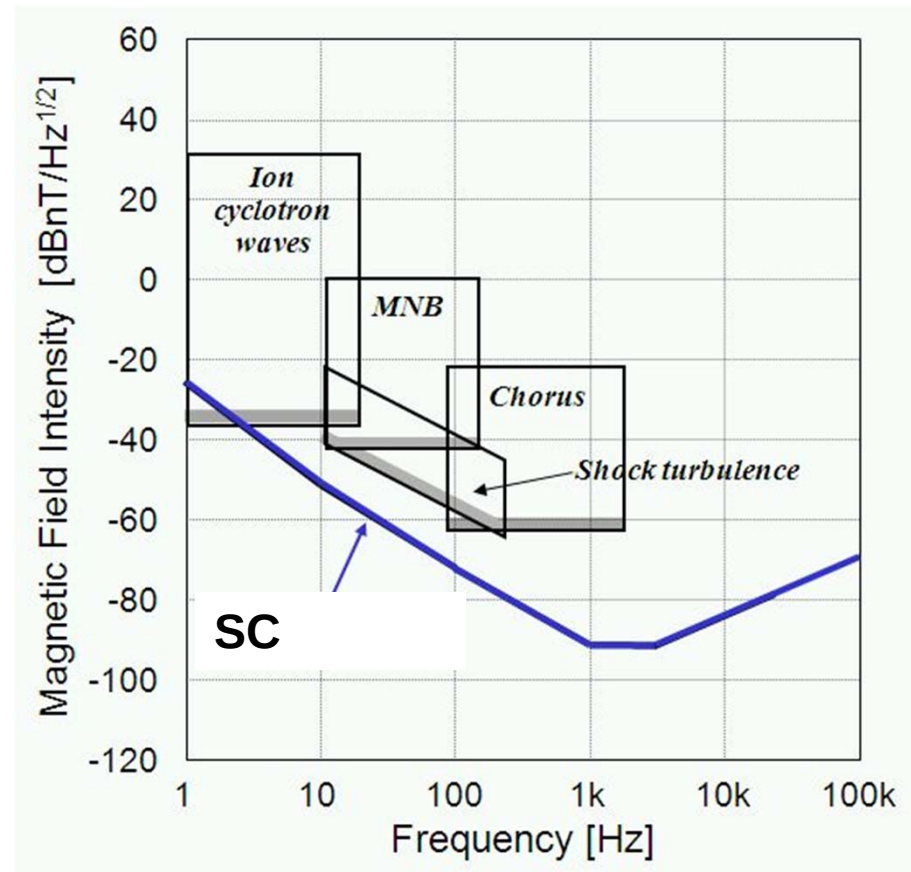
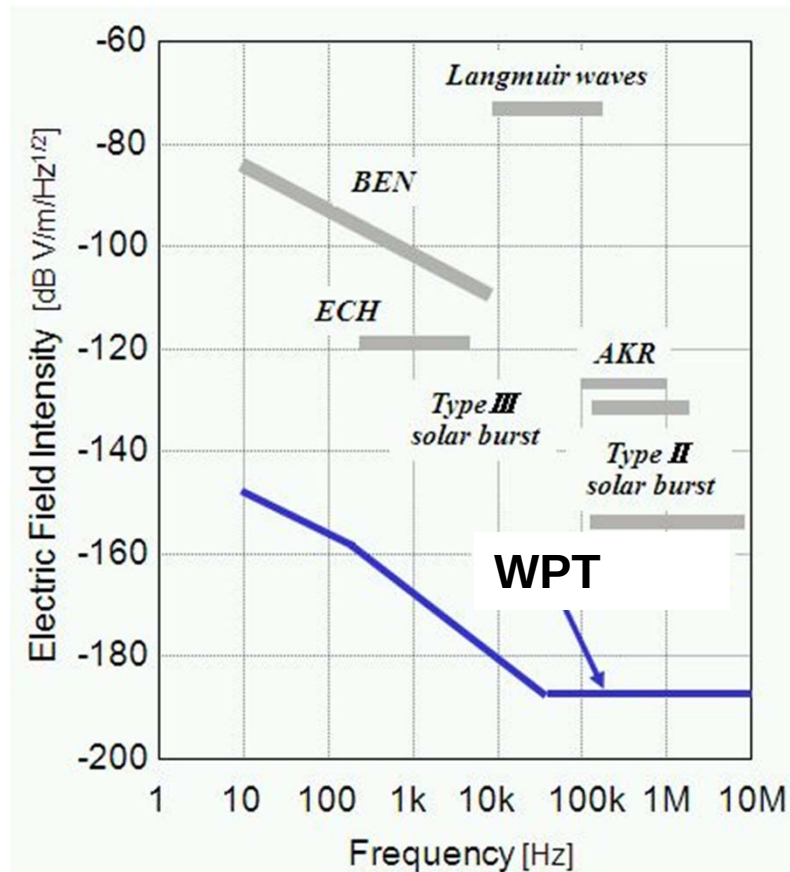
The design is almost the same one with the GEOTAIL search coils. However, the size is drastically miniaturized.

* Specifications: (Mother and daughter spacecraft)

Frequency	10 Hz ~ 100kHz
Sensitivity	$\sim 90 \text{ dBnT/Hz}^{1/2} @ 1 \text{ kHz}$
Resource	0.89kg (Including Preamplifier)



Sensitivities of electric field and magnetic field sensors



DC electric field		
	Max. (Resolution)	
Electric field(X/Y/Z vectors)	500mV/m (0.015mV/m)	Double probe
Spacecraft potential	100V (0.003mV)	Single probe

Receivers

EFD: DC & Low frequency Electric field Receiver

[Functions] *Electric field measurement Double Probe (Vectors : X/Y/Z axes)

DC ~ Low frequency (128Hz sampling)

Amplitude: $\pm 500\text{mV/m}$

Plasma convection and Macroscopic electric field

Acceleration due to local electric fields

Low frequency plasma waves related to

the coupling of electron-ion dynamics

*Measurement of spacecraft potential Single probe

Density measurement with the high time resolution ($\sim 10\text{msec}$)

[Specifications]: Mother and daughter spacecraft

-6 elements of electric fields (WPT x 4, SPT x 2(*))

Outputs -6ch(*): Single probe (Digital)

8/(128)Hz x 6ch

-3ch: Double probe (Digital)

128Hz x 3ch

(*)親機はMonopoleになるため、1コンポーネント、5chの測定となる。

OFA/WFC: Onboard Frequency Analyzer/Waveform Capture

[Functions]

- Direct waveform sampling for three components of E and three components of B (WFC)
- Sampled waveforms are stored on the memory and are telemetered to the ground after the data selection (WFC)
- FFT spectra are calculated by the onboard processor(OFA)



- 3D structure of nonlinear plasma waves
- 3D poynting flux measurement
- Quantitative measurement of Wave-particle interaction

Specification: Mother and daughters

Electric field component(WPT x 2, SPT x 1) (**SPTはMonopole mode**)

Frequency:	10Hz~300Hz	(Low frequency mode)
	10Hz~20kHz	(Boundary region mode)
	10Hz~100kHz	(Solar wind/Shock region mode)

Magnetic field component(SC: 3axes)

Frequency:	10Hz~300Hz	(Low frequency mode)
	10Hz~10kHz	(Boundary/Solar wind/Shock region mode)

HFA: High Frequency Analyzer

●Targets

- **AKR**(Auroral Kilometric Radiation)
 - Activities of the terrestrial magnetosphere
- Type II/III solar radio bursts
 - Solar activities and interplanetary disturbances
- Boundary crossing detector by monitoring plasma densities with very high time resolutions

●Specifications(Mother and daughters)

Frequency: **10kHz~10MHz**

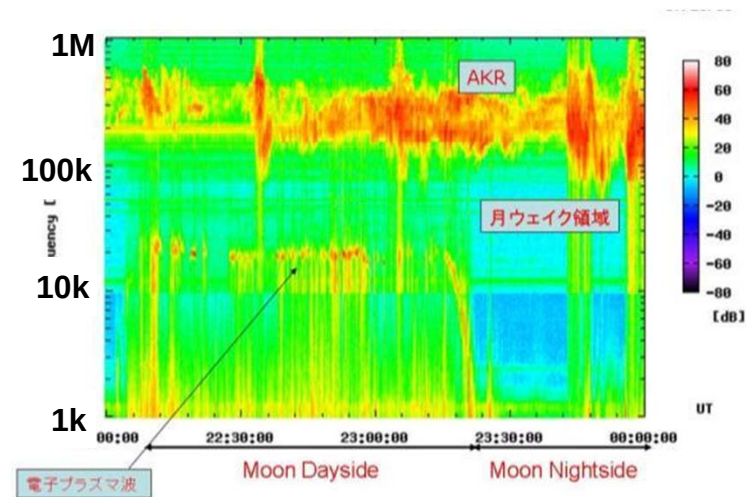
Range: **$>10^{-19}\text{W/m}^2\text{Hz}$** (Galaxy noise)

66dB(12bits)

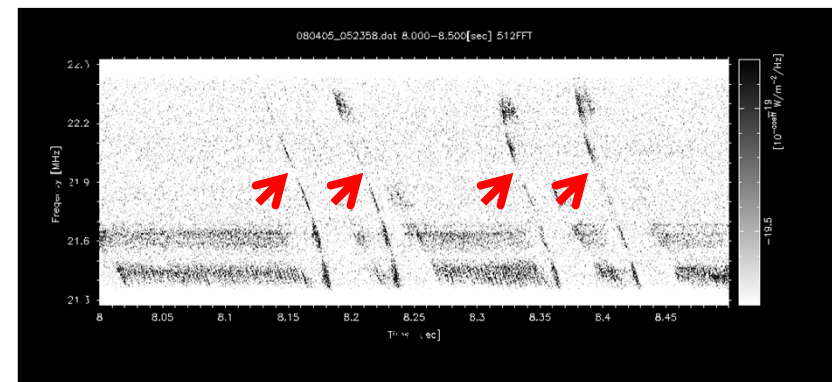
Design: High speed waveform sampling(80MHz)

DDC(Digital Down Conversion) installed
inside the **FPGA**(Field Programmable Gate Array) realizes the spectrum data with high speed frequency steps

HFAは、ERG衛星にも搭載予定である。

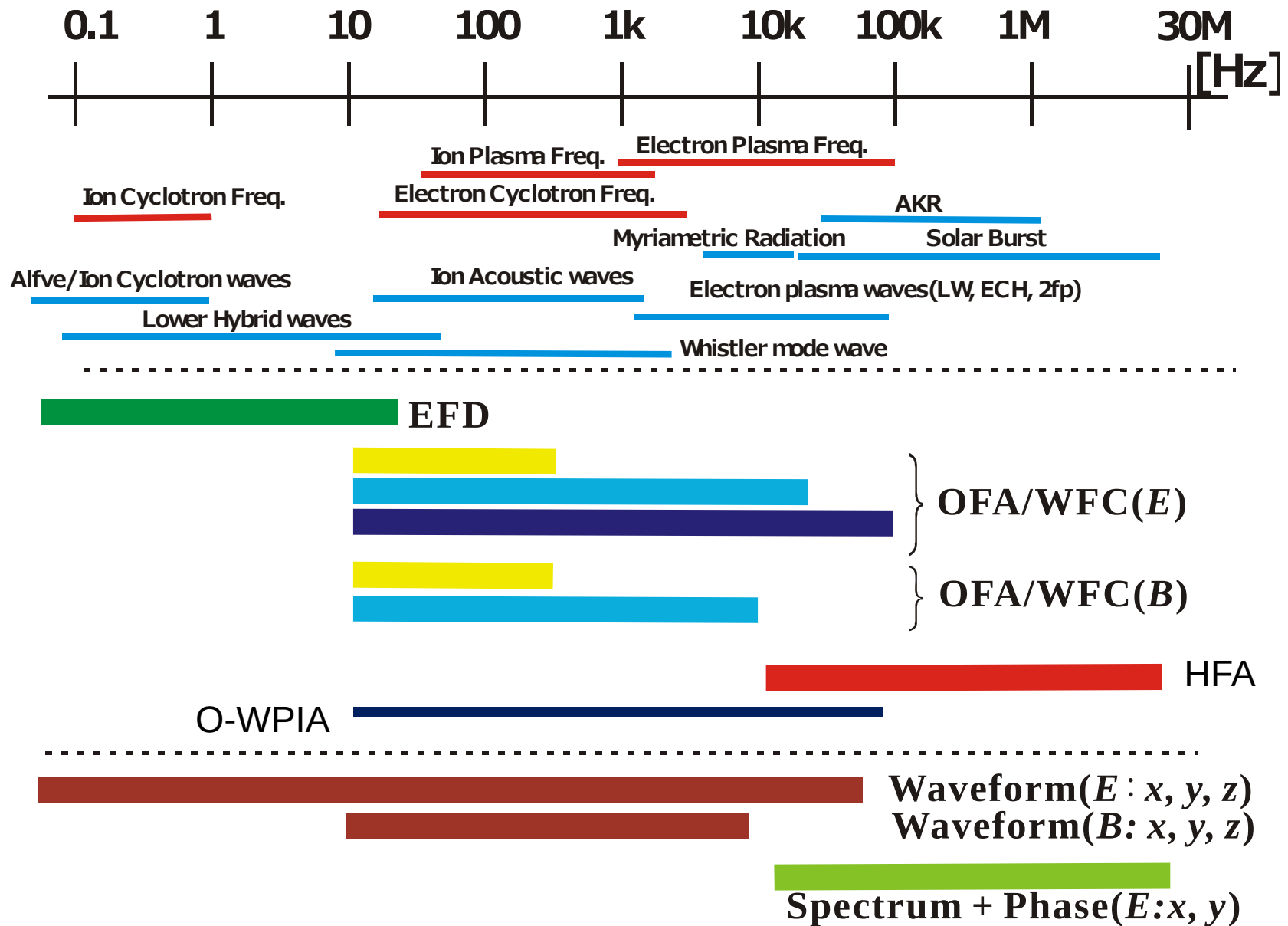


AKR and waves in the lunar wake
[Kasahara et al., 2008]



Jovian solar bursts
[Tohoku Univ.]

Frequency Coverage of the PWI receivers

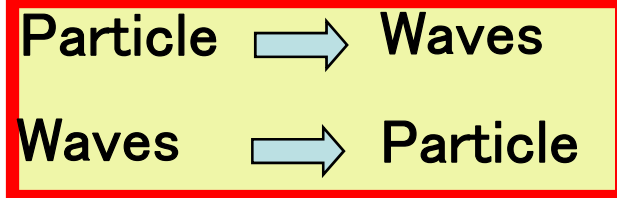
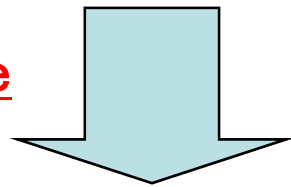


ERG衛星用に関開発を進めている
WPIA(Wave-Particle Interaction Analyzer)を
SCOPE用アレンジして搭載

In Wave-Particle Interactions, the phase relation of waves and particle velocity vectors determines the energy flow direction

$$\frac{d}{dt} \left(\frac{1}{2} m V^2 \right) = \mathbf{E} \bullet \mathbf{V} = q |\mathbf{E}| |\mathbf{V}| \cos \theta$$

Energy flow balance



粒子速度ベクトルと電界ベクトルのスカラー積により波動-粒子間のエネルギーフローを定量的につかむことができる。

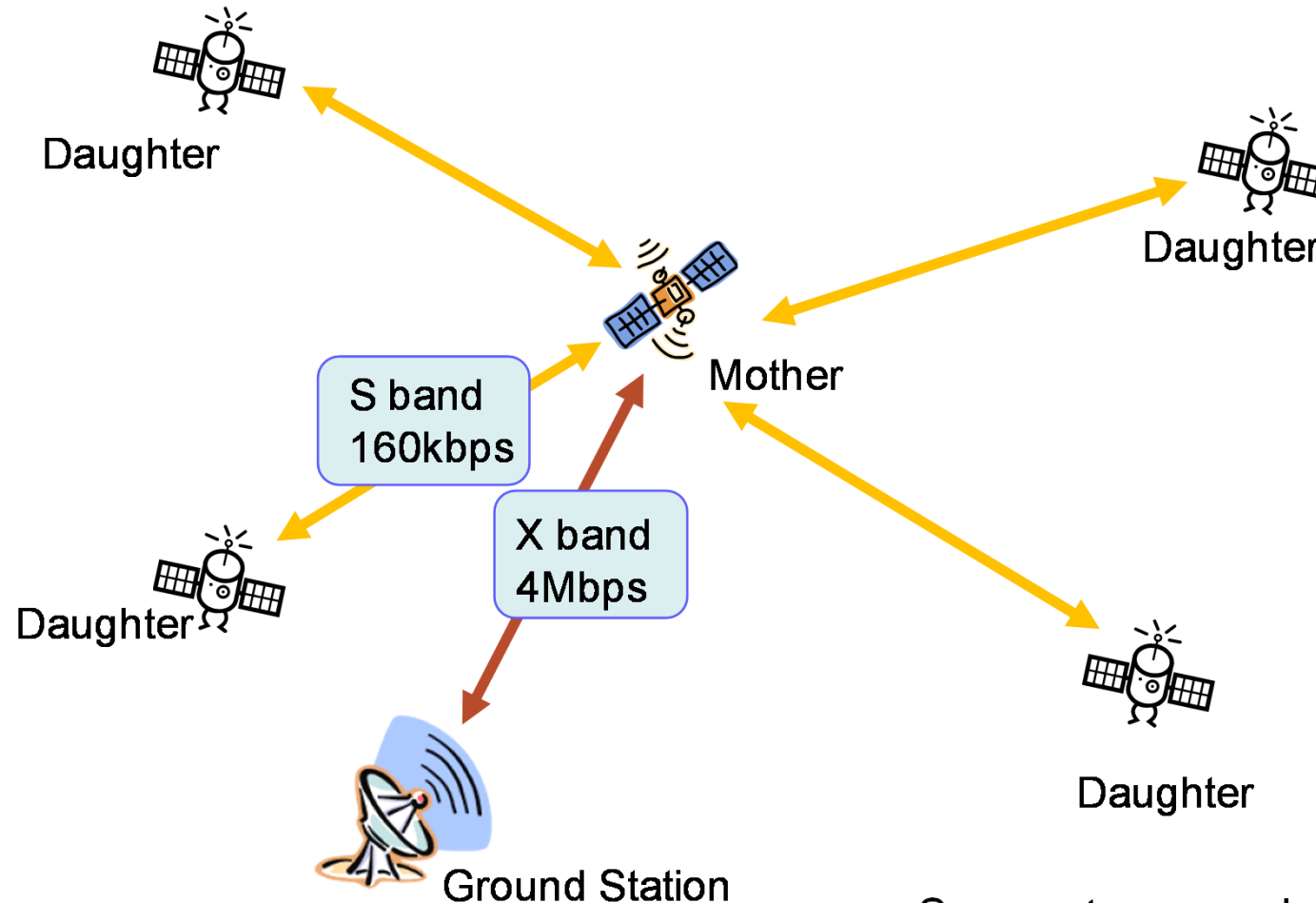
SCOPEでは、ターゲットとなるプラズマ波動現象が、ERGよりも多様性に富んでいる

従って、より多くの計算アルゴリズムを搭載したWPIAを開発する必要がある。

ERGでの実績を踏まえ、よりIntelligentな動作を保証するWPIAの開発を進める。

SCOPE編隊飛行用連携観測シミュレータの開発

The multi-spacecraft communication simulator will allow us to simulate the plasma wave data flow among spacecraft. It will be very helpful for establishing the operation strategy.



See poster paper by Kasahara et al.

- PC1, 2 and 3 are equivalent to three spacecraft.
- They communicate with each other through the control PC.
- The control PC simulates the quantity and quality of the communication line between each spacecraft.

SCOPE: Plasma Wave Instruments(PWI)

SCOPE編隊飛行用連携観測シミュレータの開発

シミュレータの概要

□ 地球宇宙内の編隊飛行衛星

➡ LANで相互接続した複数PC

□ 宇宙PC

(宇宙環境を模擬)

✓ 時分割多重通信の制御

✓ 通信パラメータの制御

✓ 通信容量

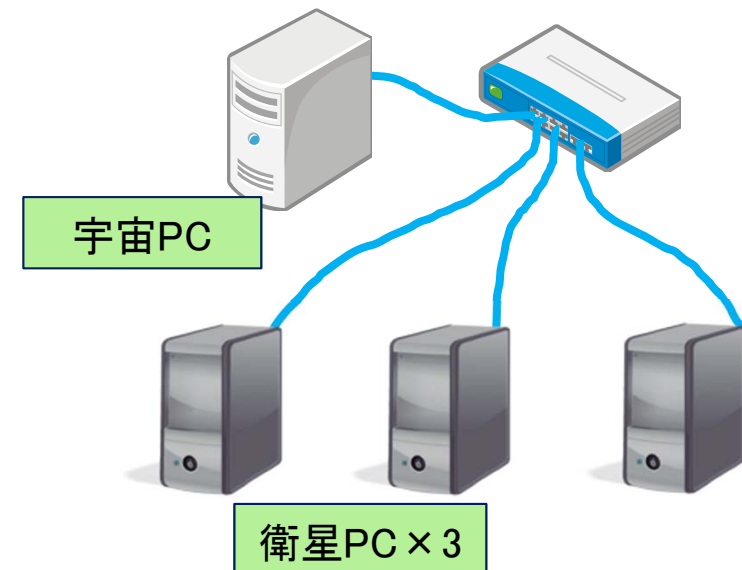
✓ 通信遅延

□ 衛星PC

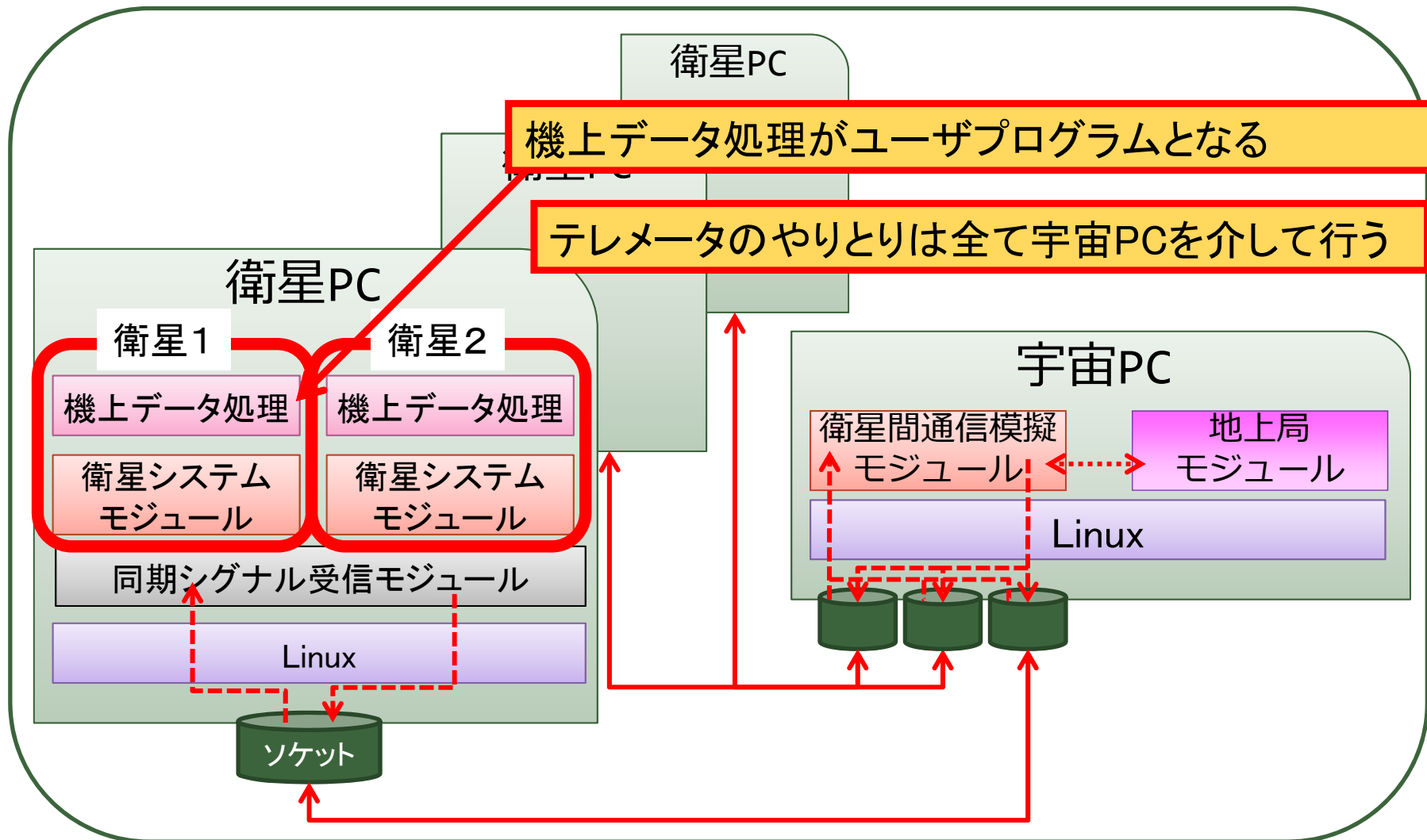
(それぞれの衛星を模擬)

✓ 衛星システム

✓ 機上データ処理



システムの階層構造

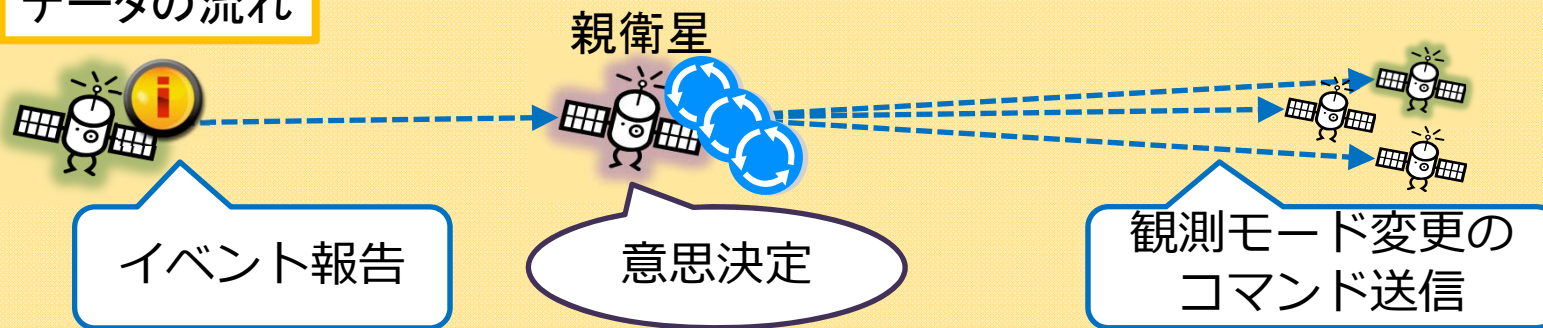


連携観測手法の概要

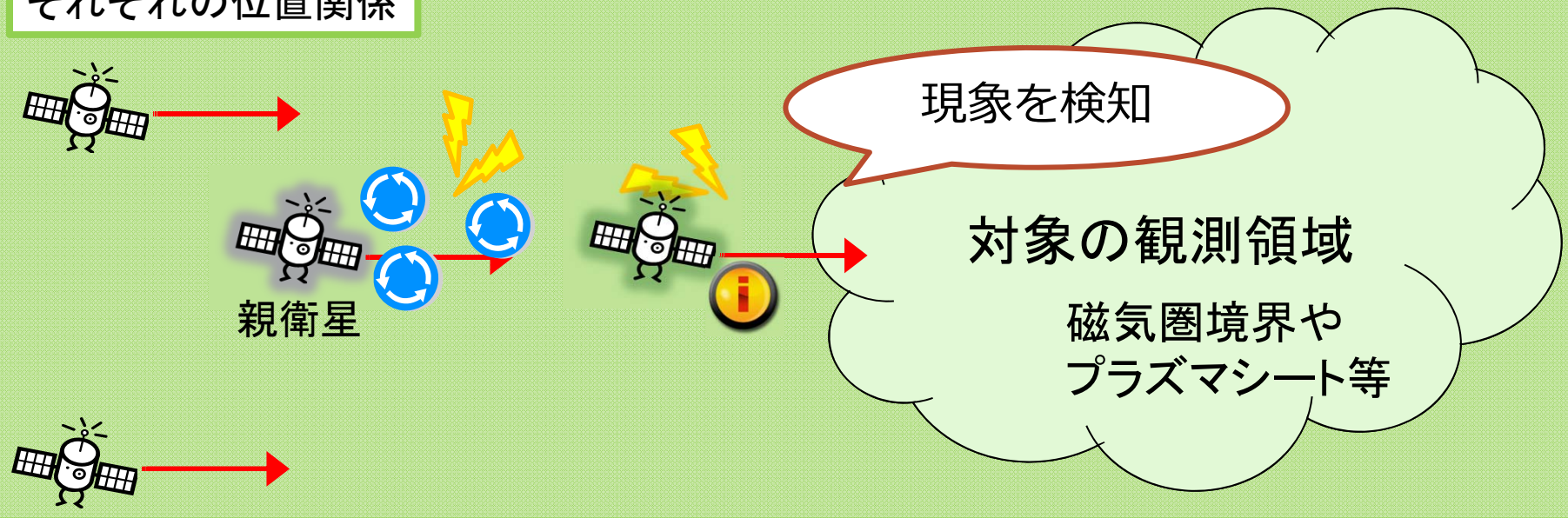
- 機上データ処理にイベント検出機能を実装する
 - ✓ イベント・・・磁気圏内の領域境界通過など
 - ✓ 波動観測器で言えば、波形およびスペクトルの急激な変化を読取る
 - ✓ イベントはタイムアウトおよび優先度のパラメータを持つ
- 子衛星はイベント情報を親衛星に報告する
- 親衛星はそれらの報告を基に
 - ✓ 最適な観測モードを決定
 - ✓ 子衛星にコマンドを送信して指揮を執る
- イベントのタイプをやりとりするので、低容量の通信回線でも実現可能
 - ✓ SCOPE では 20[bps] の通信容量が使える

提案手法における情報の流れ

データの流れ



それぞれの位置関係



シミュレータにおける意思決定アルゴリズム

- 最適な観測モード
 - = 各衛星が報告したイベントの内最も優先度の高いものに依じる
 - ✓ ただし一定時間(タイムアウト値)の間に過半数の衛星が同じイベントを検出しない場合は元のモードに戻る
- 親衛星は累積された報告を基に意思決定を行う
- 最適観測モードは全衛星に同時に通知する
 - ✓ 観測対象の内外で複数点同時に観測を行うことにより, 現象の時間的・空間的構造を把握する

期待される成果

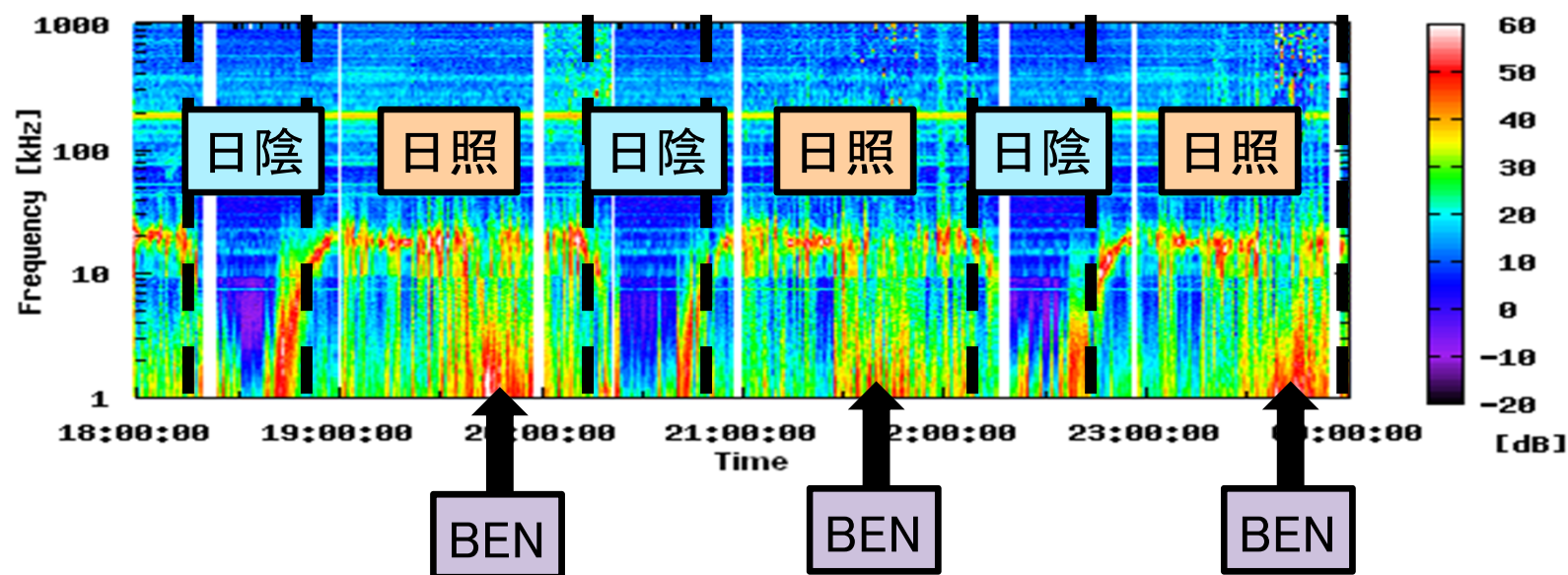
- 領域境界周辺の空間構造のさらなる解明
- 局所的現象の捕捉

擬似イベントによる実験



かぐや (SELENE) データによる疑似実験

3種類のイベントタイプを定義



BEN (Broadband Electrostatic Noise)

優先度

BEN > 日照 > 日陰

SCOPE編隊飛行用連携観測シミュレータの開発

かぐやWFCデータを使った評価結果

- 最適観測モードとの一致度の平均をモード毎に計測
- 親子間通信を行わない場合(表1)
 - ✓ 親子間通信を行わない単独運用の際に取り得る評価値
 - ✓ 全観測時間のおよそ5割で不適切な観測
 - ✓ BENでいうと、2割の時間帯しか最適な運用ができない
- 親子間通信を行う場合(表2)
 - ✓ 100%となっていないのは、衛星間通信の遅延が影響
 - ✓ 単独運用と比べると46ポイント大きい評価値
- 親子間通信によって高品質な観測データを得ることができる

表1: 単独運用の評価値

日陰	日照	BEN	総合
87.3%	42.9%	20.4%	50.8%

表2: 親子間連携の評価値

日陰	日照	BEN	総合
97.9%	97.9%	91.1%	97.1%