Geospace Exploration by ERG/Arase Project

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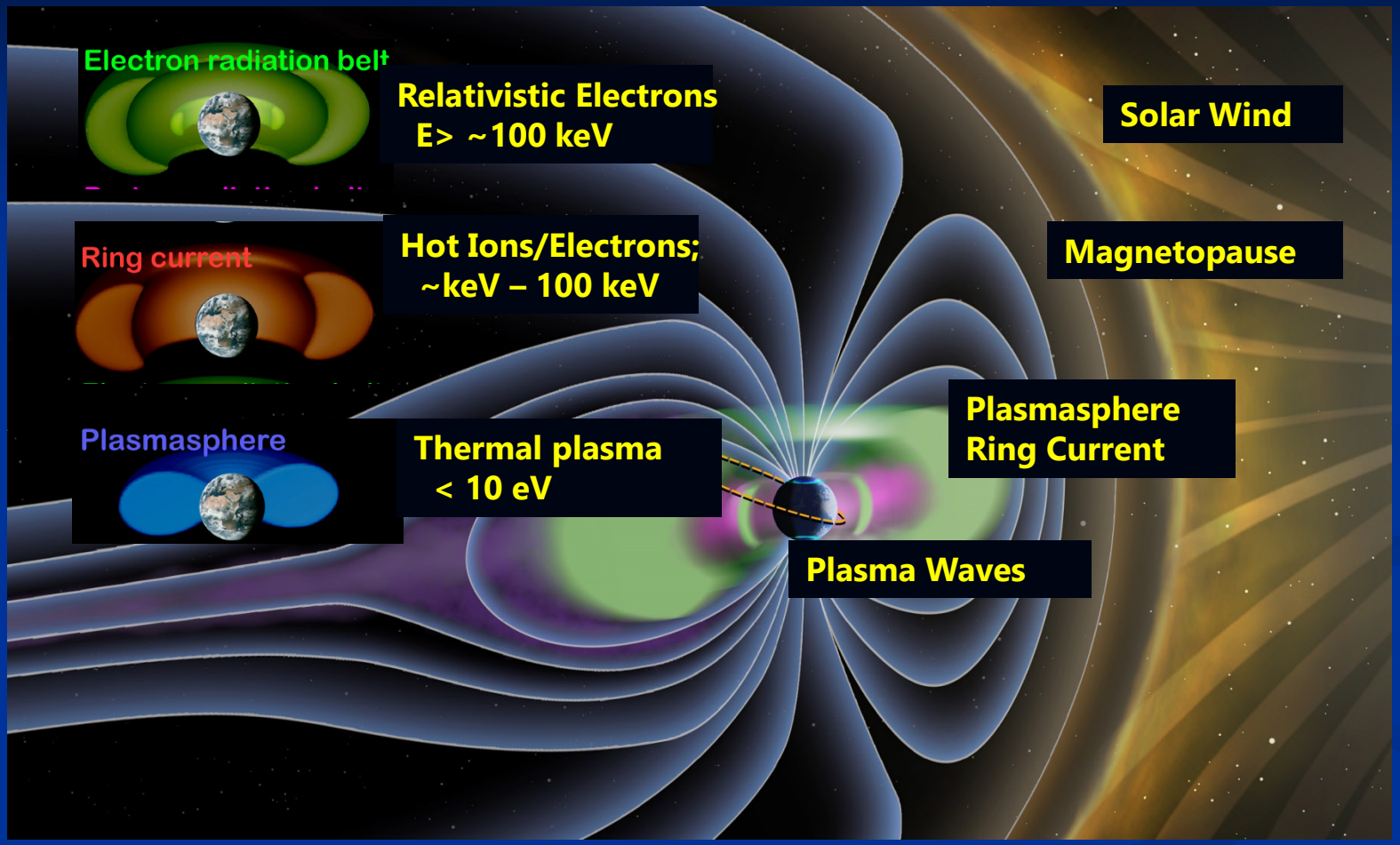
T. Mitani, Y. Kazama, S.-Y. Wang,
Y. Kasahara, Y. Kasaba, S. Yagitani, A. Matsuoka, H. Kojima,Y. Katoh,
K. Shiokawa, K. Seki, and the ERG project team

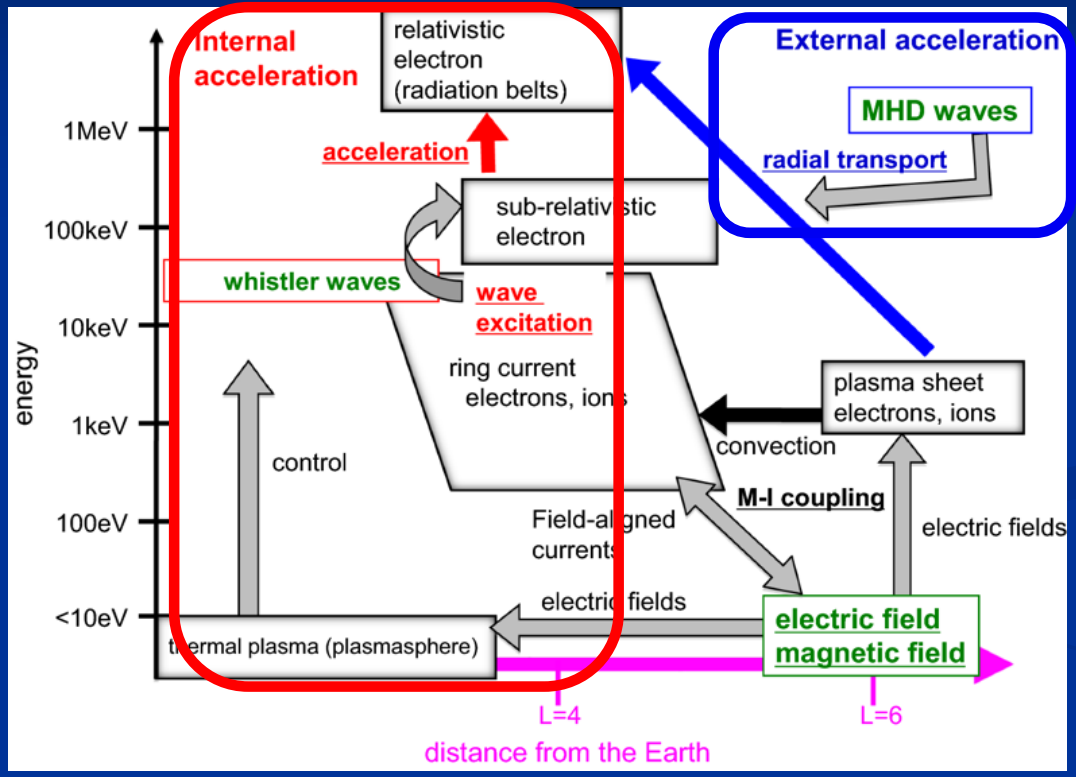
Introduction: Geospace system

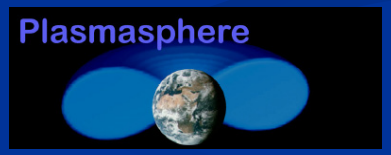


In the inner magnetosphere, different energy population with 6 orders (eV ~ MeV) coexist.
Dynamical coupling of different energy/regions through wave-particle interactions cause evolutions of the radiation belts as well as geospace storm.

Geospace system: cross-energy coupling

Understanding acceleration, transportation and loss of outer belt electrons, dynamics of inner magnetosphere and geospace storms in the context of cross-energy/cross-regional couplings



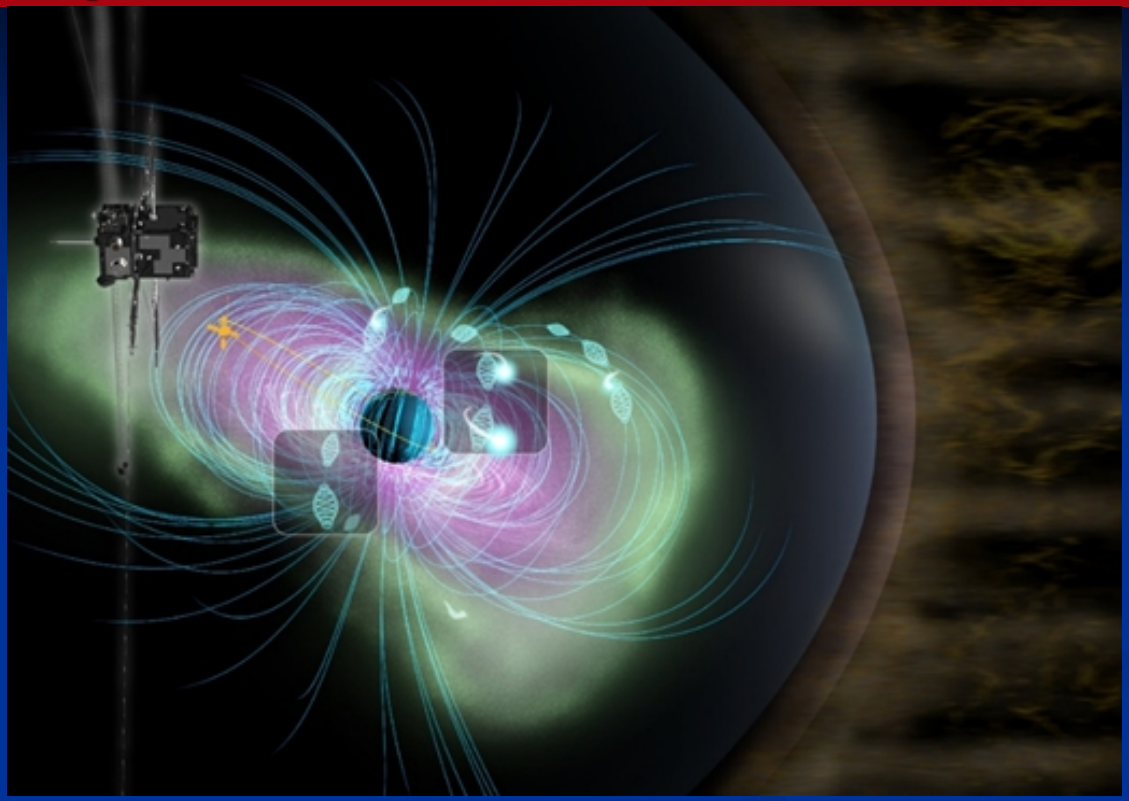


Miyoshi+ [2018, EPS]

Key points of the ERG project:

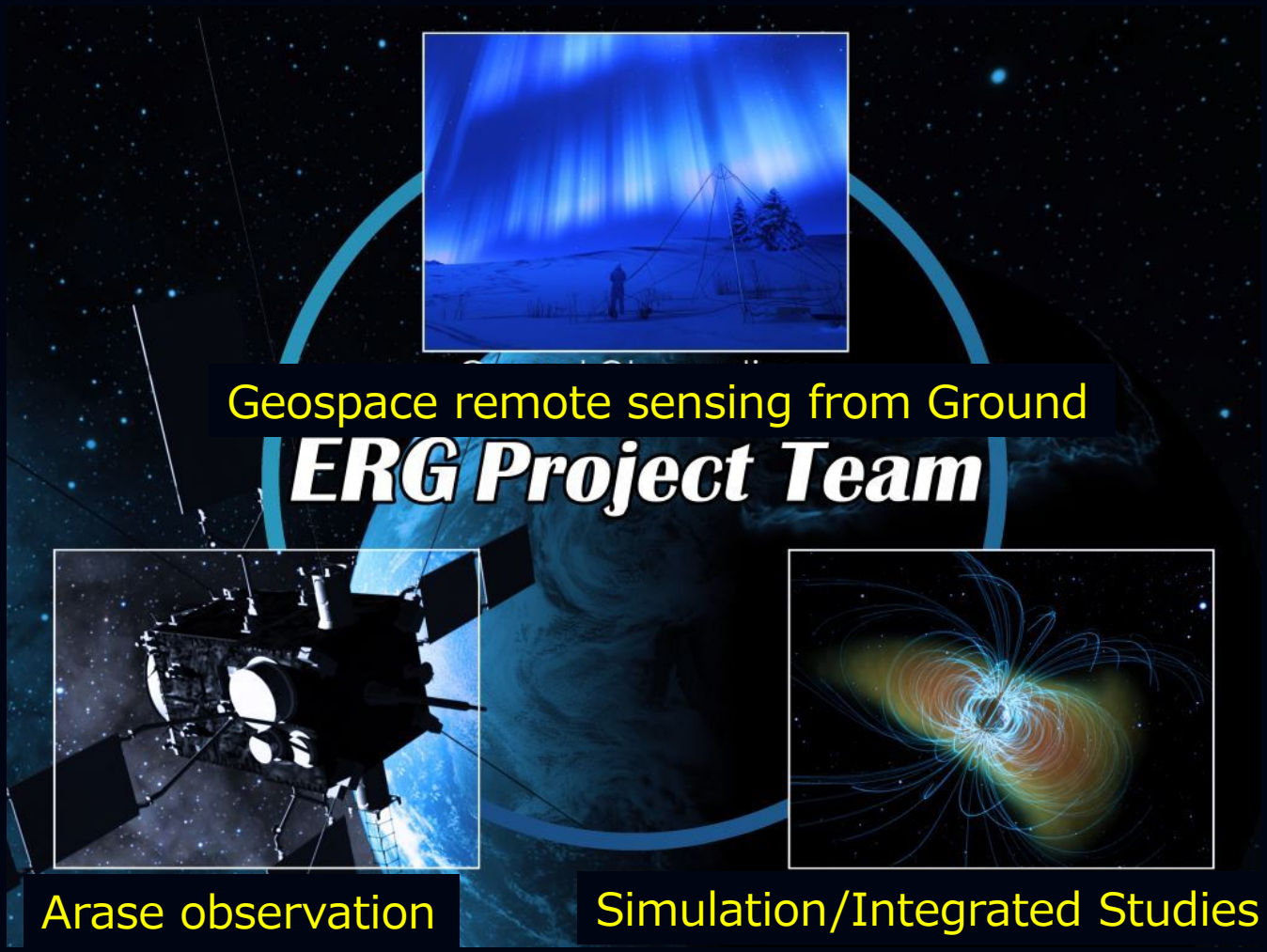
- **Comprehensive observations to understand the whole process from the generation of waves to acceleration and losses**
- **Observations on wide energy plasma/particles and wide frequency field and waves.**
- **Conjugate observations with ground-based network observations and other geospace satellites.**

Geospace Exploration Satellite: Arase



- **Launch:** Dec. 20, 2016
- **Prime Mission:** March 2017 – October 2018
- **Extended Mission:** November 2018 – March 2022
- **Apogee :** 32246 km
- **Perigee :** 400 km
- **Inclination Angle :** 31.427deg
- **Spin Periods :** 8 sec
- **Orbital Periods:** 563.85 min

ERG /Arase Project

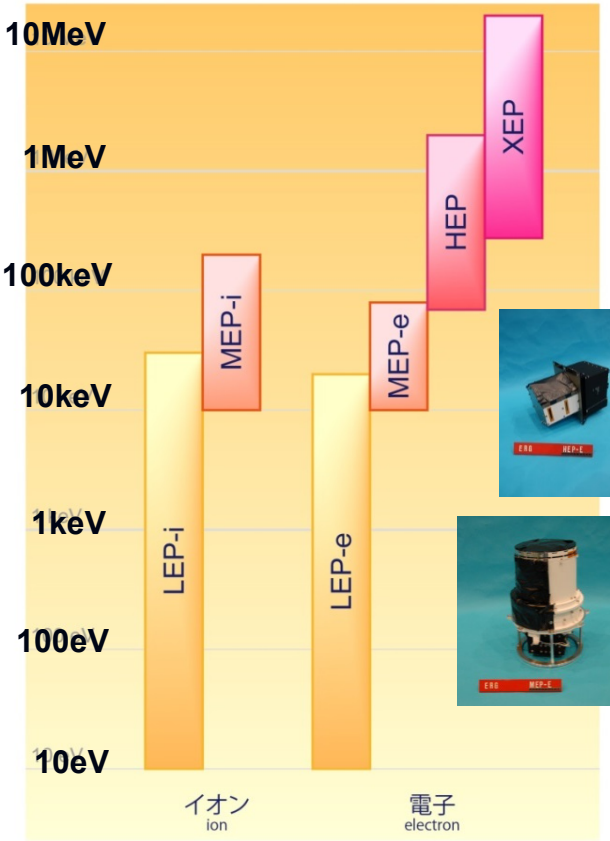


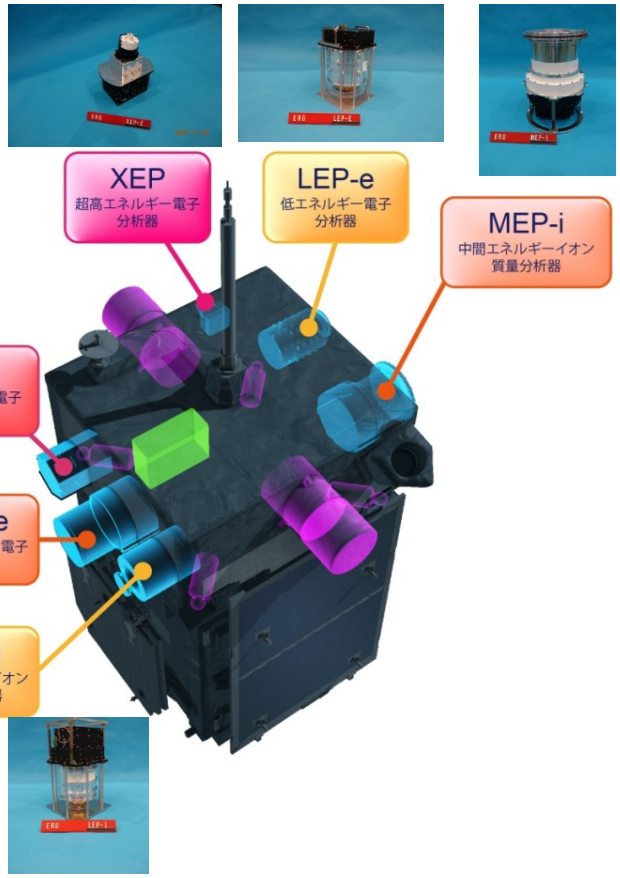
More than 100 researchers in Japan and Taiwan joined this project.

Please see Miyoshi+[2018, EPS] for overview of the project.

Science Instruments (plasma/particles)

PI/Co-PIs [N. Higashio, T. Mitani, S. Kasahara, S. Yokota, K. Asamura, S-Y Wang, Y. Kazama]





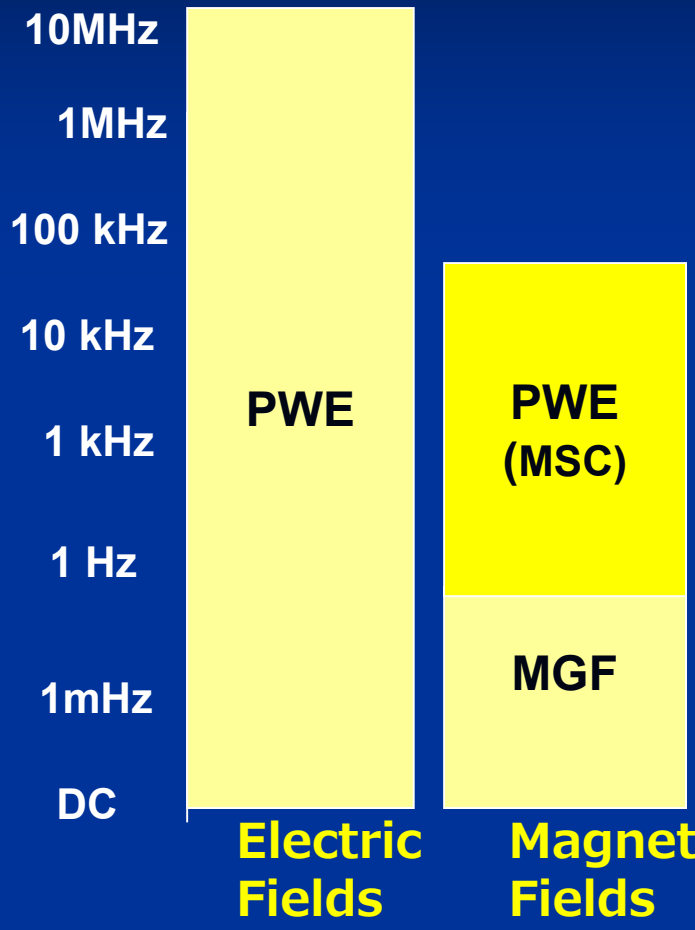
- Wide energy plasma/particles from 10eV – 20 MeV can be observed.

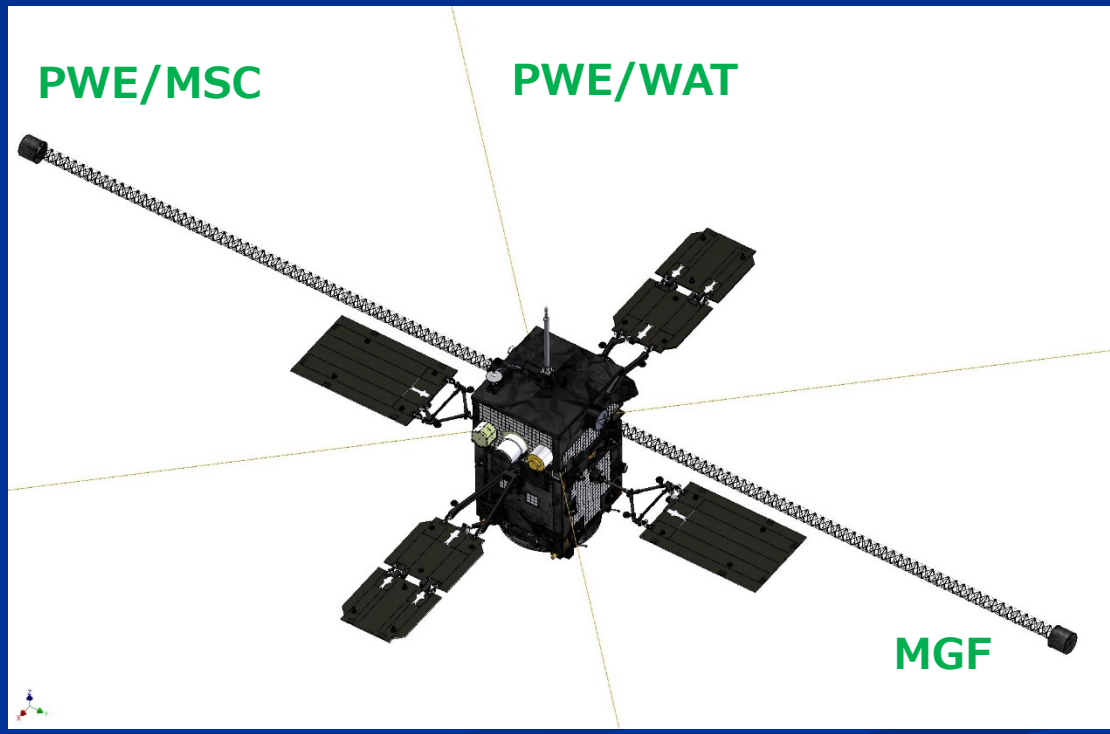
Science Instruments (Fields/Waves)

PWE: Plasma Wave and Electric Field Experiment (DC-10MHz)

PI. Y. Kasahara, Co-PI: Y. Kasaba, S. Yagitani, H. Kojima

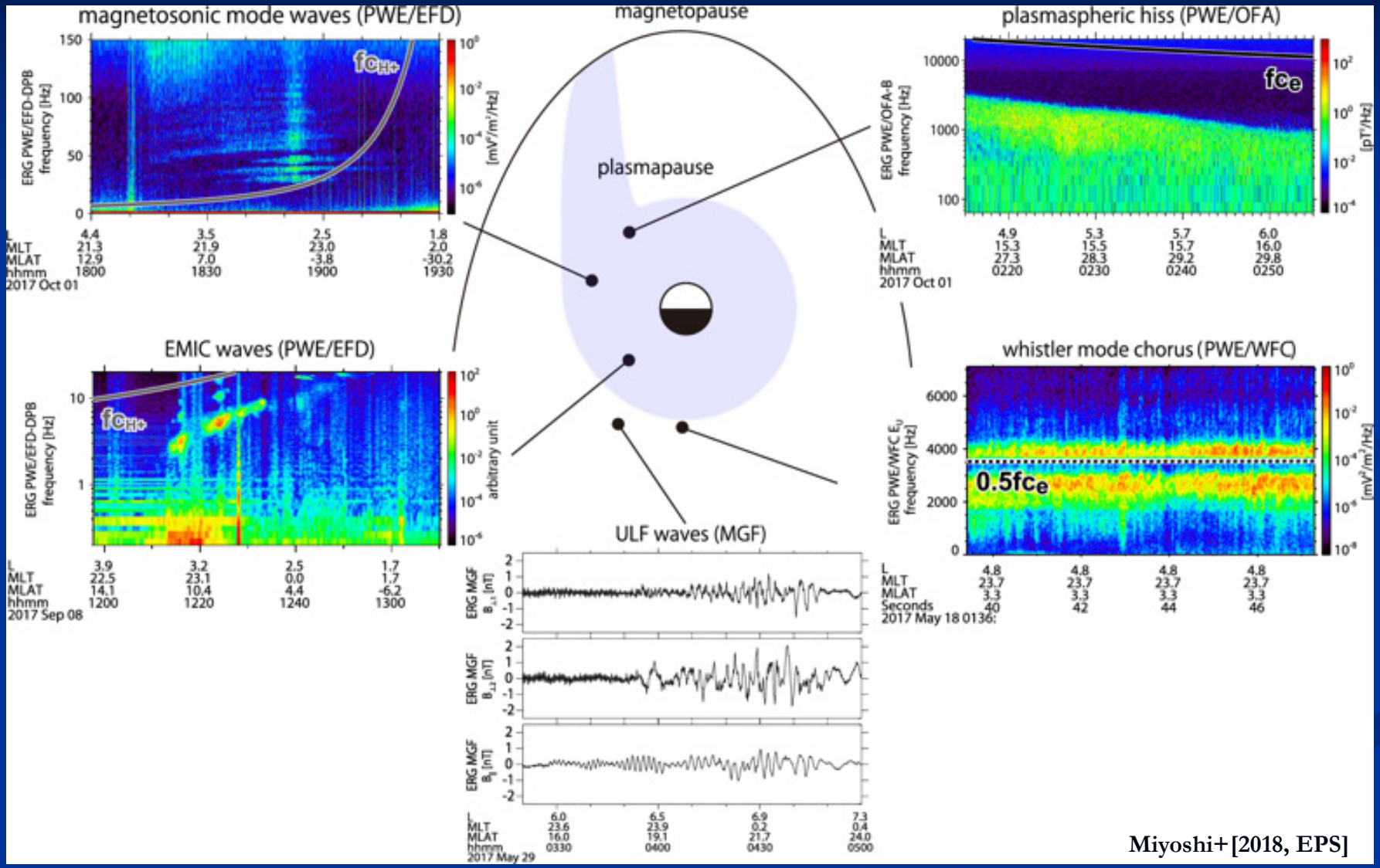
MGF: Magnetic Field measurement (DC-100kHz) PI: A. Matsuoka



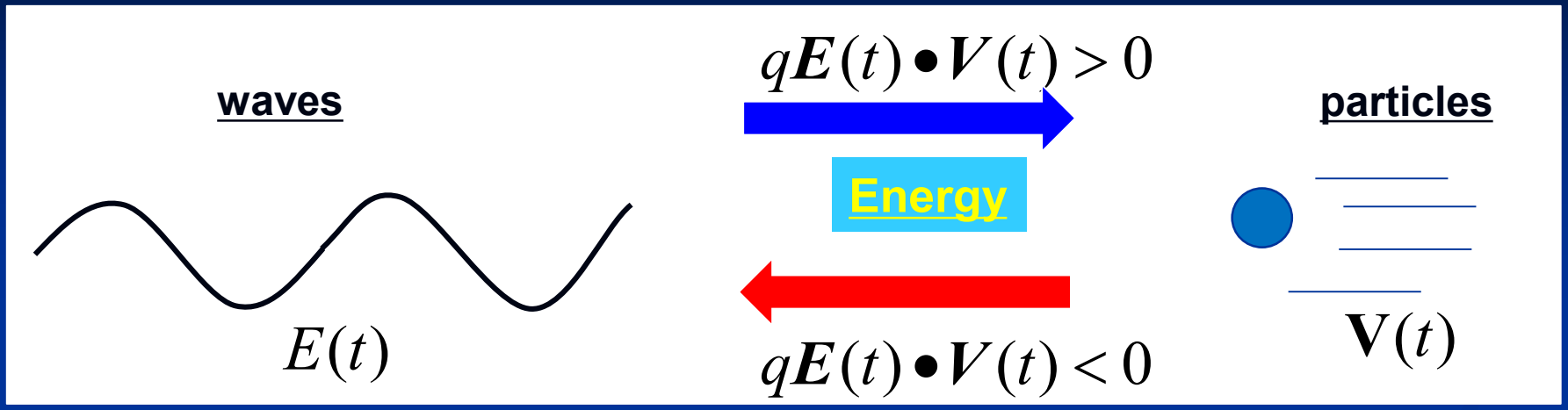


- Observations of waveform (256/64Hz sampling)
- Burst mode observations for waveform (64 kHz sampling)
- Electron density from UHR from 400 km to 32000 km.

Comprehensive fields/wave observations

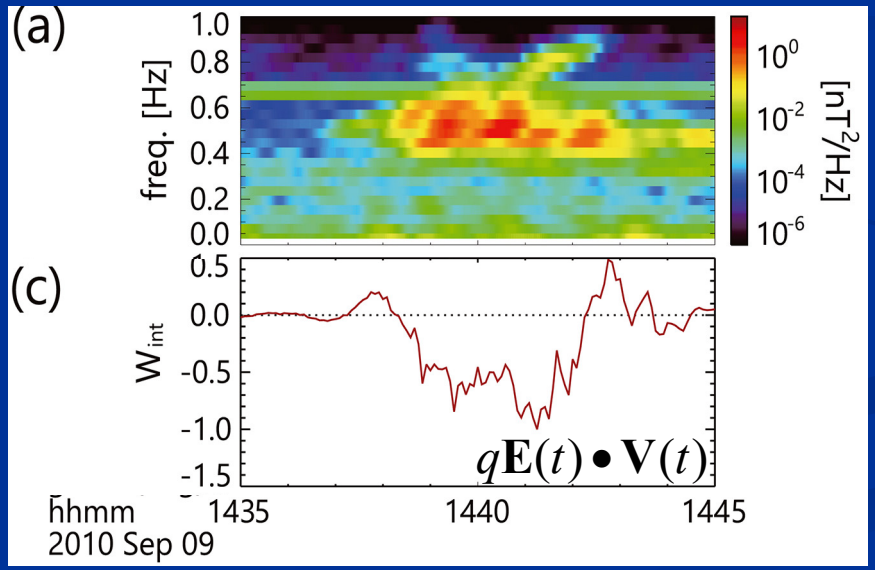


S-WPIA: Wave-particle interaction analyzer (PI: Kojima)



Measurements of electric fields and particles with 10 microseconds resolution for whistlers

WPIA analysis of EMIC waves (THEMIS data)



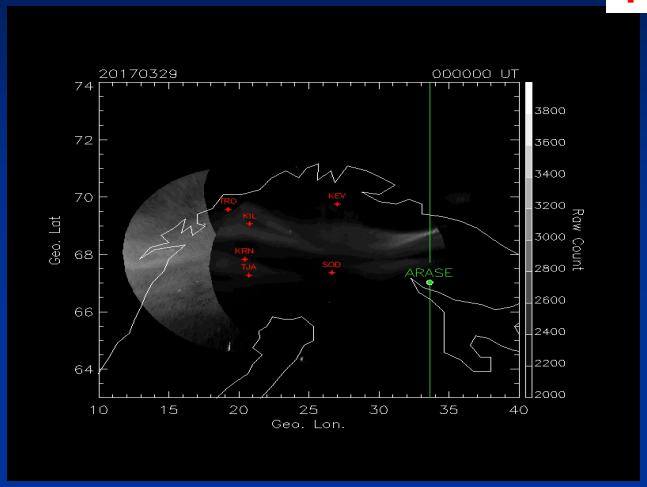
[Shoji+, GRL, 2017]

WPIA principle is confirmed by other waves[Shoji+, GRL, 2017, Kitamura+, Science, 2018]

Overview: Coordinated observations with ground

- high speed camera network

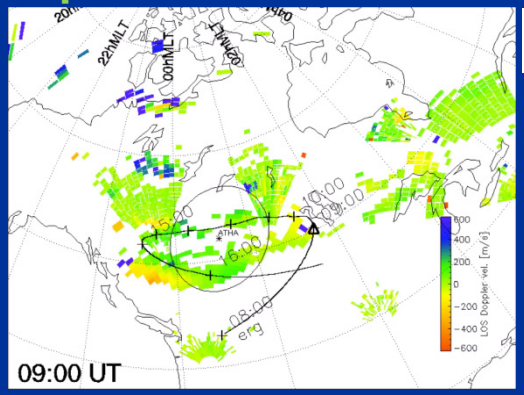
precipitation



- EISCAT, PFISR
  PANSY (Antarctica)

precipitation

- SuperDARN



ULF/convections

- MillStone Hill Radar
  Kharkiv Radar Conjunctions

SAPS/SAID, convection

RC-plasmasphere

- Magnetometer (Pc1), loop antenna(Chorus)

More than 3000 conjugate observations between Arase and ground observations have been operated since the end of March 2017.

Collaborative observations with SuperDARN

ERG Science Center Wikipage

ERG-SuperDARN collaboration

This website is to share useful information on the collaborative studies between the ERG project and the SuperDARN (SD) project. The brief introduction, scientific targets, and actual strategic plans regarding the ERG-SD collaboration are summarized in ***Memorandum for ERG and SuperDARN collaborative studies @Google doc***.

Anyone who is interested in and/or has an idea for the collaborative study can join us. Any idea/comment/suggestion for the memorandum would be most welcome.

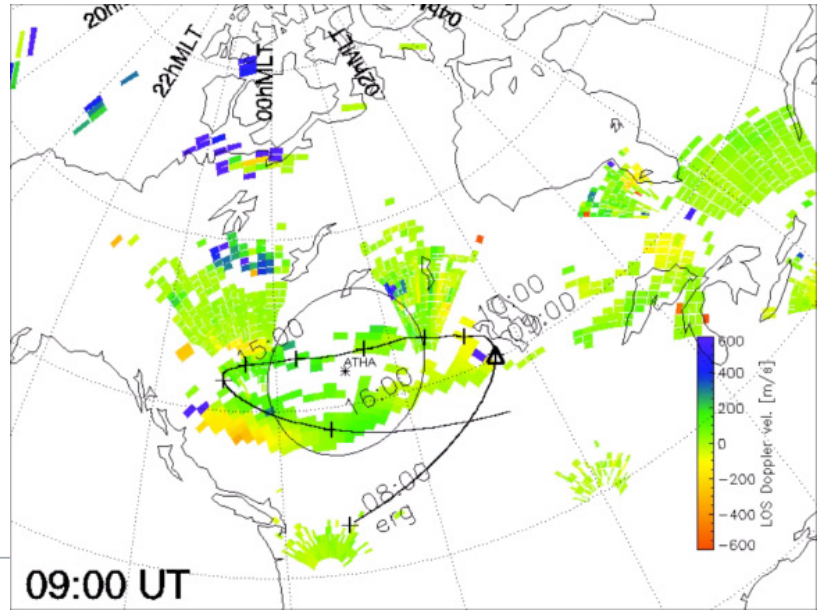
SuperDARN campaign observation for ERG

SuperDARN is going to support in-situ measurement of the ERG satellite by running some pre-scheduled special mode observations over SD radars closely located at the footprint of the ERG satellite. The ERG satellite will start the regular observation with all of the onboard instruments from March, 2017. Accordingly, The Japanese ERG-SD collaboration team has been preparing monthly schedule requests for the designated SD observations in concert with ERG that will start as well from March, 2017.

While the ERG campaign observations of SD are carried out as "special time observations", the data resulting from them are made publicly available to the science community as practicable as possible, basically following the same data policy as the common time data.

ERG-SuperDARN conjunction summary plot

ERG-SuperDARN conjunction summary plot



Campaign observation for 2018-2019 fall to winter season

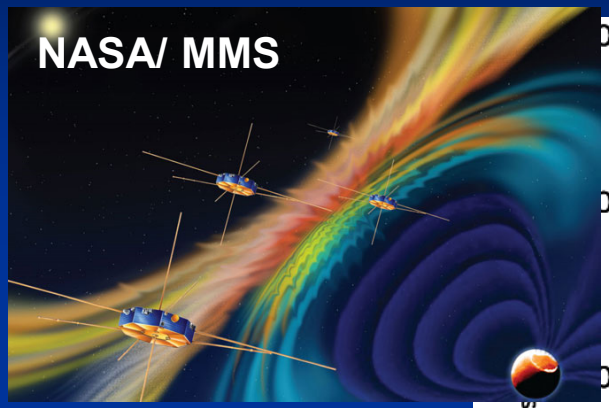
Scheduled operations for the Arase-Van Allen Probes-SuperDARN conjunctions aiming at satellite-ground multipoint observations of SAPS

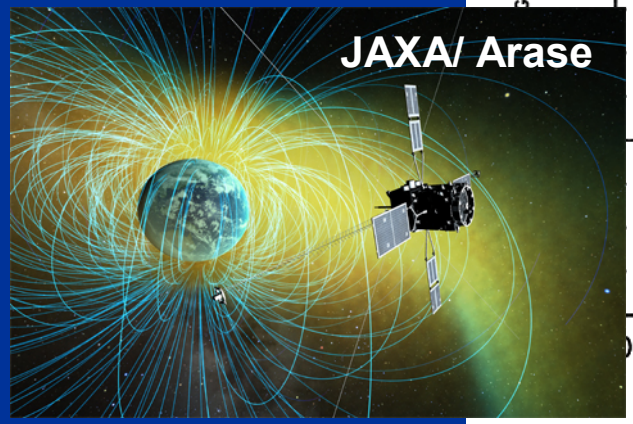
- **45 conjugate observations between SuperDARN and Arase in FY2018**

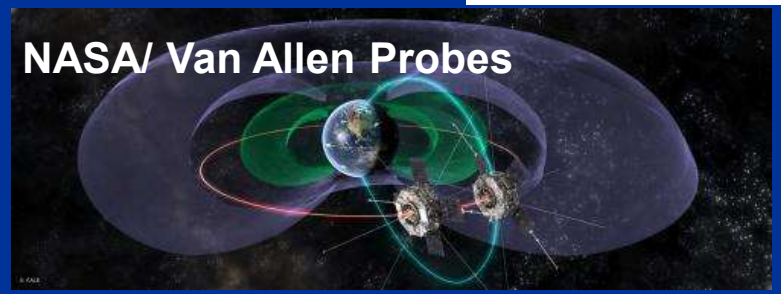
Thank you very much for your kindly collaborations.

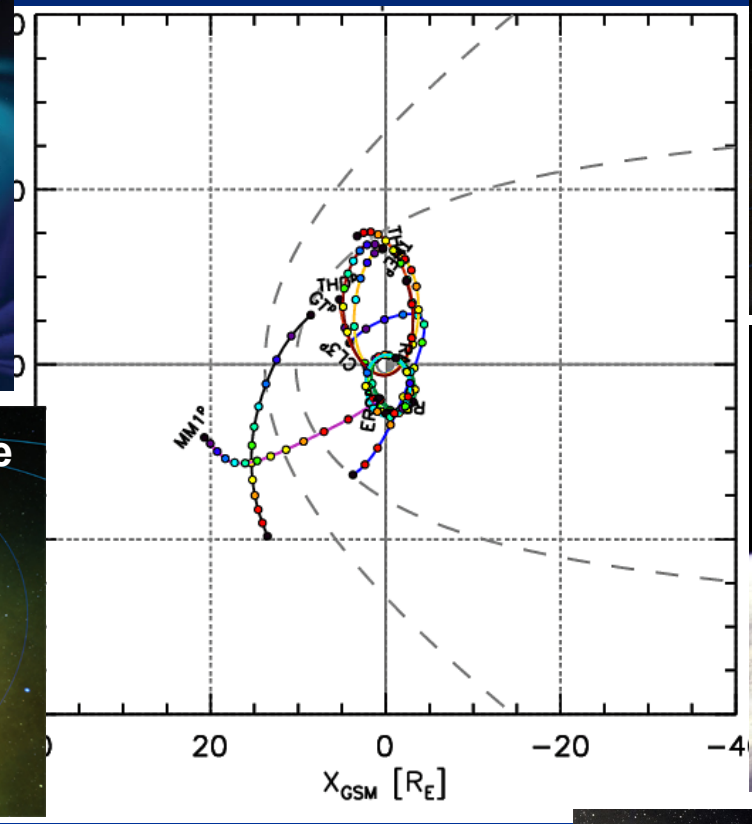
International Fleet of Geospace Satellites

Arase contributes to geospace study as a part of international fleet of satellites

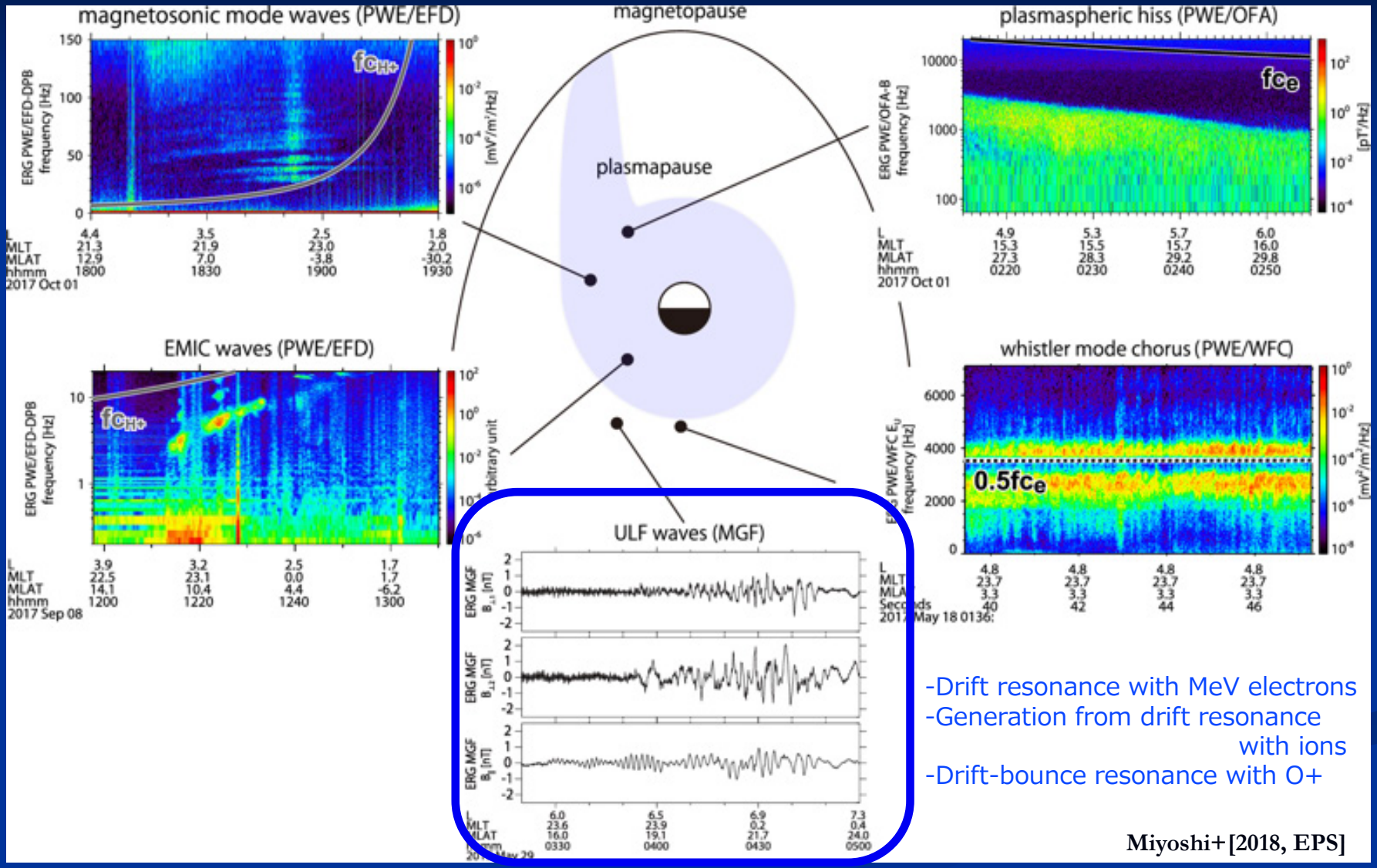




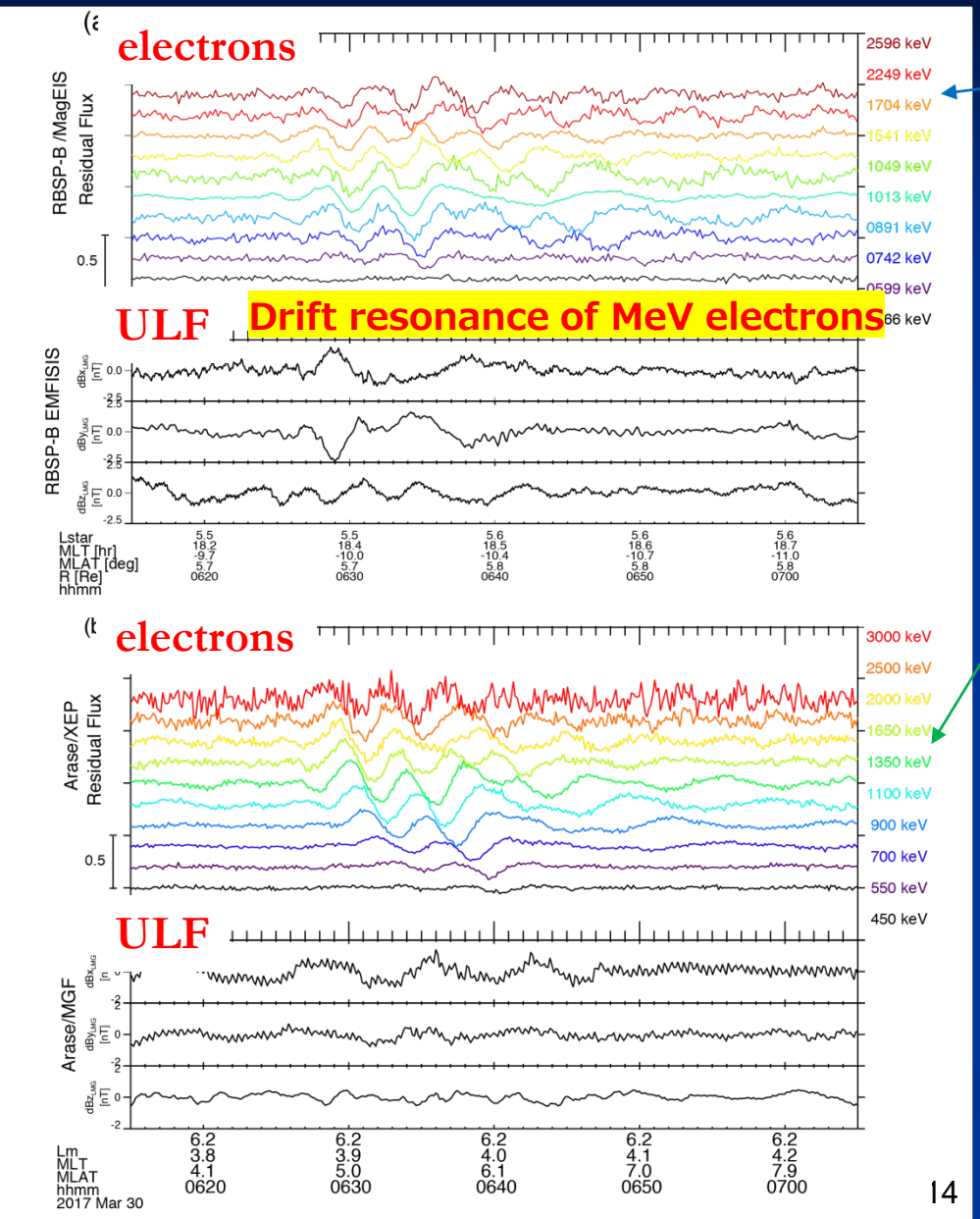


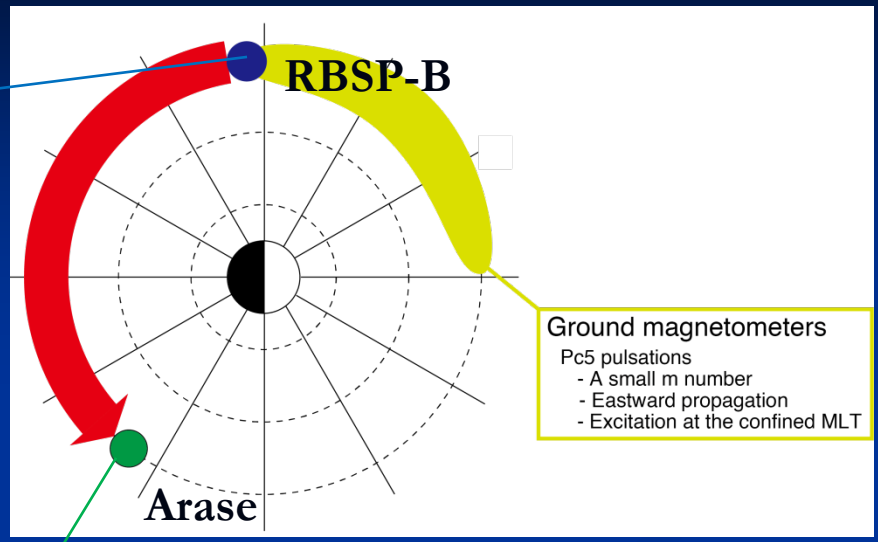


MHD fast mode waves



Interaction between ULF waves and electrons (Arase/RBSP)





- Drift-resonance between drifted-electrons and ULF waves are observed.

$$\omega = m\omega_d$$

- Multi-satellite observations identified longitudinal distributions of wave-particle interactions between MHD waves and drifted electrons.

[Teramoto+, GRL, submitted]

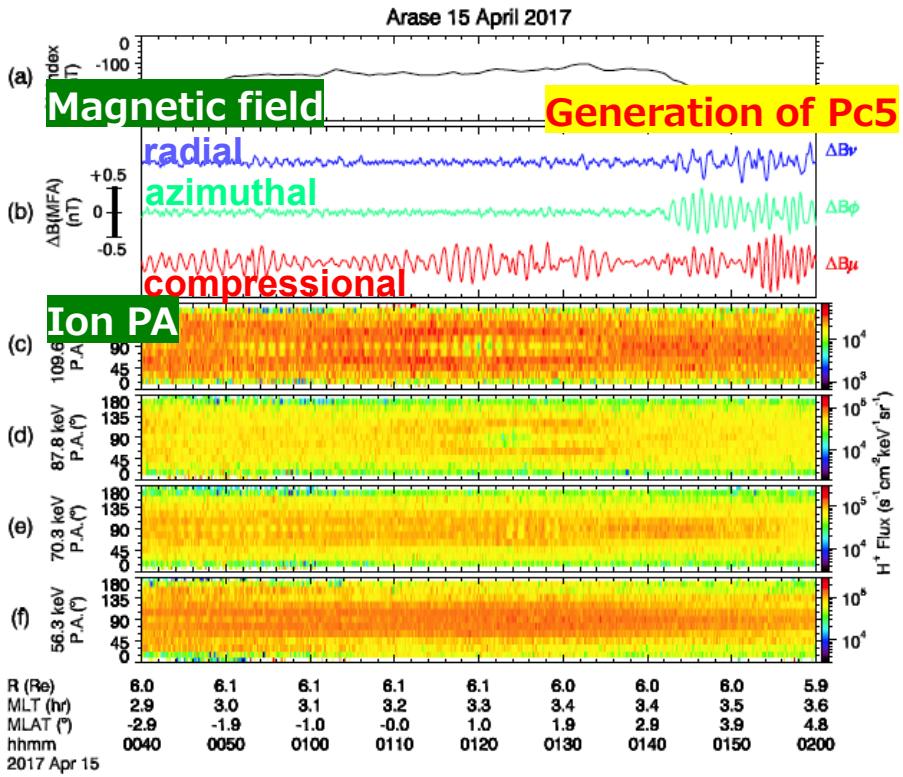
Drift resonance with protons (Arase)

- Detail observations of ULF pulsations and distribution function using ion sounding.
- Free energy is the steep earthward gradient of the phase space density rather than the bump-on-tail structure in energy spectrum of the phase space density

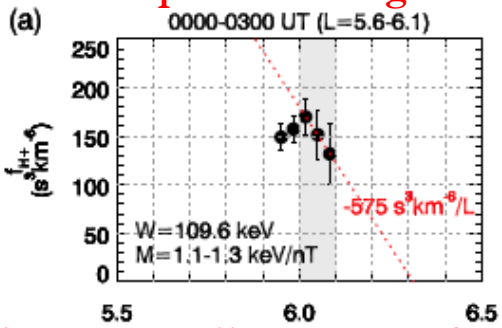
$$\omega - m\omega_d = 0$$

$$\gamma_1 \propto \frac{\partial f}{\partial L}, \gamma_2 \propto \frac{\partial f}{\partial E}$$

[Southwood, 1969]

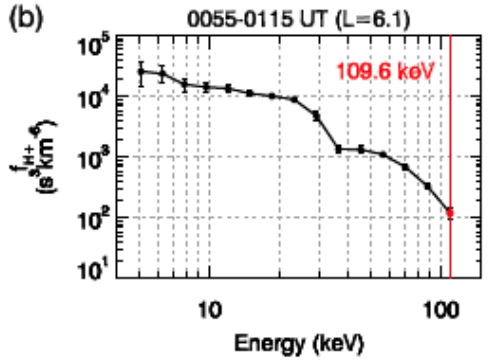


steep earthward gradient (100keV)



$$\gamma_1 \propto \frac{\partial f}{\partial L}$$

bump-on-tail structure of spectrum



$$\gamma_2 \propto \frac{\partial f}{\partial E}$$

[Yamamoto+, 2018, GRL]

- Simulation team reproduced this process by 5-D drift kinetic simulation.

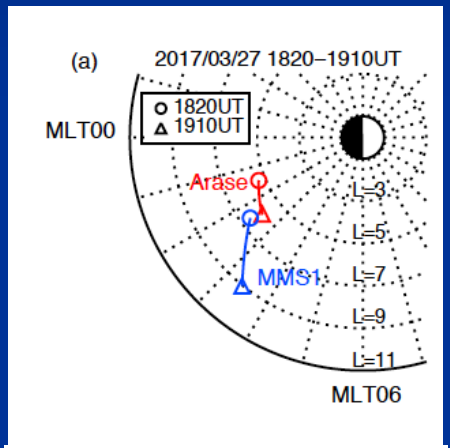
[Yamakawa+, 2019, GRL]

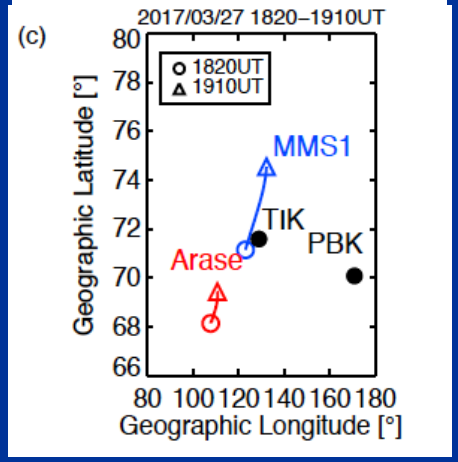
Drift/Bounce resonance with O+ ions (Arase/MMS/Ground)

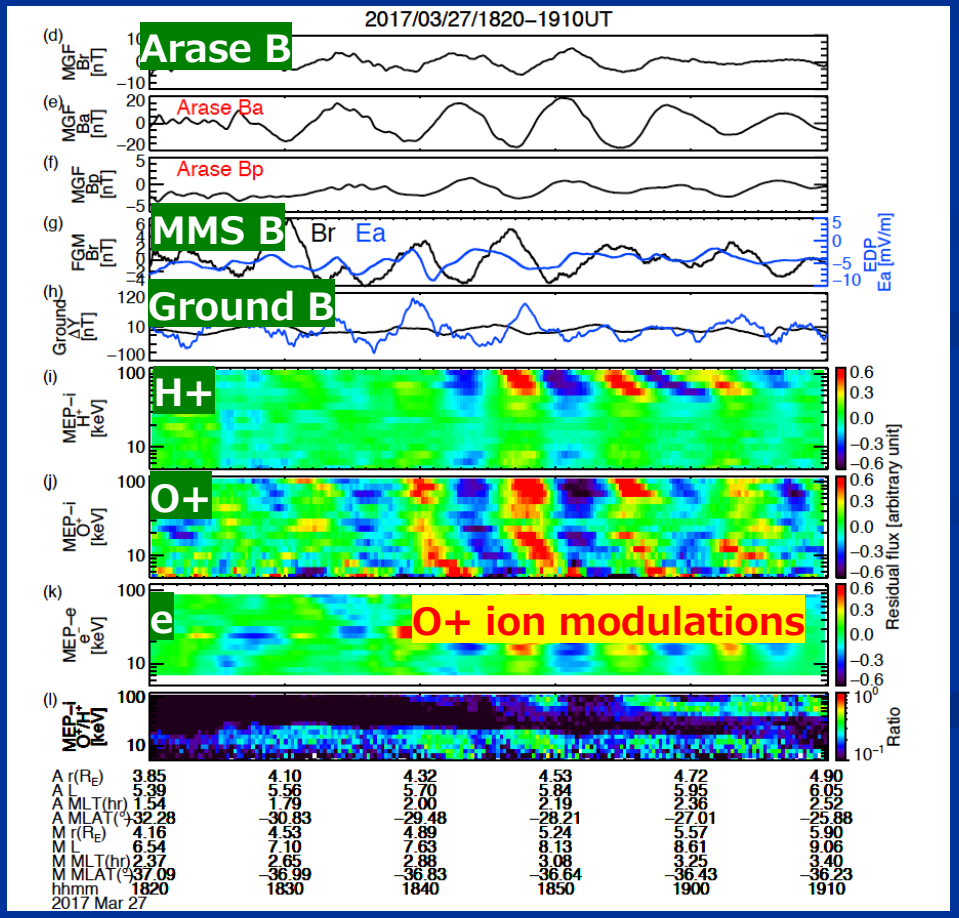
- Pc5 pulsations observed by the Arase, MMS, and ground stations resonated with energetic particles (H^+ and O^+).
- Resonances of O^+ at multiple energies via drift (>50keV) and bounce (<20keV) resonances are simultaneously observed for the first time.

[Oimatsu +, GRL, 2018]

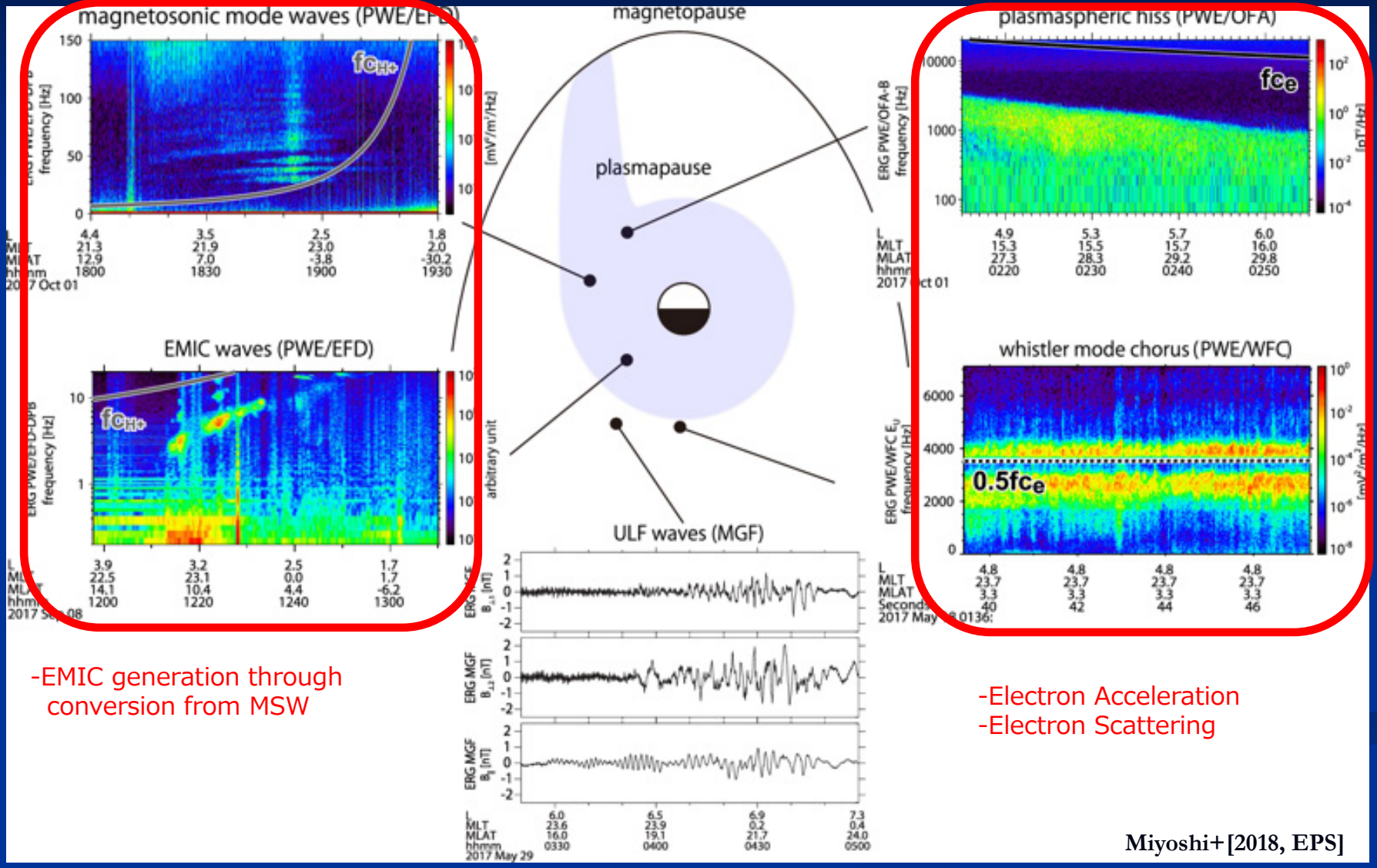
$$\omega - m\omega_d = N\omega_b$$







Whistler mode waves/EMIC waves: acceleration & scattering

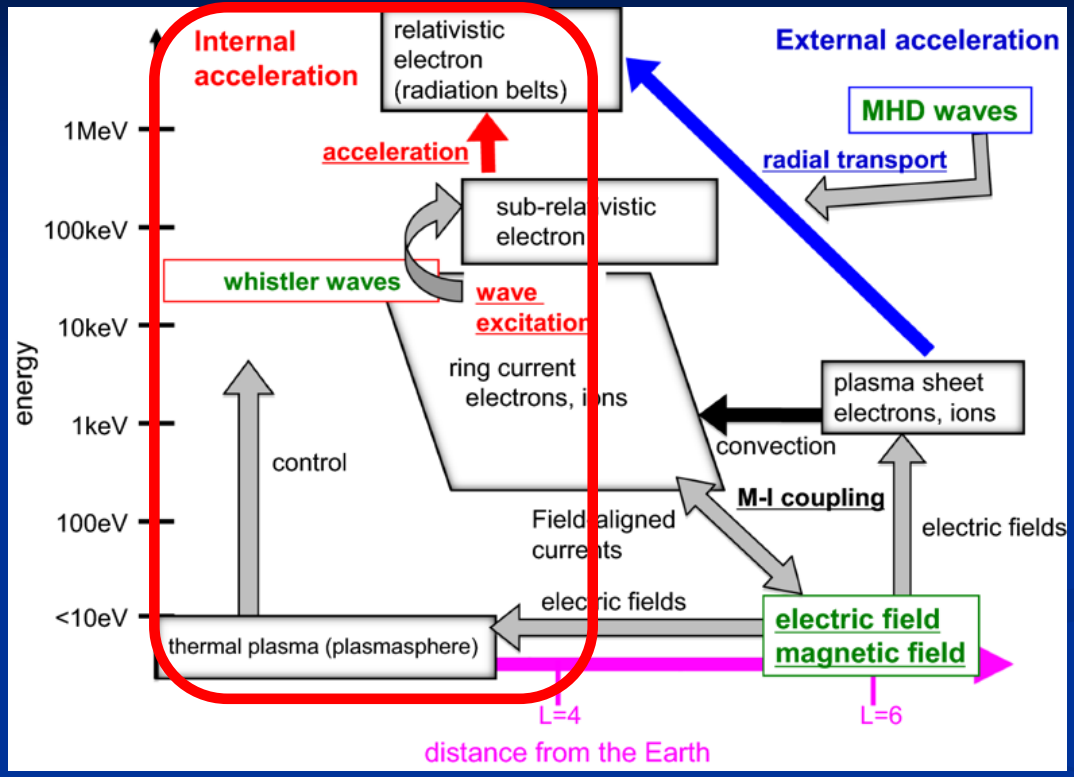


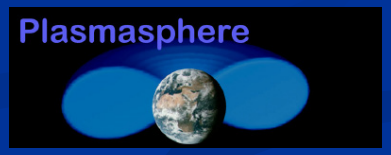
-EMIC generation through conversion from MSW

-Electron Acceleration
-Electron Scattering

Miyoshi+[2018, EPS]

Acceleration/Scattering of the outer belt MeV electrons

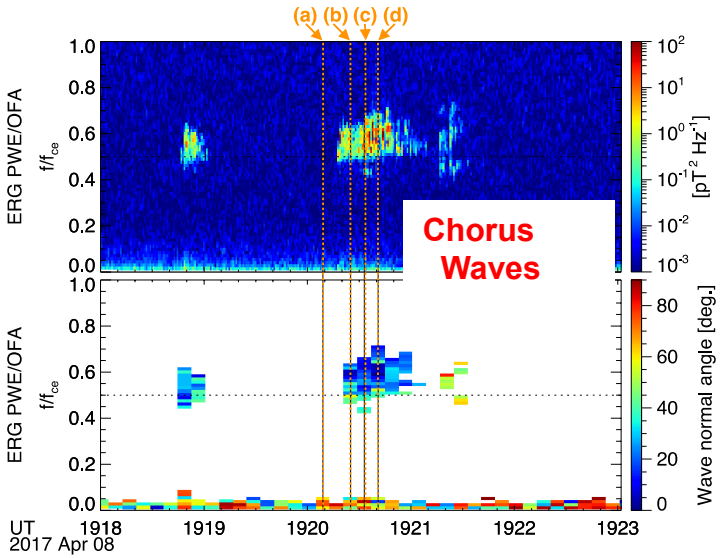




Miyoshi+ [2018, EPS]

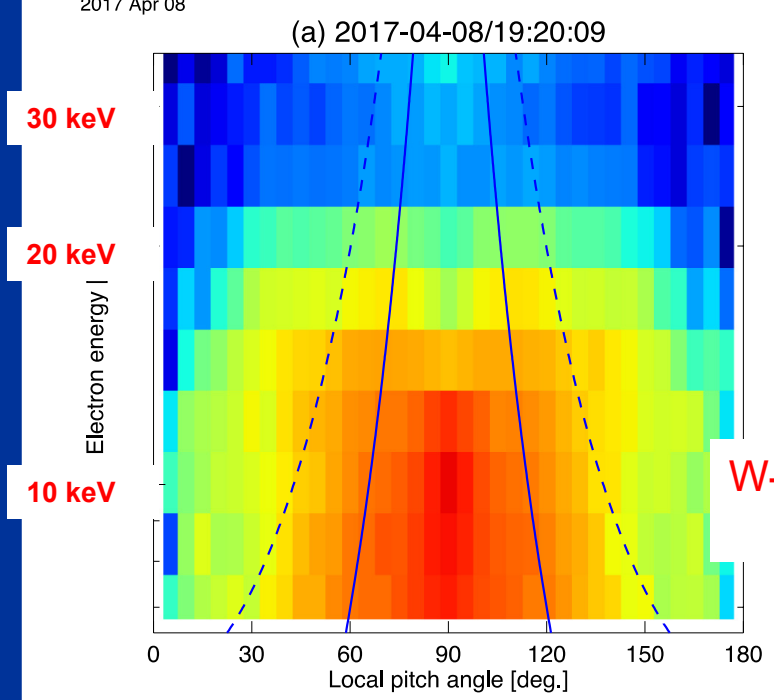
- **Adiabatic Process: Interactions with MHD-Fast mode waves (Drift Resonance)**
- **Non-adiabatic process: Interaction with whistler waves (Cyclotron Resonance)**

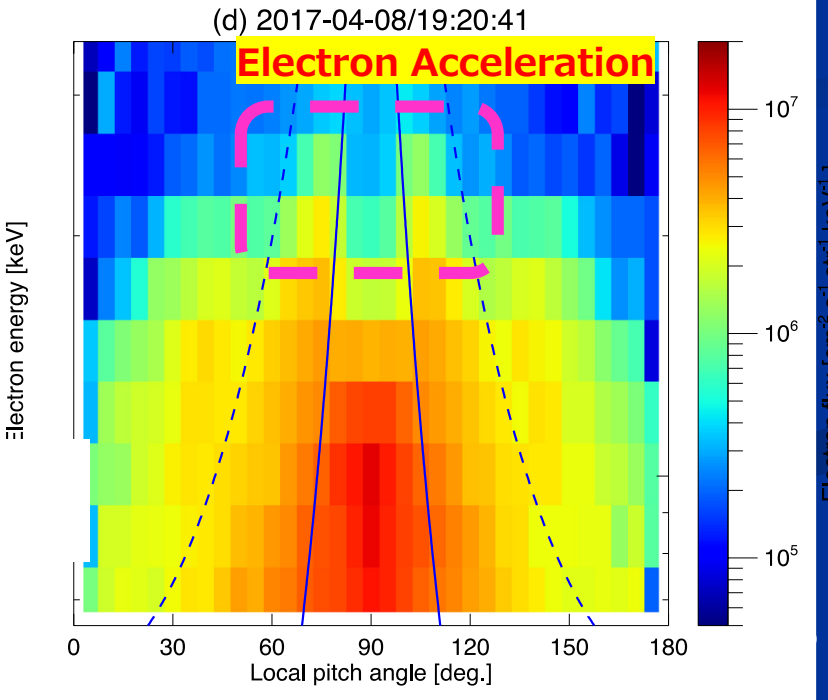
Acceleration of energetic electrons by chorus waves



- Acceleration of energetic electrons occur through wave-particle interactions.

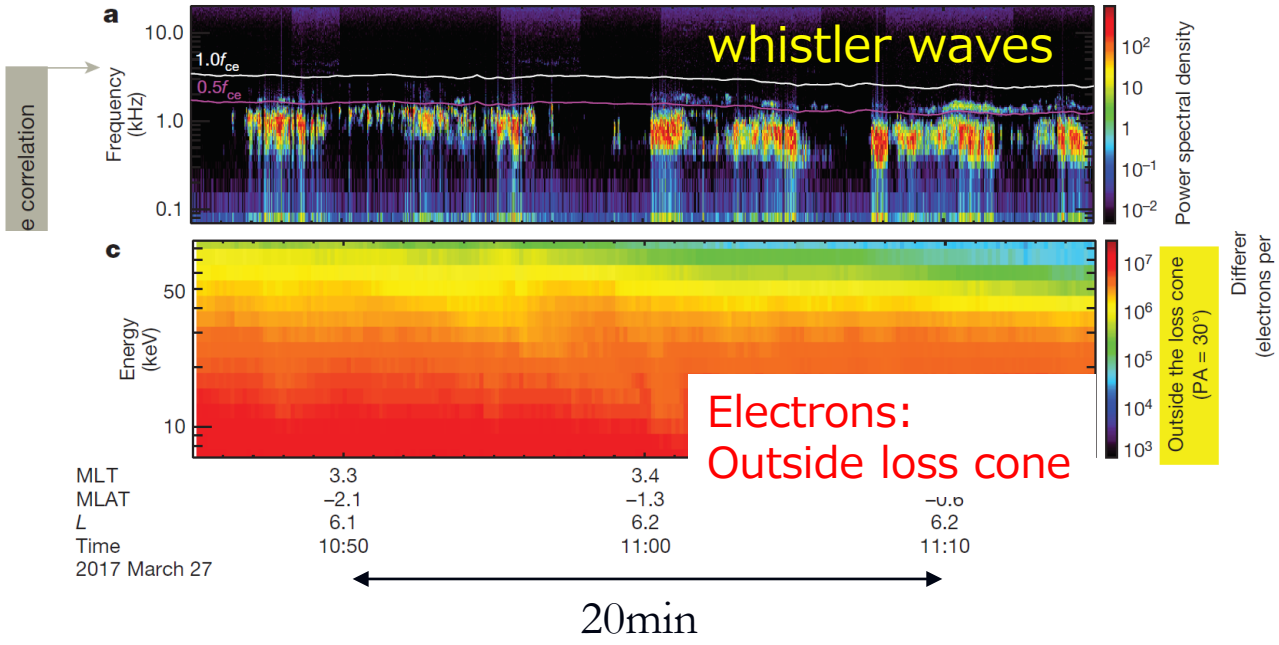
Kurita+[GRL, 2018]





First direct evidence of pitch angle scattering by plasma waves

Electrons inside loss cone are firstly observed by Arase



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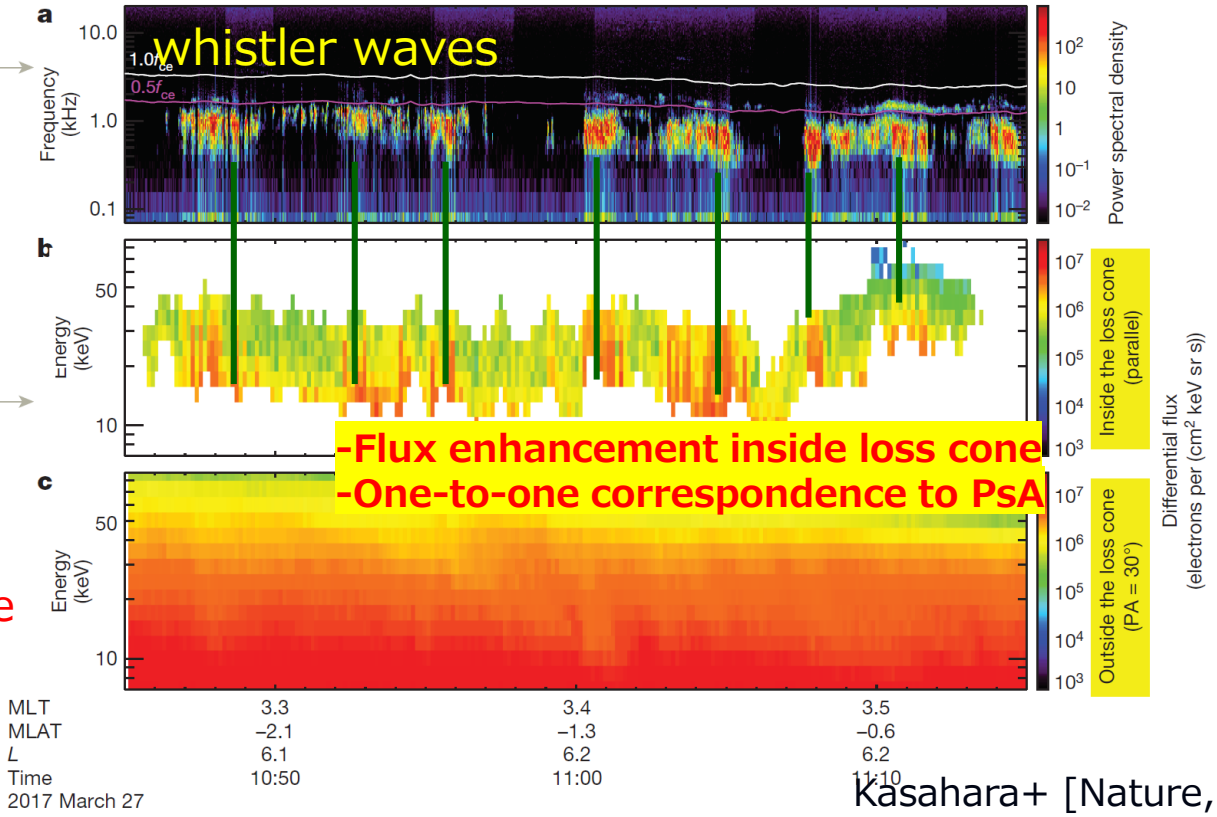


Electrons:
Inside loss cone

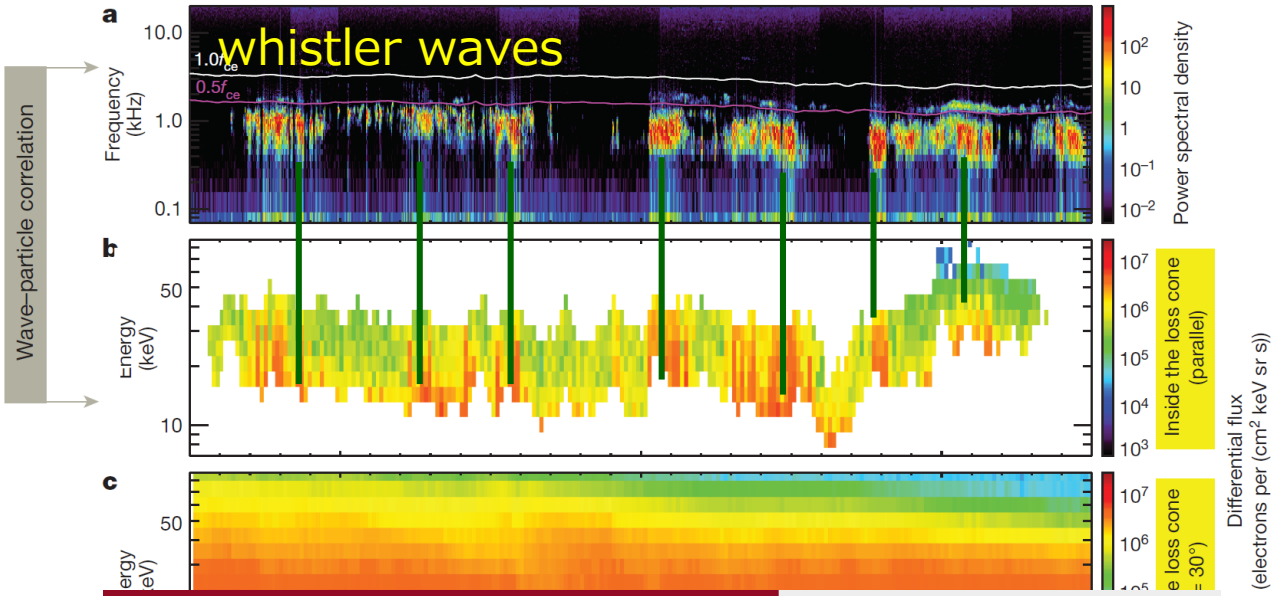
Electrons:
Outside loss cone

Kasahara+ [Nature, 2018]

- One-to-one correspondence between whistler mode waves and precipitating electrons.
- This is the first direct evidence to indicate pitch angle scattering in space plasma.

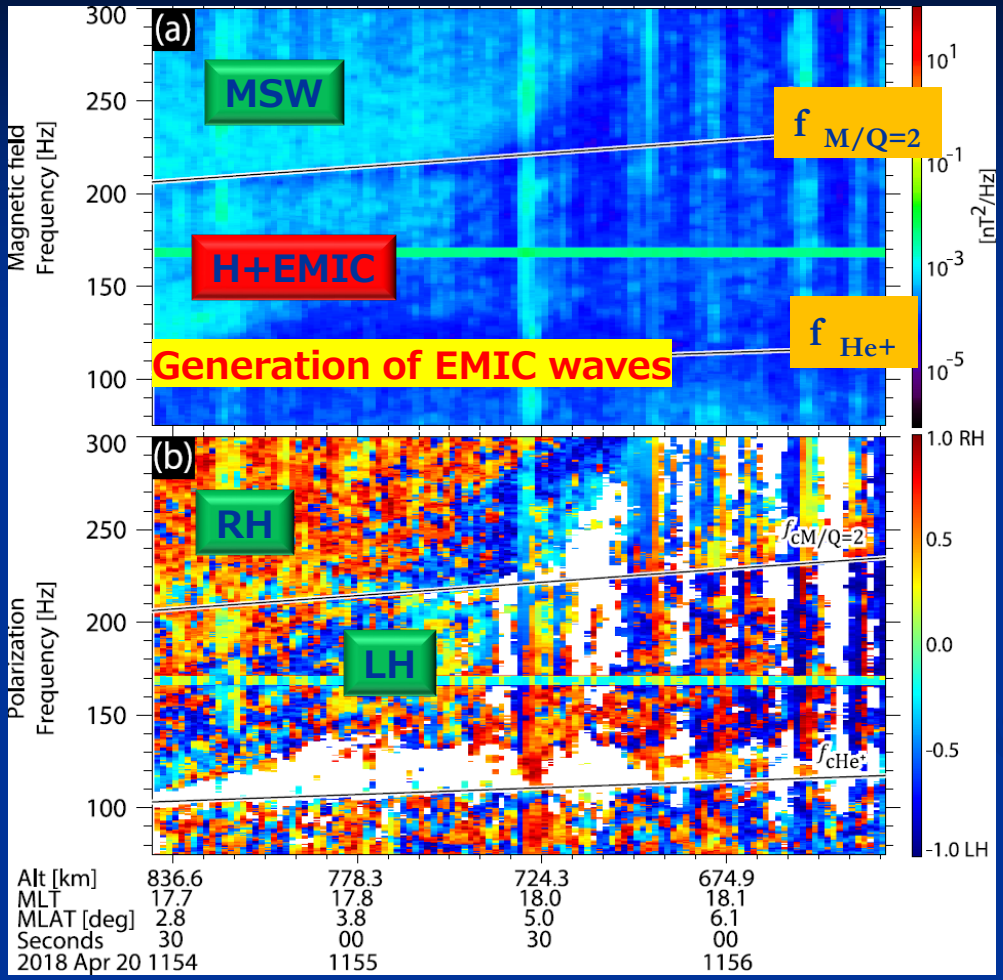
First direct evidence of pitch angle scattering by plasma waves

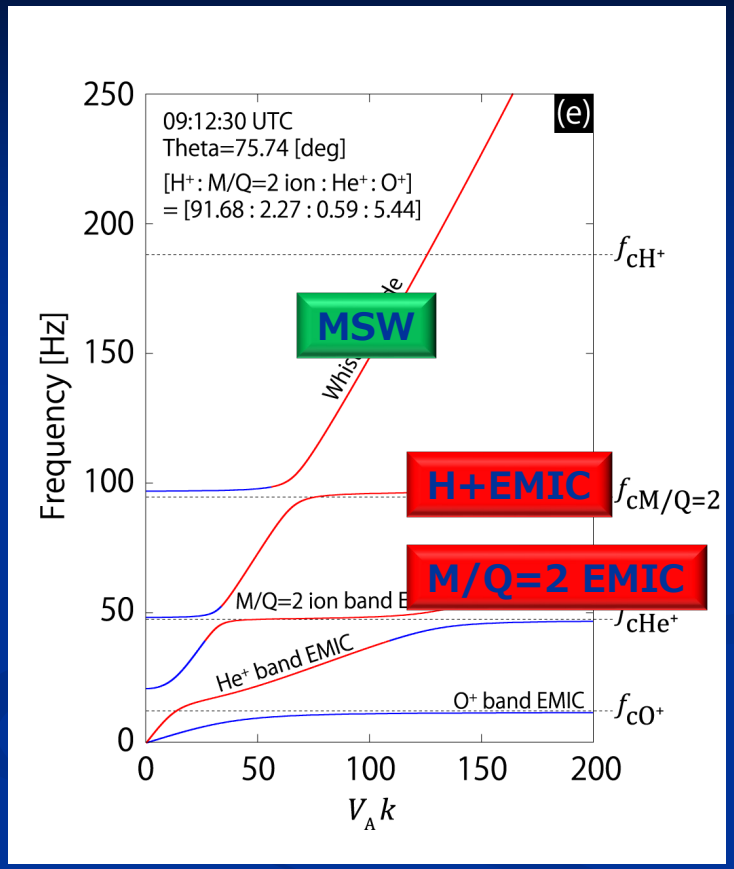
Electrons inside loss cone are firstly observed by Arase



[8, Nature]

New Generation Mechanism of EMIC waves & M/Q=2 ions



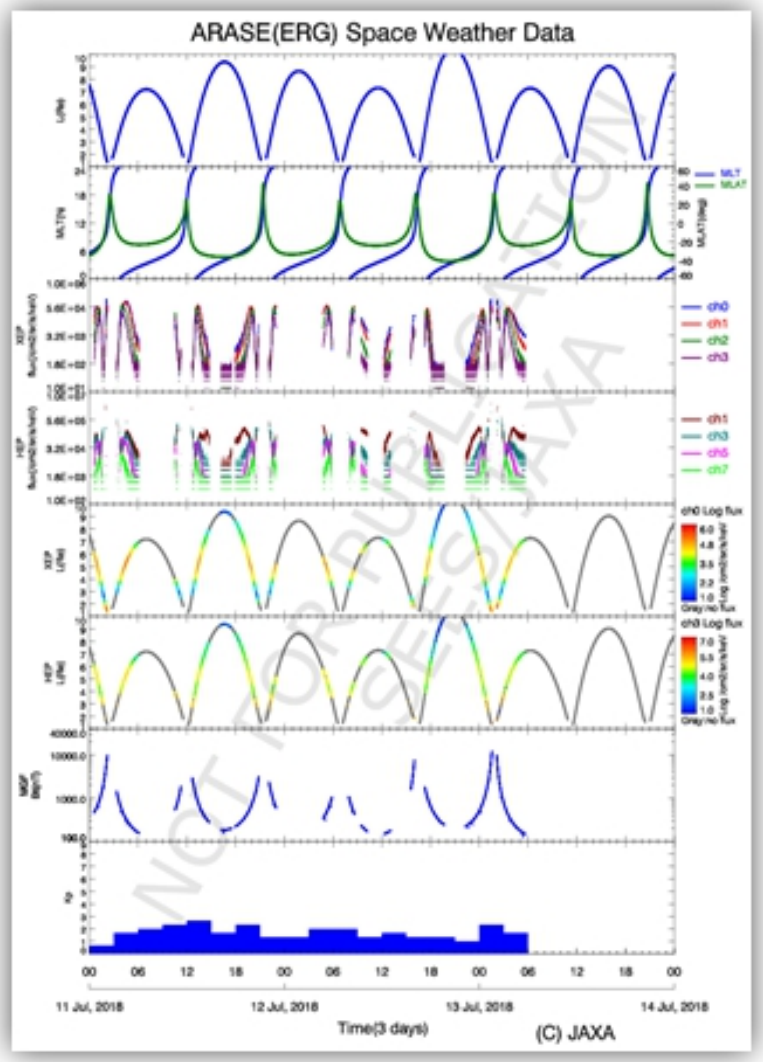


- MSWs convert into H+-band EMIC waves in the presence of M/Q=2 ions (Deutron or Alpha particle) in the topside ionosphere.
- There are 10% of M/Q=2 ions in the low-altitude.

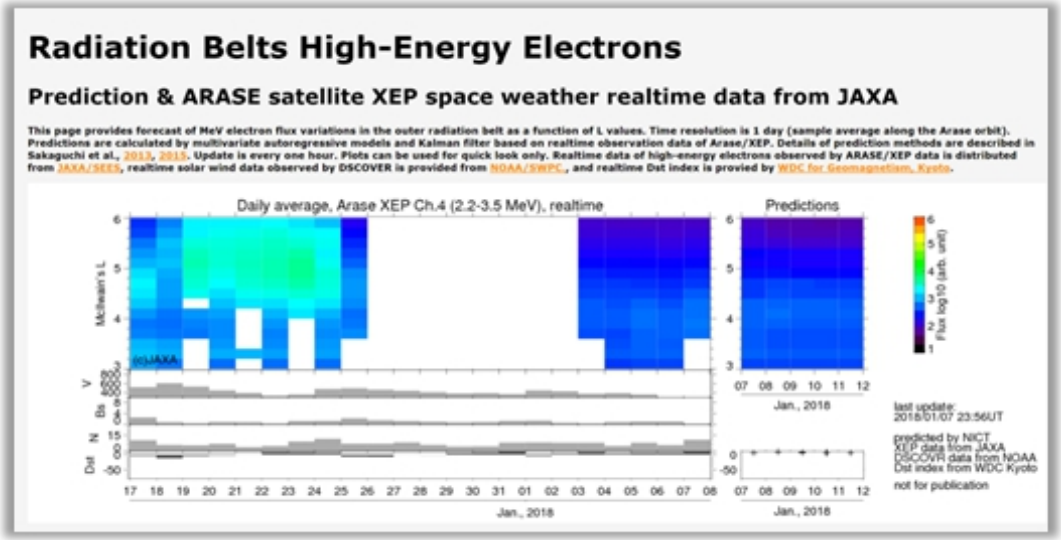
[Miyoshi+, GRL, 2019]

Contribution to Space Wx (nowcast/forecast)

Arase Space Wx data (JAXA/SEES)



Radiation Belt Forecast (NICT)

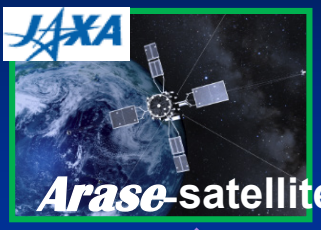


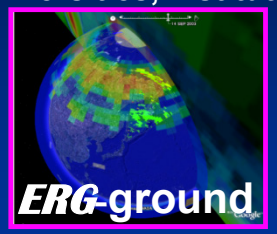
http://seg-web.nict.go.jp/ERG-spaceweather/forecast.html

Arase data files and software / ERG Science Center

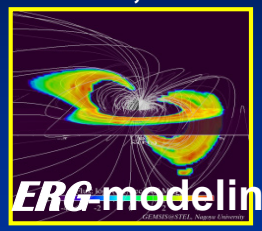
ERG project data

Universities, Institutes





Universities, Institutes



ERG – Science Center

a joint research center for space science
(ISAS/JAXA & ISEE/Nagoya Univ)

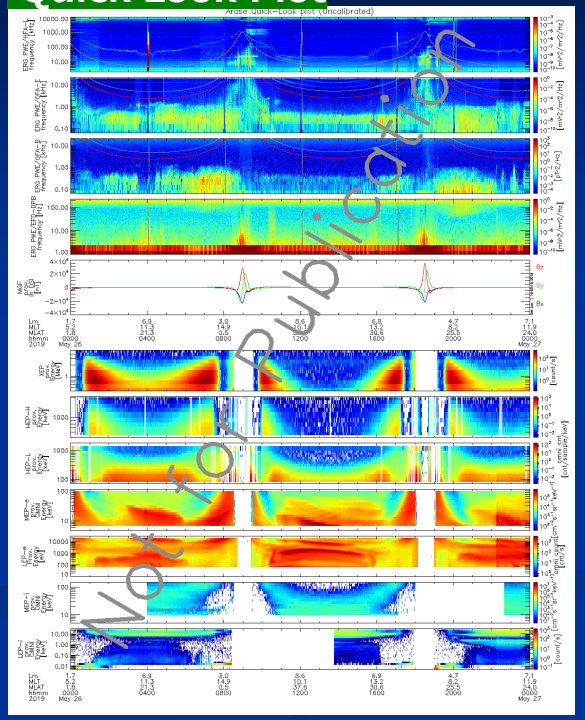
Science Data Archive

Integrated Analysis Tool
(based on IDL/SPEDAS)

Researcher

Google ERG Science Center

Quick Look Plot



- Level-2 data for al instruments are archived with CDF format and opened to the public from the ERG Science Center.
- ERG Plug-in software for SPEDAS can be downloaded from the ERG Science Center.
- SPEDAS software for SuperDARN data are also available in SPEDAS.

4. Summary

1) Arase has successfully observed dynamical evolutions of Van Allen Belts and inner magnetosphere since March 2017. The satellite condition is very good.

2) Various observations on radiation belts, inner magnetosphere, plasma waves have been realized. Collaborations with ground-based observations/satellites are going well.

Arase/ERG project will contribute comprehensive understanding on radiation belts and various phenomena in geospace.
We look forward to further collaborations with SuperDARN.

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