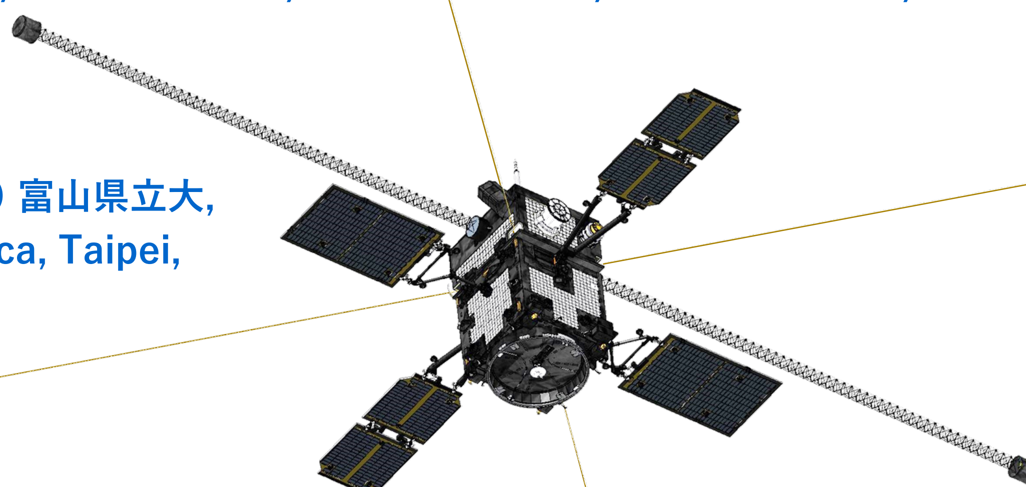
P-081

# あらせ (ERG) 衛星による プラズマ波動観測ハイライト

# Highlights from plasma wave observation by Arase (ERG)

笠原 禎也[1], 松田 昇也[2], 笠羽 康正[3], 土屋 史紀[3], 熊本 篤志[3], 尾崎 光紀[1], 八木谷 聡[1], 石坂 圭吾[4], 三好 由純[5], 栗田 怜[5], 小路 真史[5], 中川 朋子[6], 風間 洋一[7], 吹澤 瑞貴[3], 橋本 弘藏[8], 新堀 淳樹[5], 疋島 充[2], 加藤 雄人[3], 小嶋 浩嗣[8], 笠原 慧[9], 横田 勝一郎[10], 寺本 万里子[5], 堀 智昭[5], 津川 靖基[5], 松岡 彩子[2], 篠原 育[2]

(1) 金沢大, (2) JAXA/ISAS, (3) 東北大, (4) 富山県立大, (5) 名大, (6) 東北工大, (7) Academia Sinica, Taipei, (8) 京大, (9) 東大, (10) 大阪大

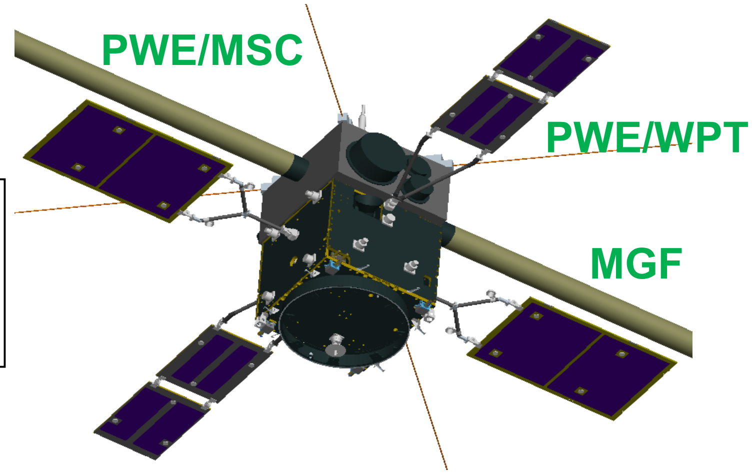


# Plasma Wave Experiment (PWE) Overview

## Sensors

Electric Field Sensors (32m tip-to-tip dipoles)
WPT (Wire-Probe anTenna) [2 pairs] DC-10MHz [Tohoku U et al.]

Magnetic Field Sensors (search-coils)
SCM (3-axis Search-Coils) 0.1 Hz – 100kHz [Kanazawa U et al.]

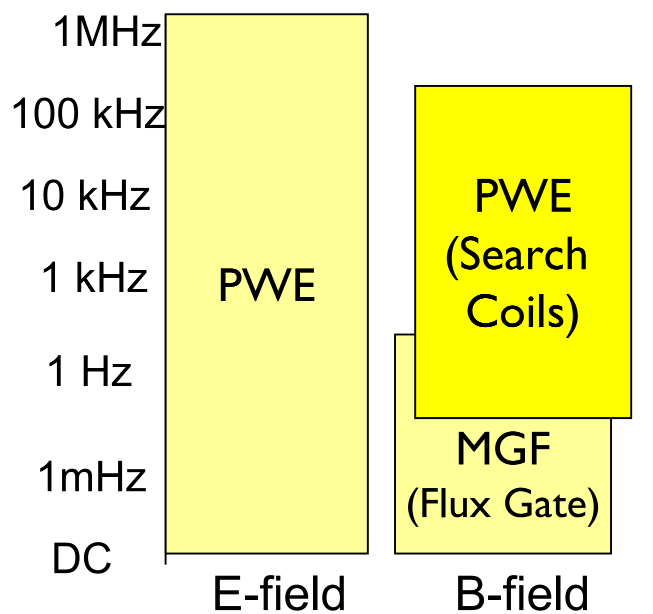



## Receivers

DC/Low frequency Electric field (E-2ch: DC – 128Hz [256Hz waveform])
EWO - EFD (Electric Field Detector) [Toyama Pref. U et al.]

Low/medium frequency E/B field (E-2ch: 10Hz - 20kHz + B-3ch: few - 20kHz)
EWO - WFC/OFA (WaveForm Capture/Onboard Frequency Analyzer)
[Kyoto U et al.]

High frequency E field (E-2ch: 10kHz - 10MHz or E-1ch + B-1ch: 10kHz - 100kHz)
HFA (High-Frequency) [Tohoku U et al.]



# Nominal Operation modes of the PWE (Survey data)

- **EFD (with MGF) ・・・DC E-Field, Potential, EMIC waves etc.**
  - Apogee mode(waveform, fs=64Hz)
  - Perigee mode (waveform, fs = 256Hz)

- **OFA (Spectrum)・・・Chorus, Plasmaspheric Hiss, MSW, EMIC (~perigee) etc.**
  - |E| + |B| spectra ($f$< 20kHz, ⊿$t$=1s) (～2017/4/30)
  - $E_U$ + $B_\alpha$ (or $B_\beta$) spectra ($f$< 20kHz, ⊿$t$=1s) (2017/5/1～)

- **HFA (Spectrum, E:10k <$f$<10MHz, B:10k < $f$<100kHz)・・・UHR, ECH, AKR etc.**
  - EE mode (E×2 , ⊿$t$=8s) (at $f_c$<10kHz) (～2017/11/6)
  - LR mode (EL, ER , ⊿$t$=8s) (at $f_c$<10kHz) (2017/11/7～)
  - EB mode (E×1+B×1, ⊿$t$=8s) (at $f_c$>10kHz)
  - PP mode (E×1, ⊿$t$=1s, $f$<400kHz) (L~4)

HFA Special modes

- EB-1s (E×1+B×1, ⊿$t$=1s) Around perigee(L<2) (2018/04/03～)
- EE-1s/EB-1s (E×2/E×1+B×1, ⊿$t$=1s) Millstone hill conj. (2017/10～2018/02)
- AKR mode (E×1, ⊿$t$=1s, $f$>100kHz) (1hour/day, 2017/6/11～2017/10/31)
- HFA full (hfa_lr_1s) Around apogee (1hour/orbit, 2018/8/14～)

# Nominal Operation modes of the PWE（Burst data)

– **WFC (Waveform)**

- **Chorus burst** ($f_s$=**65kHz**) (~apogee)

(～2018/04/30)

Conjunction with ground-based networks ： 60sec/450sec
w/o conjunction ： 8sec/208sec

(2018/05/01～ )

Conjunction with ground-based networks ：60sec/450sec
w/o conjunction ：8sec/640sec
BARREL collaboration ：8sec/60sec
RBSP special ：8sec/60sec (2017/07/08～)

- **EMIC burst** ($f_s$=**1kHz**) (~perigee)

Mainly inside the plasmasphere (L<4) ：160s/12min

**List of waveform data availability (data downloaded to the ground)**
**https://ergsc.isee.nagoya-u.ac.jp/mw/index.php/ErgSat/Pwe**
**List of collaborative observations with Van Allen Probes**
**https://ergsc.isee.nagoya-u.ac.jp/mw/index.php/ErgGround/ErgVAPs**

# Collaborative Observations

- Campaign observation with Ground-based networks
  - 1st (Mar.-Apr., 2017) Campaign
    - Chorus burst + HFA PP
  - 2nd (Jun.-Jul., 2017) Campaign
    - Chorus burst + HFA PP
  - 3rd (Sep.-Oct., 2017) Campaign
    - EMIC burst (or Chorus burst at mid-night) + WPIA mode (w/o PWE)
  - 4th (Dec., 2017 – Jan. 2018) Campaign
    - EMIC burst + Chorus burst
  - Collaborative operation is still continuing
    - ~2300 conjunction observations have been done.
- Collaboration with other projects
  - Van Allen Probes : ~260 conjunctions (June 13, 2017 ～ )
  - MMS, Geotail, Mill Stone Hills Radar etc.

**Lists of collaborative observations (ERG Science Center Wiki-page)**
**https://ergsc.isee.nagoya-u.ac.jp/mw/**

# Data-pipeline processing status

– EFD
  - EFD/l2/E-Spin : EFD spinfit (**VxB not subtracted**)
  - EFD/l2/pot : EFD Potential

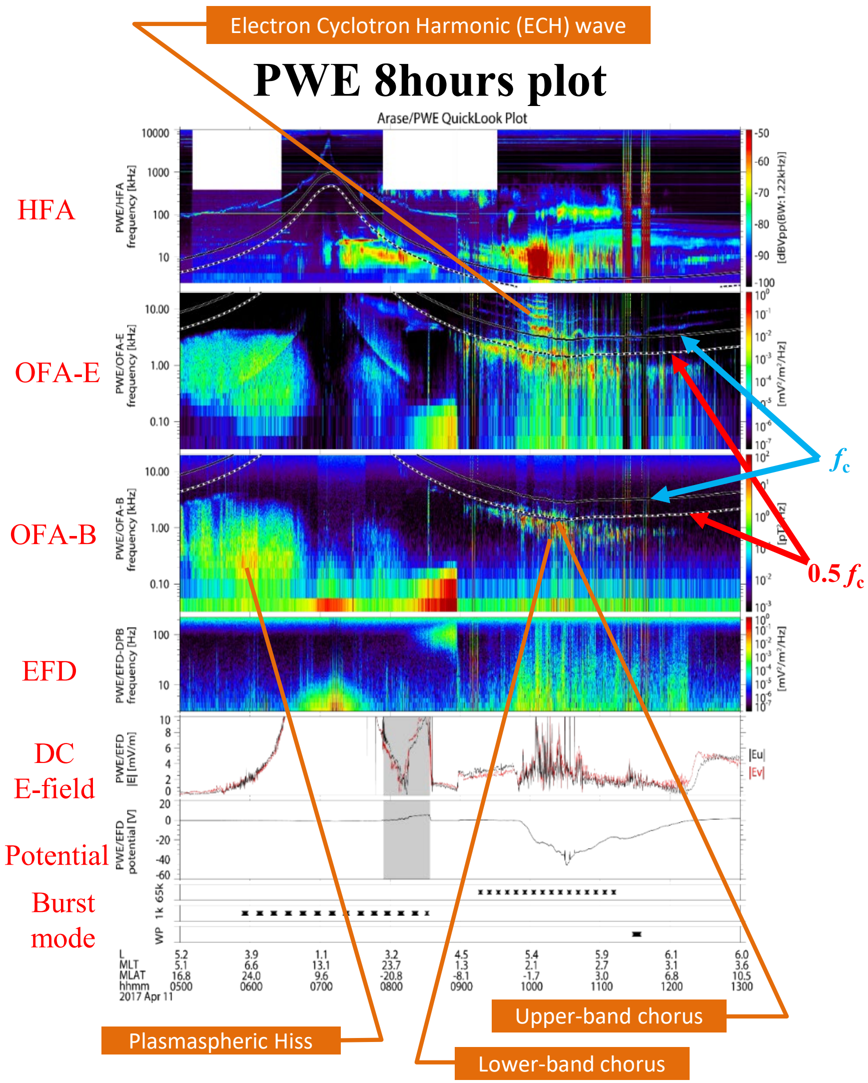
– OFA
  - OFA/l2/spec : OFA Spectrum
    (**E-field is provisionally calibrated** combining the theoretical antenna capacitance in vacuum and the typical plasma resistance.)

– HFA
  - HFA/l2/spec/[high/low/monit] : HFA Spectrum
  - HFA/l3/ne/1min : UHR + electron density (1min. Resolution)
    (HFA/l3/ne/hires : generated on request)

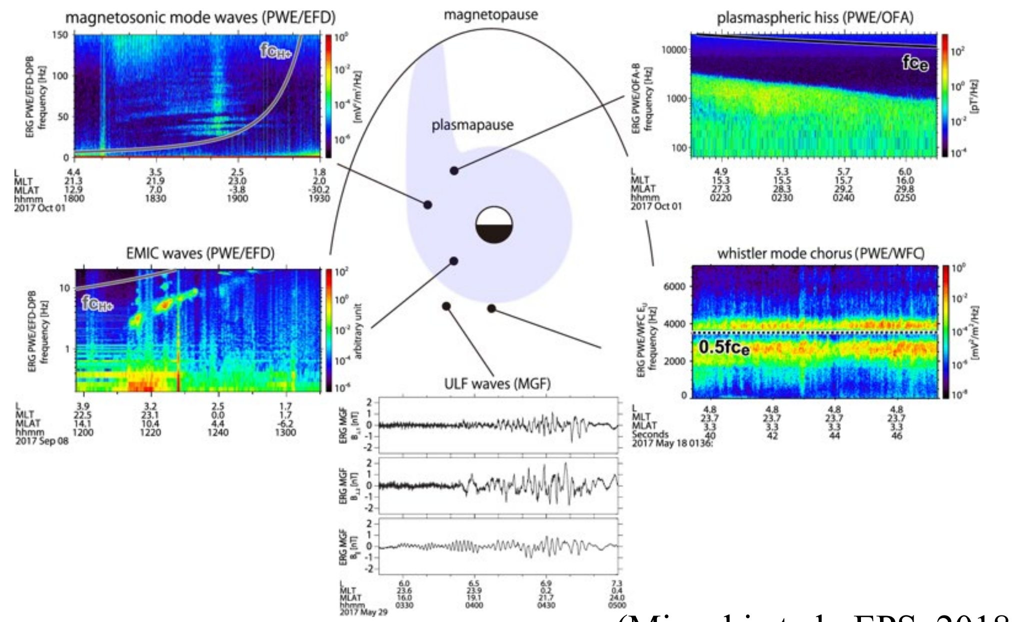
– WFC
  - Calibration process was fixed, and L1' data are in production.
  - L2 data in preparation. WFC-spec, WFC-waveform will be generated.

**Artificial signals could be included in the data.**
https://ergsc.isee.nagoya-u.ac.jp/mw/index.php/ErgSat/Pwe artificial_signals_ver2.pptx
**Please don't forger to refer "quality flag/note".**

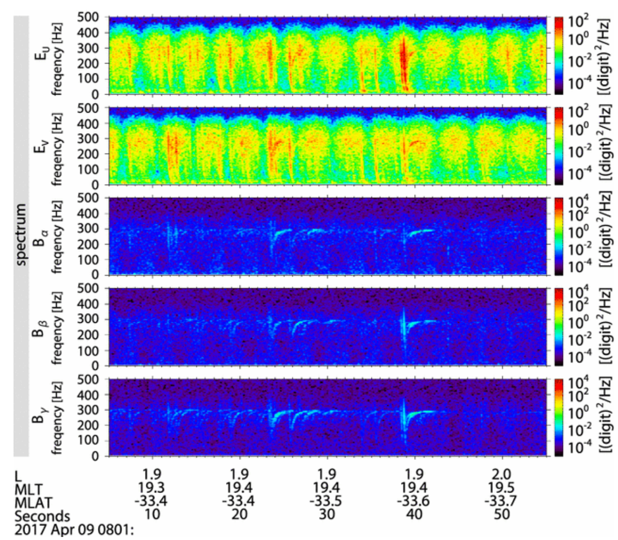
# Examples of Plasma waves observed by Arase




(Kasahara et al., EPS, 2018)

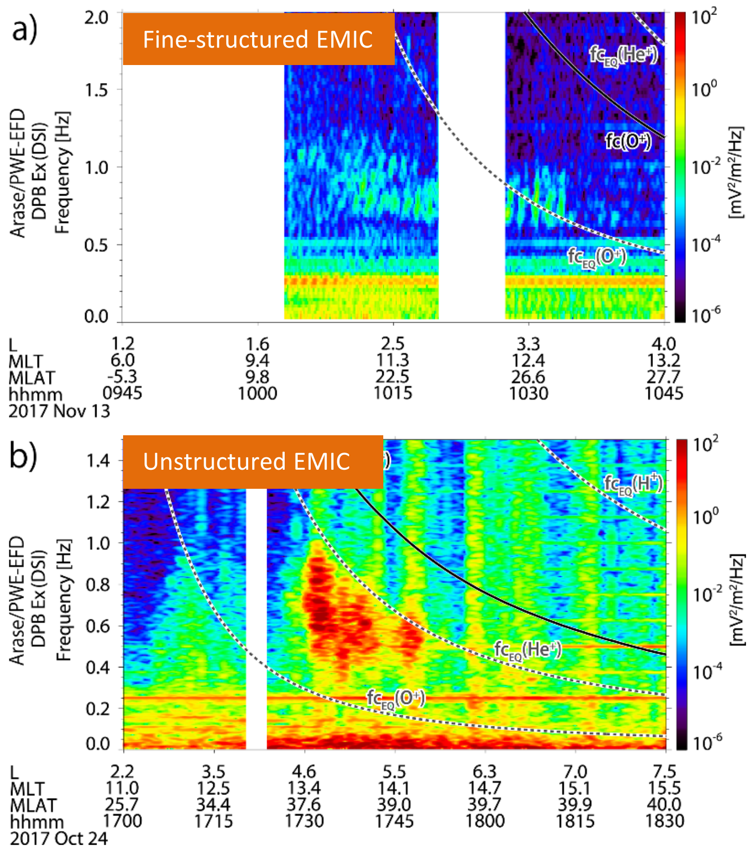


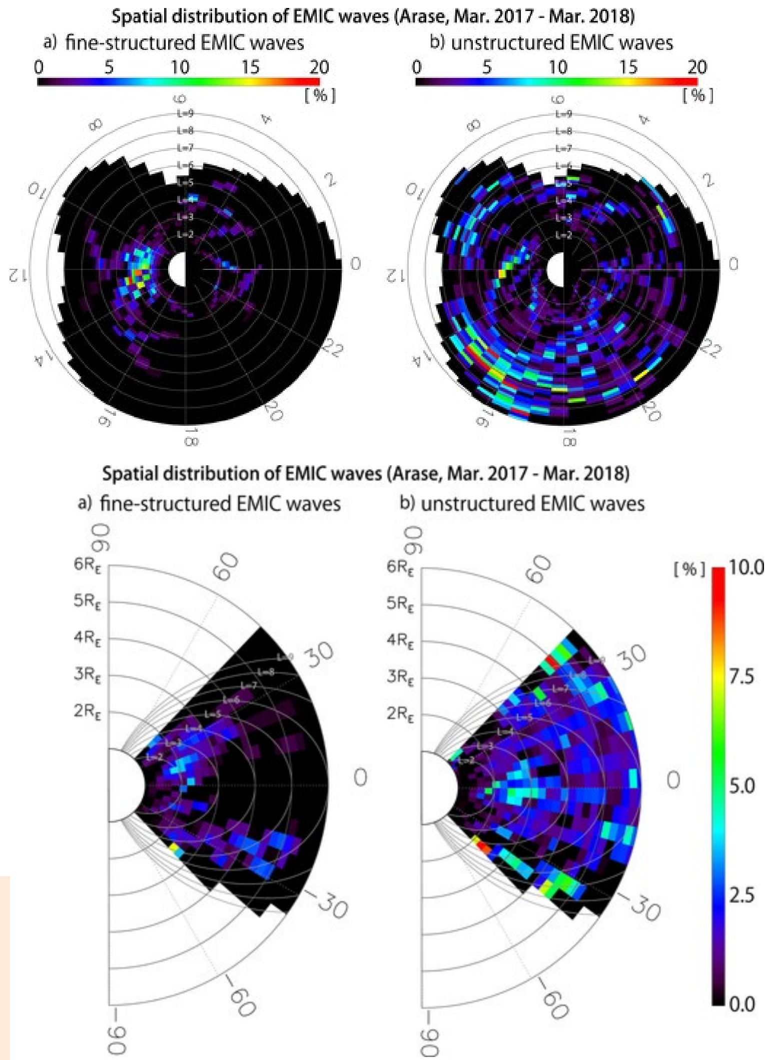

(Miyoshi et al., EPS, 2018)




Ion cyclotron whistlers
(Matsuda et al., EPS, 2018)

# Spatial Distribution of EMIC Waves observed by PWE
# ~ Fine-structured EMIC vs. Unstructured EMIC ~



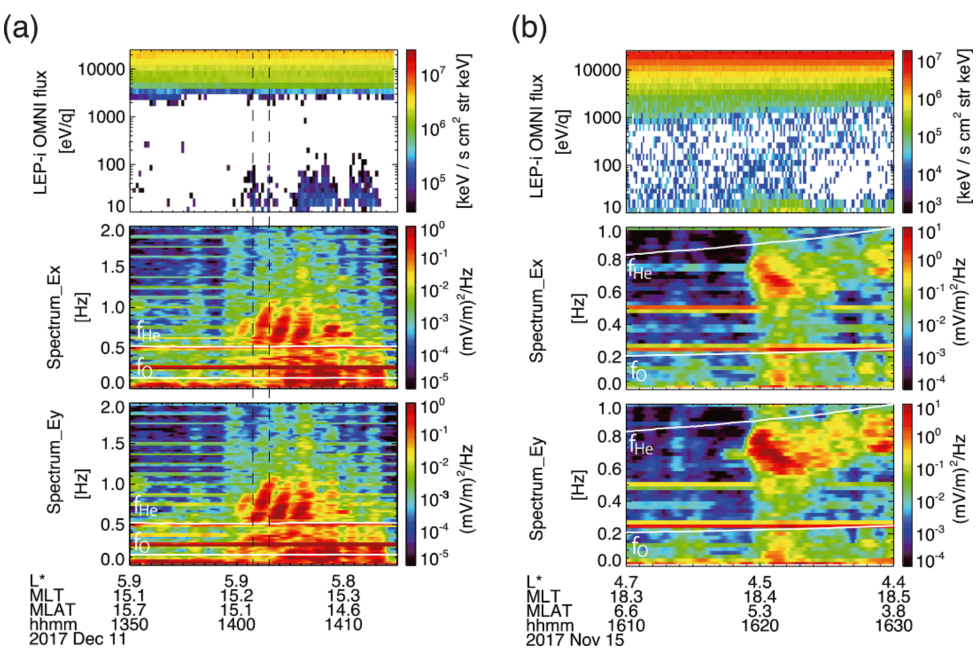




**Matsuda et al. (2018)** surveyed 378 electromagnetic ion cyclotron (EMIC) wave events during the first year observation period, and demonstrated that two types of EMIC waves (fine-structured and unstructured) have different spatial distribution.

Fine-structured EMIC were mainly distributed in the off-equatorial region around the noon sector, which is a new finding due to the unique orbital condition of Arase.

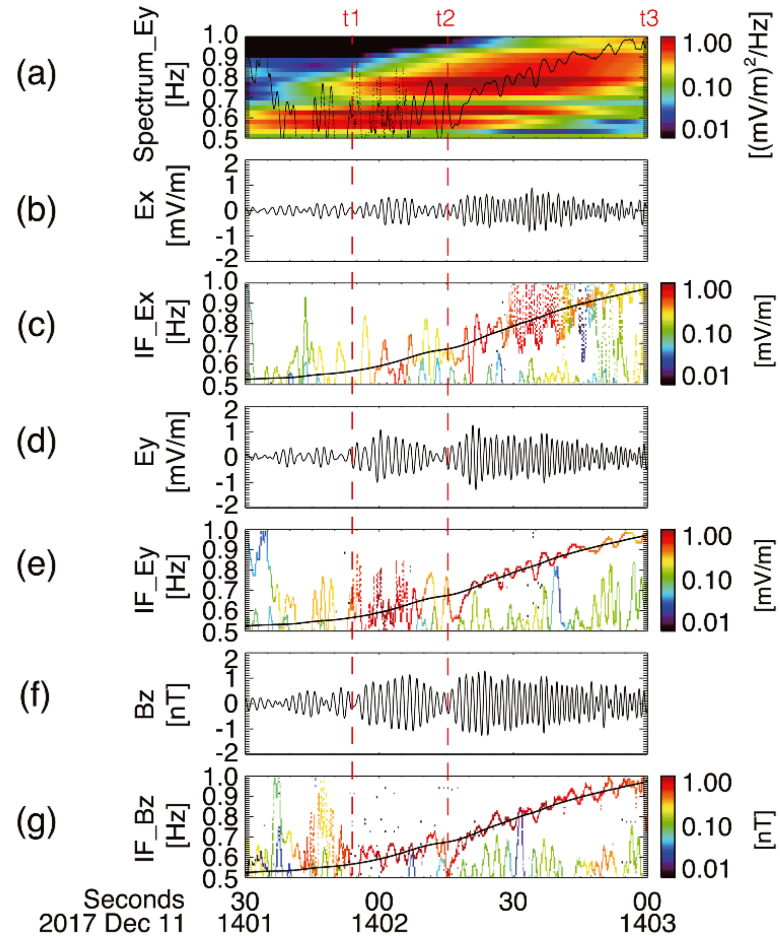
(Matsuda et al., GRL, 2018)

# Instantaneous Frequency Analysis on Nonlinear EMIC Emissions




Rising tone EMIC

Falling tone EMIC

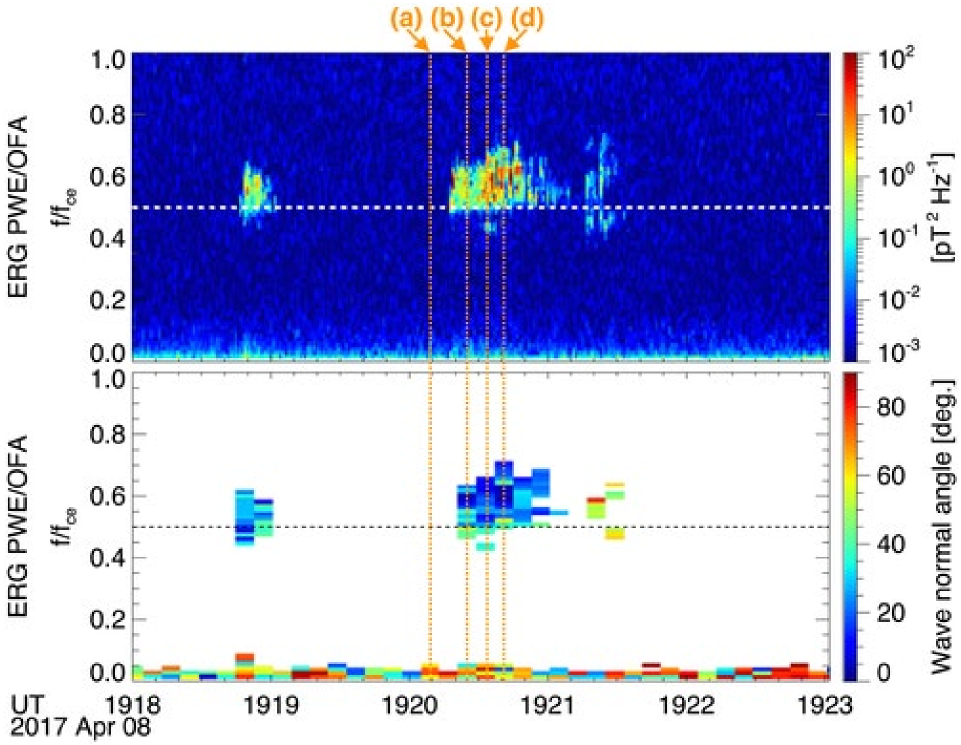



Instantaneous frequency change in rising tone EMIC

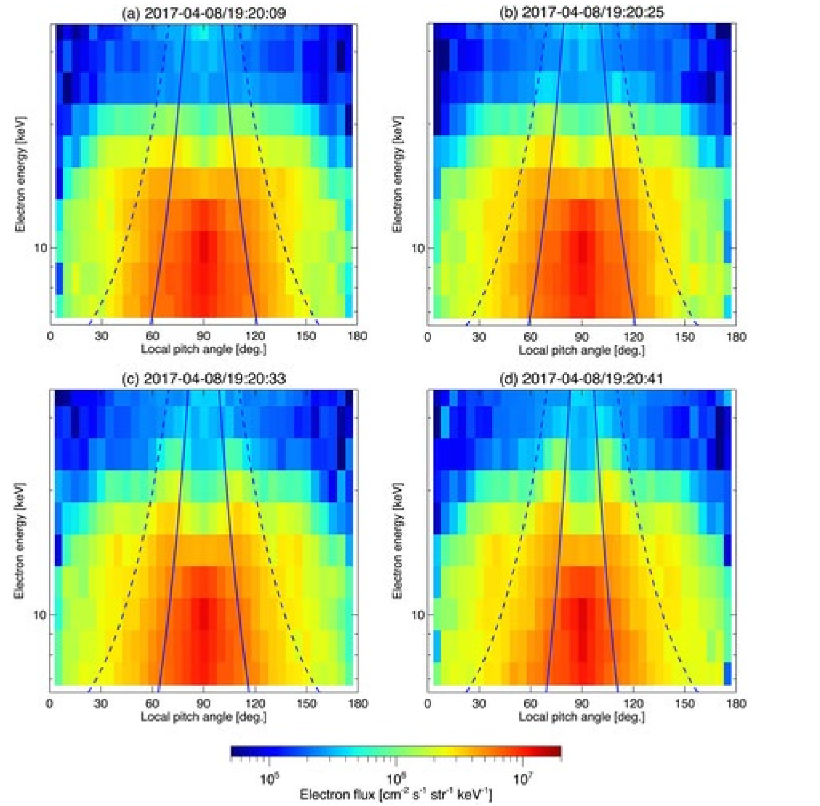
We have observed EMIC waves with rising and falling frequencies. The frequency sweep rate of the EMIC wave is an important parameter for the resonant particle trajectory in phase space. Instantaneous frequency of the rising tone EMIC wave was studied by **Shoji et al. (2018)** using the Hilbert-Huang transformation (HHT). They found that the time variation of the instantaneous frequency shows a good agreement with the nonlinear theory for the frequency evolutions.

(Shoji et al., GRL, 2018)

# Deformation of Electron Pitch Angle Distributions Caused by Upper-band Chorus




Upper-band chorus emissions and their wave normal angles

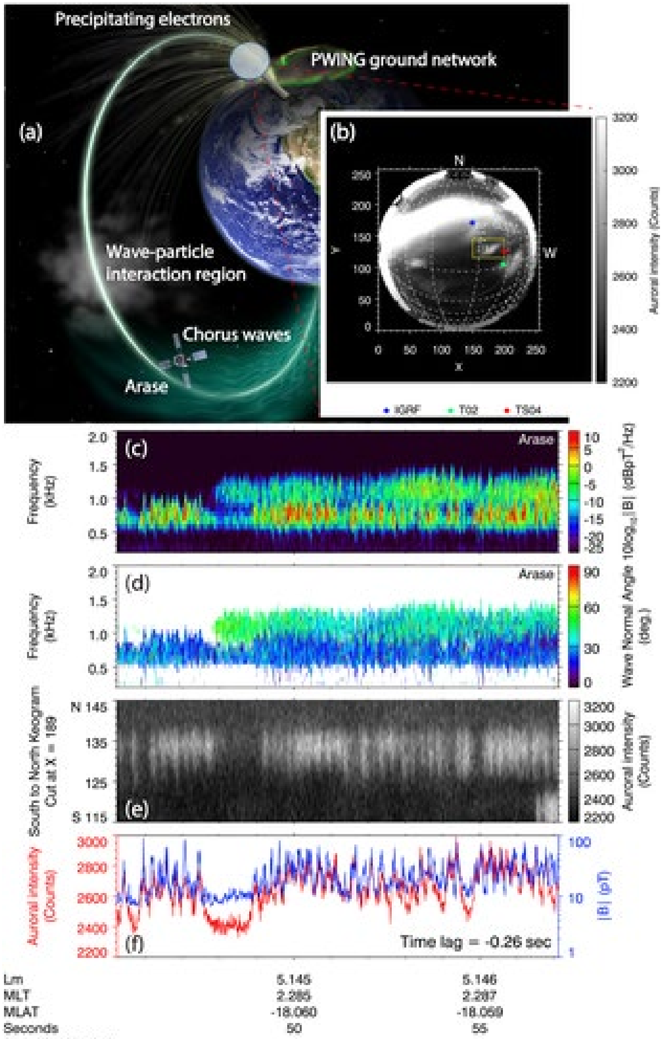



Evolution of electron fluxes in association with the activation of upper band chorus

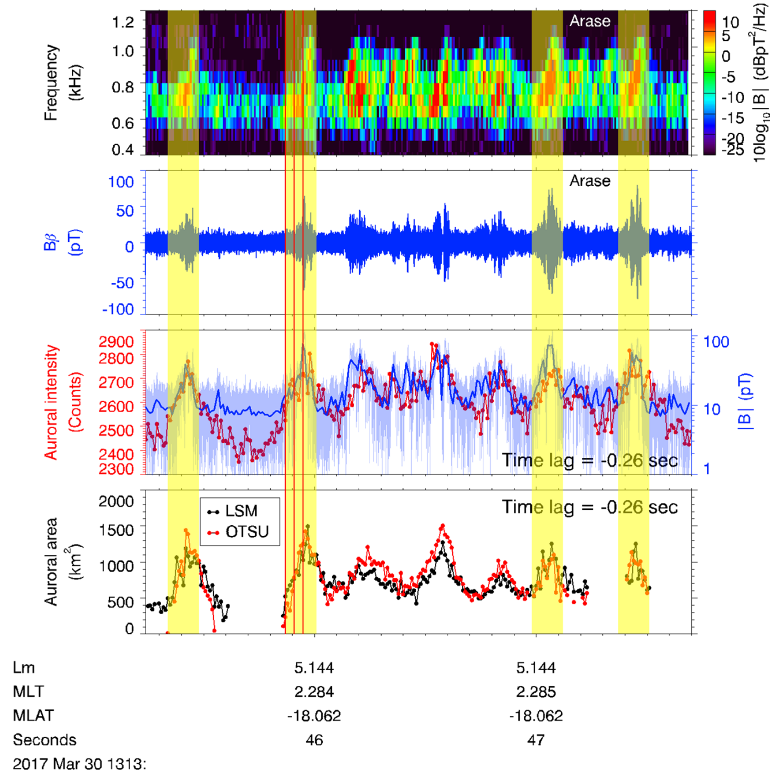
**Kurita et al. (2018)** reported on deformation of electron pitch angle distributions associated with upper band chorus. They found that tens of keV electrons are rapidly accelerated by upper-band chorus waves within 30 seconds, which suggests the deformation is a consequence of wave-particle interactions between electrons and upper-band chorus.

(Kurita et al., GRL, 2018)

# Microscopic Observations of Pulsating Aurora Associated With Chorus Element Structures
## ~ Coordinated Arase Satellite - PWING Observations ~




One-to-one correspondence of the chorus wave amplitude and the time-shifted auroral intensity variation

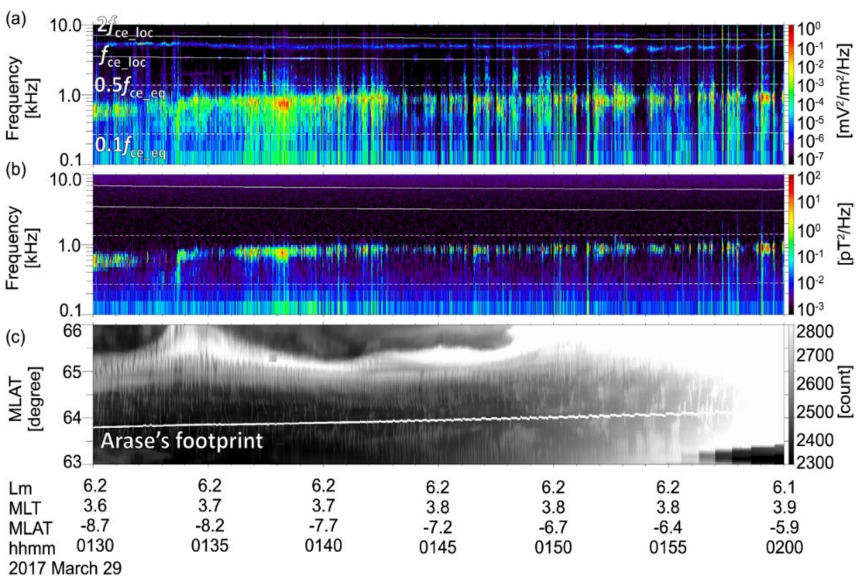



Correlation between chorus subpackets and auroral intensity modulations with time scale of tens of milliseconds.

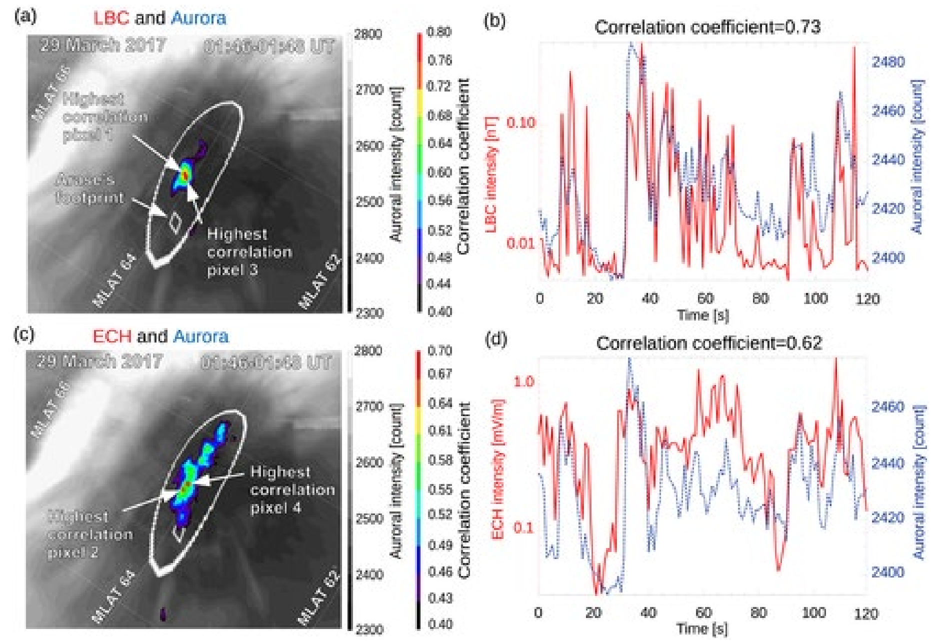
Coordinated Arase and PWING observation revealed a direct link between discrete chorus elements and intensity modulations in a pulsating auroral patch. **Ozaki et al. (2018)** reported rapid (<1s) intensity modulation of pulsating auroras correlated with successive chorus elements as a consequence of wave-particle interactions.

(Ozaki et al., GRL, 2018)

# Electrostatic Electron Cyclotron Harmonic (ECH) Waves as a Candidate to Cause Pulsating Auroras




Lower-band chorus (LBC) and electron cyclotron harmonic (ECH) wave observed by the PWE/OFA, and pulsating auroras (PsA) at the footprint of the Arase.

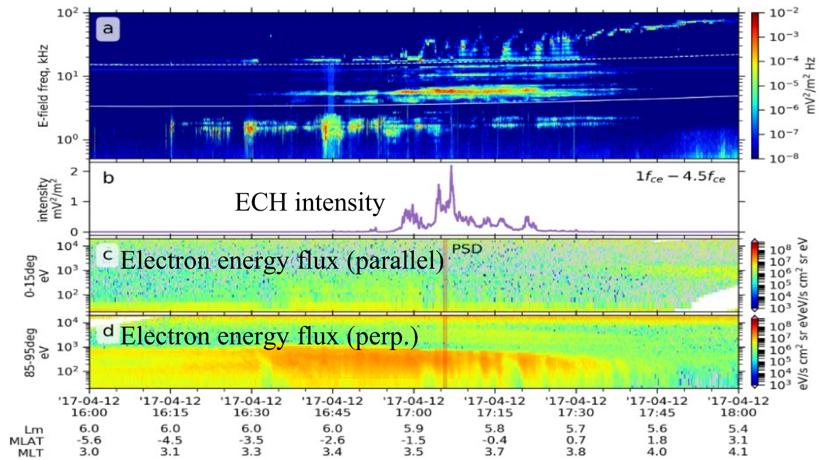



(a) Spatial distribution and (b) time series of correlation coefficient between LBC and auroral intensity.
(c) Spatial distribution and (d) time series of correlation coefficient between ECH and auroral intensity

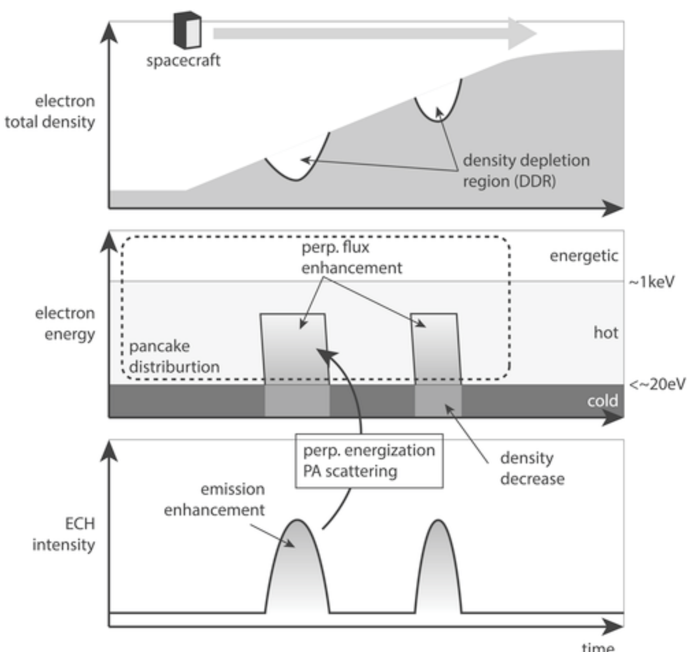
**Fukizawa et al. (2018)** analyzed an event of conjugate between Arase and ground-based imager measurements during a period when quasiperiodic LBC and ECH wave emissions were simultaneously observed. They demonstrated that not only the LBC but also ECH wave intensity had correlation with the PsA intensity.

(Fukizawa et al., GRL, 2018)

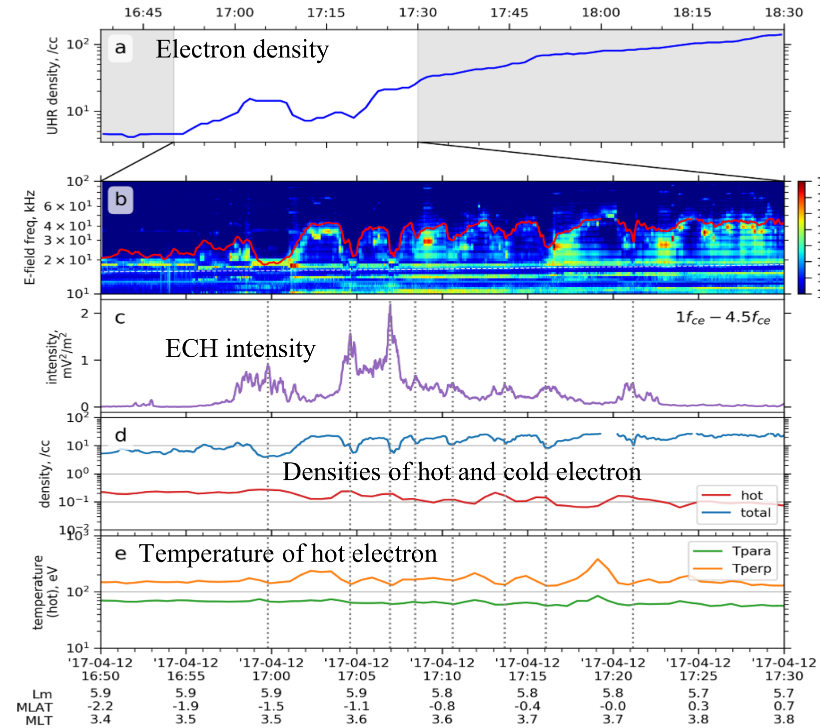
# Density Depletions Associated With Enhancements of Electron Cyclotron Harmonic (ECH) Emissions



ECH waves vs. electron energy flux



Schematic picture of the event

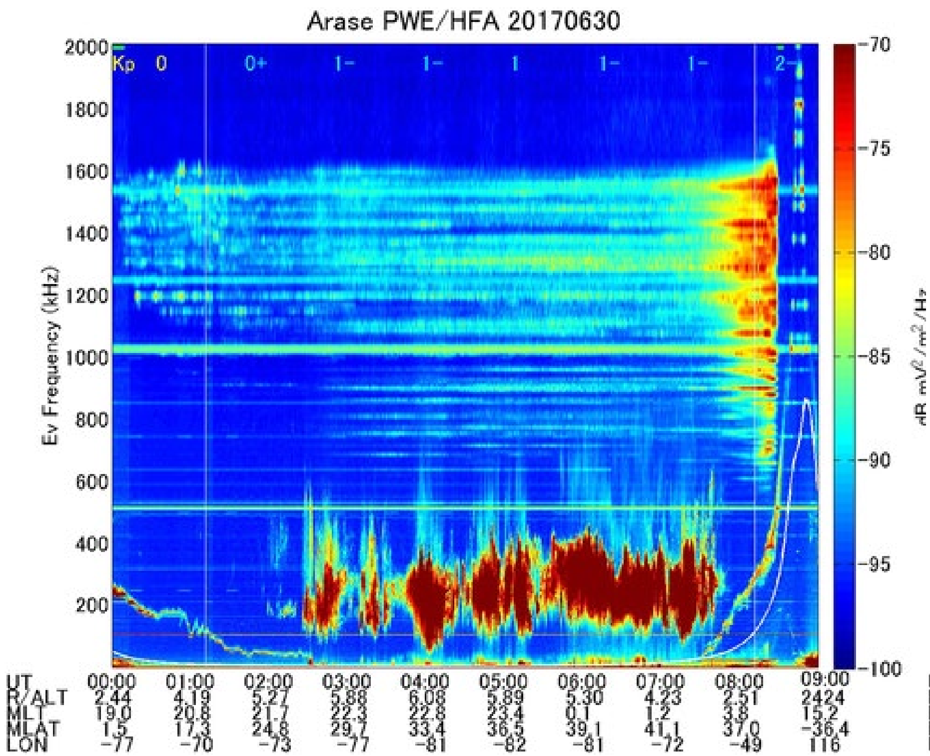


Densities and temperatures of cold and hot electrons during the period of ECH enhancement

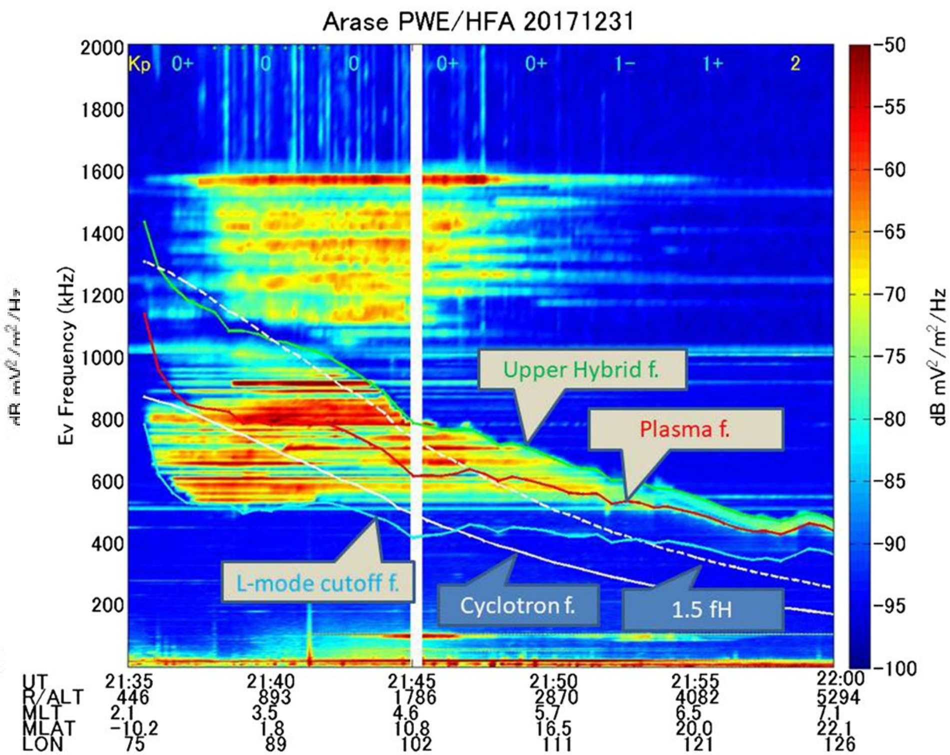
**Kazama et al. (2018)** reported an event near the magnetic equator, where plasmapause had small-scale density depletions of cold electrons associated with enhancements of ECH waves. They also reported enhancements of hot-electron fluxes perpendicular to the local magnetic field probably due to perpendicular energization of cold electrons by the ECH waves.

(Kazama et al., GRL, 2018)

# Hectometric Line Spectra




Typical spectra of the hectometric line spectra (HLS) observed by PWE/HFA.



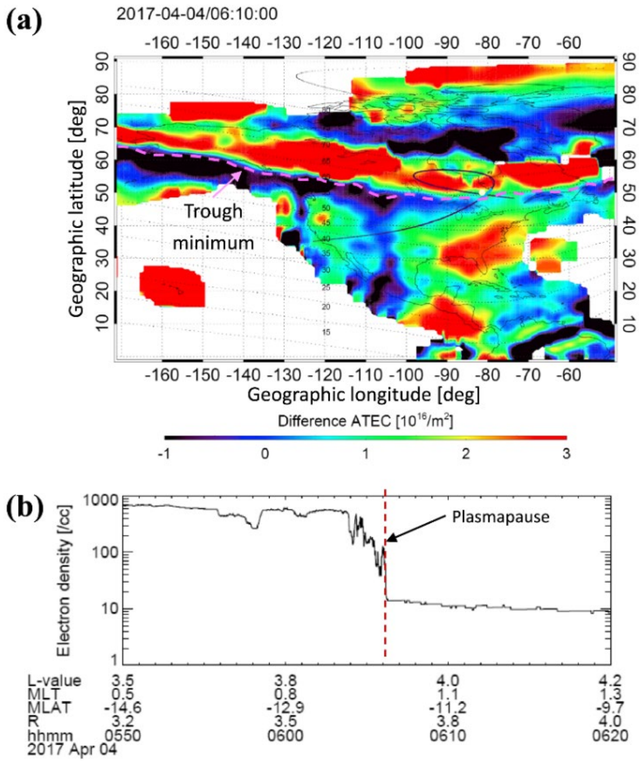

Strong HLS observed in the range of 525–1,600 kHz. The waves below 1,100 kHz are in the Z mode, while the waves above 1,100 kHz are in the L-O mode.

**Hashimoto et al. (2018)** reported hectometric line spectra (HLS) composed of line emissions from 525 to 1,700 kHz. They suggested that a broadcasting wave is partially mode-converted to the Z mode in a depleted electron density region such as a plasma bubble. The Z-mode waves can be also mode-converted to the L-O mode and propagate widely in the lower density side of the density gradient surface.

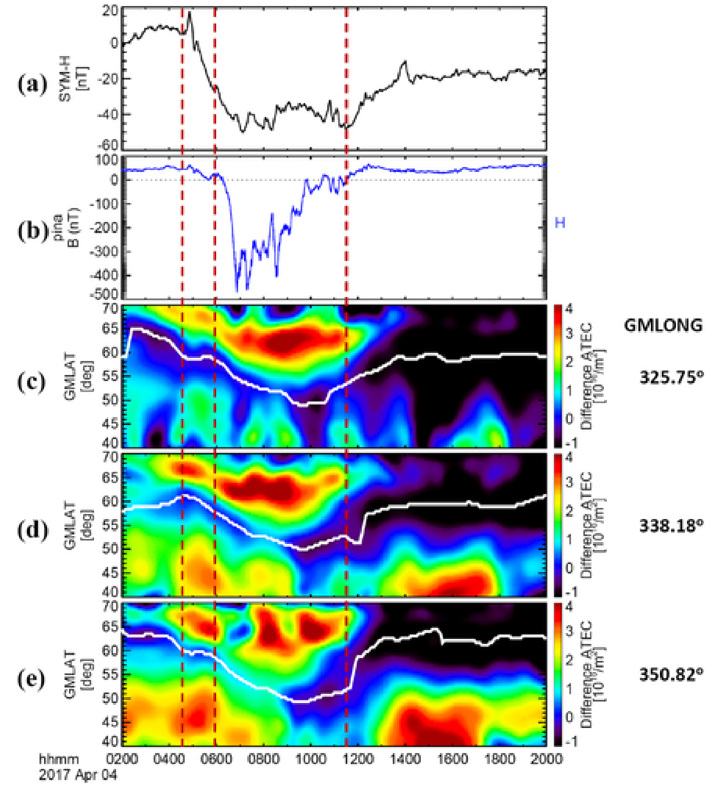
(Hashimoto et al., GRL, 2018)

# Temporal and Spatial Variations of Storm Time Mid-latitude Ionospheric Trough

## ~ Global GNSS - TEC and Arase Observations ~




(a) GNSS-TEC map in North America and (b) electron density along the Arase satellite orbit. The black curve and the yellow circle in (a) show the footprint of Arase and the location of plasmapause identified from the electron density profile, respectively.




The trough minimum moves equatorward after the geomagnetic storm commencement within 4 hr., and rapidly moves poleward back after the recovery phase within 4 hr.

Temporal and spatial variations of the mid-latitude ionospheric trough during a geomagnetic storm on 4 April 2017 have been investigated by **Shinbori et al. (2018)** using Global Navigation Satellite System (GNSS) total electron content (TEC) data together with Arase observation.

(Shinbori et al., GRL, 2018)

# Summary

- The nominal data (EFD, OFA, and HFA) as well as the WFC burst data ("Chorus burst" and "EMIC burst") were successfully obtained, and various kinds of plasma waves were observed by the PWE.

- Campaign observations were intensively conducted and will be scheduled with ground observation networks (PWING, EISCAT, SuperDARN etc.) and the other satellites (Van Allen Probes, MMS, THEMIS etc.).

- Many science papers using the PWE data have been published and those works provided important clues to understand the plasma physics in the inner magnetosphere.

- The data pipeline processing and further calibration are in progress, and the data products (L2 data) are released from the ERG science center via the web interface.

- During the extended mission period, new collaborative observations with DSX, ELFIN and EISCAT_3D etc. will provide further advanced view of science in the inner magnetosphere.