SuperDARN研究集会
OCT 16 (Tue), 2018
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# Drift-bounce resonance between Pc5 wave and ions: Arase and MMS study

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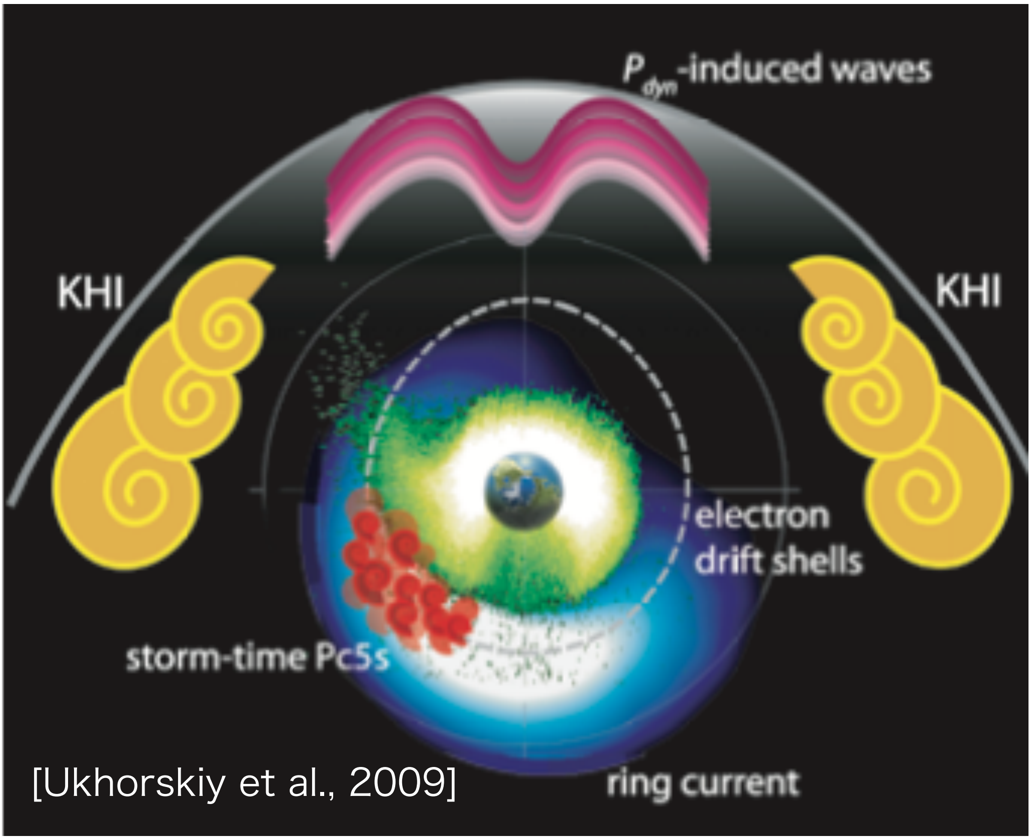
Oimatsu, S., Nosé, M., Teramoto, M., Yamamoto, K., Matsuoka, A., Kasahara, S., et al. (2018). Drift-bounce resonance between Pc5 pulsations and ions at multiple energies in the nightside magnetosphere: Arase and MMS observations. *Geophysical Research Letters*, 45, 7277–7286. https://doi.org/10.1029/2018GL078961

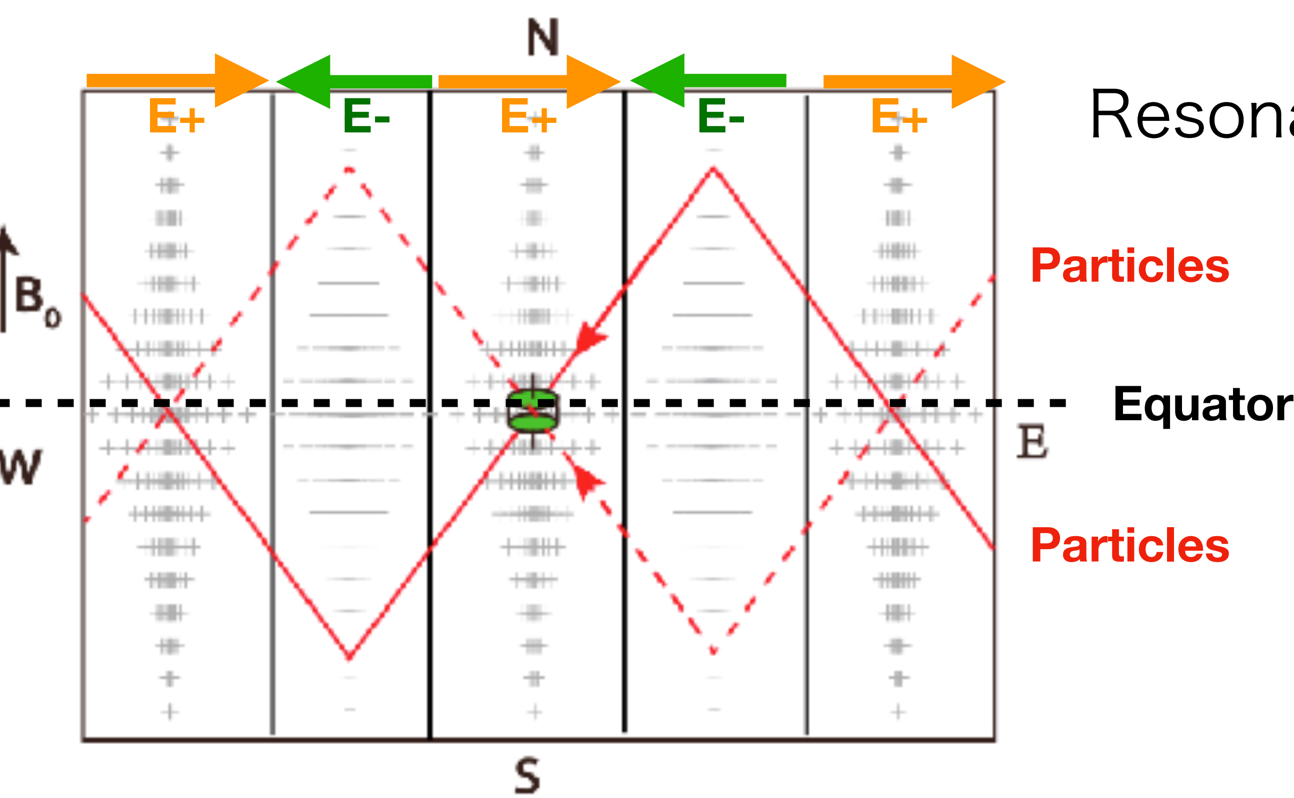
# ULF waves and drift-bounce resonance



[Ukhorskiy et al., 2009]

Wave period:
Pc4 : 40–150 s
Pc5 : 150–600 s

| | Sources | Features |
|---|---|---|
| External | • Kelvin-Helmholtz (K-H) instability<br>• Solar wind dynamic pressure | • Small m-number<br>• Toroidal mode |
| Internal | • Plasma instability due to the ring current or substorm injection | • Large m-number<br>• Poloidal Mode |



[Ren et al., 2017]

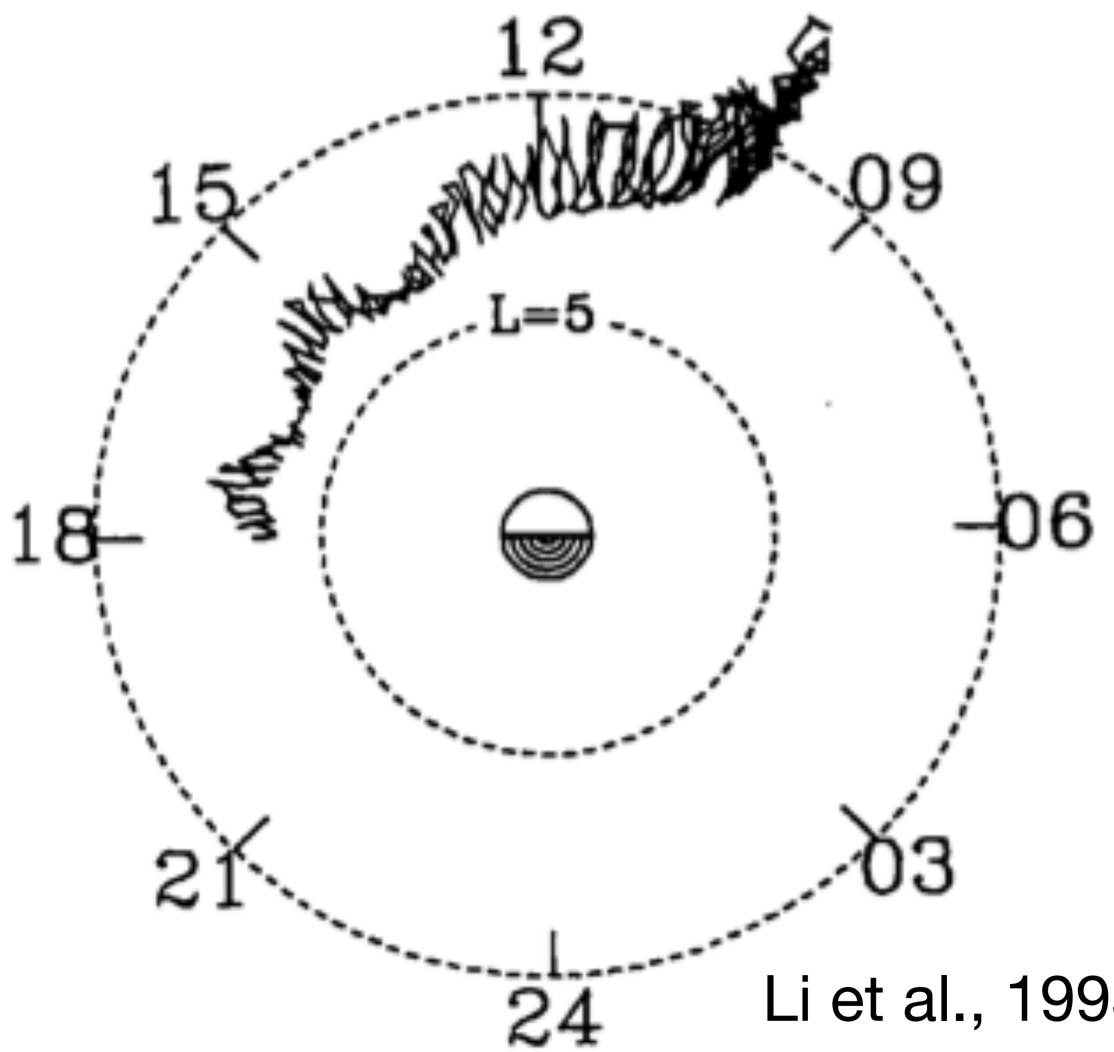
Resonance condition: $\omega - m\omega_d = N\omega_b$

ω : Wave angular frequency
m : Azimuthal wave number (m-number)
$\omega_b$ : Bounce angular frequency
$\omega_d$ : Drift angular frequency
N : Integer

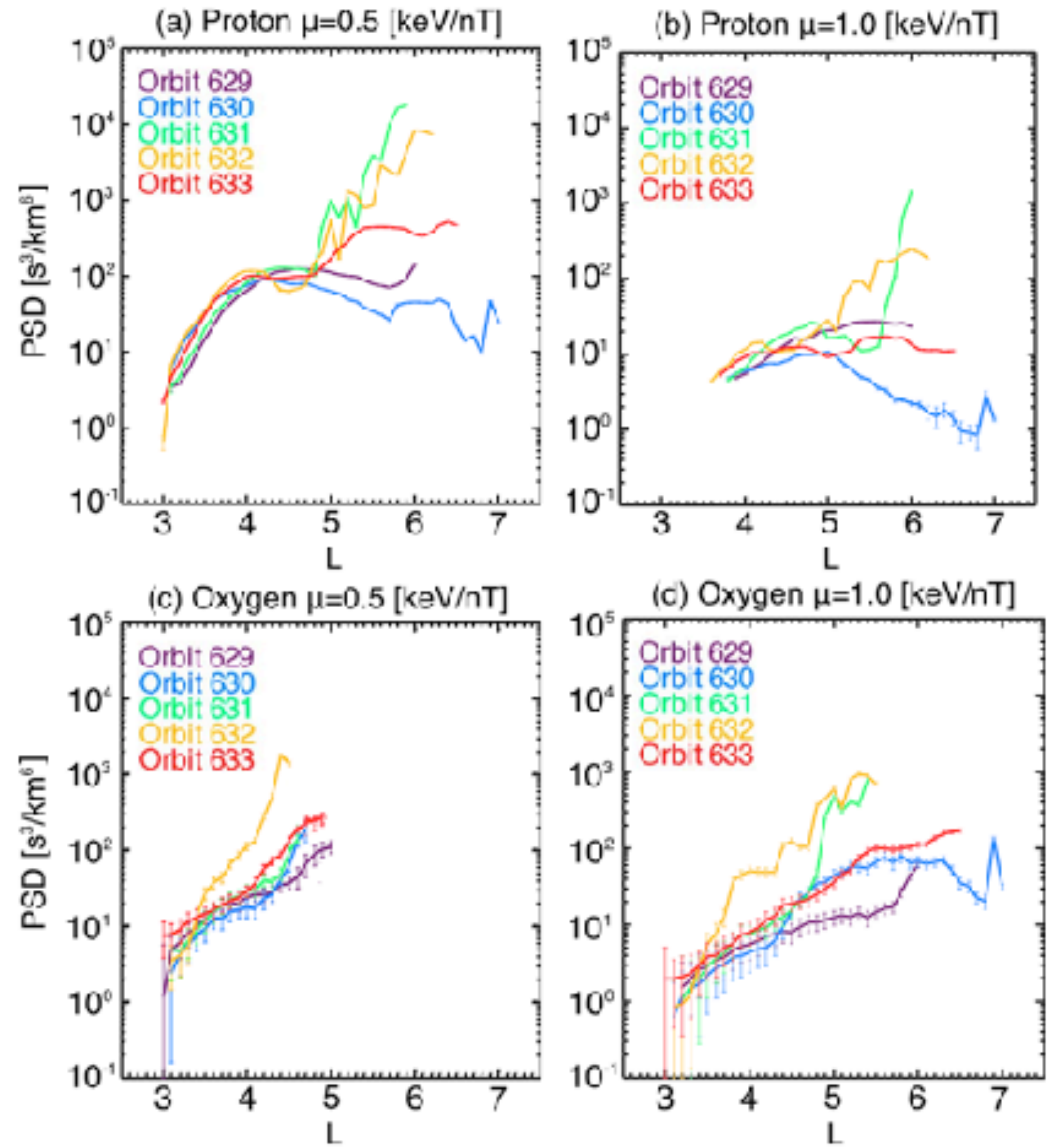
- Odd harmonic → N=2k
- Even harmonic → N=2k+1

(k : Integer, -2 < N < 2)

# Drift-bounce resonance of $O^+$ ion




Li et al., 1993



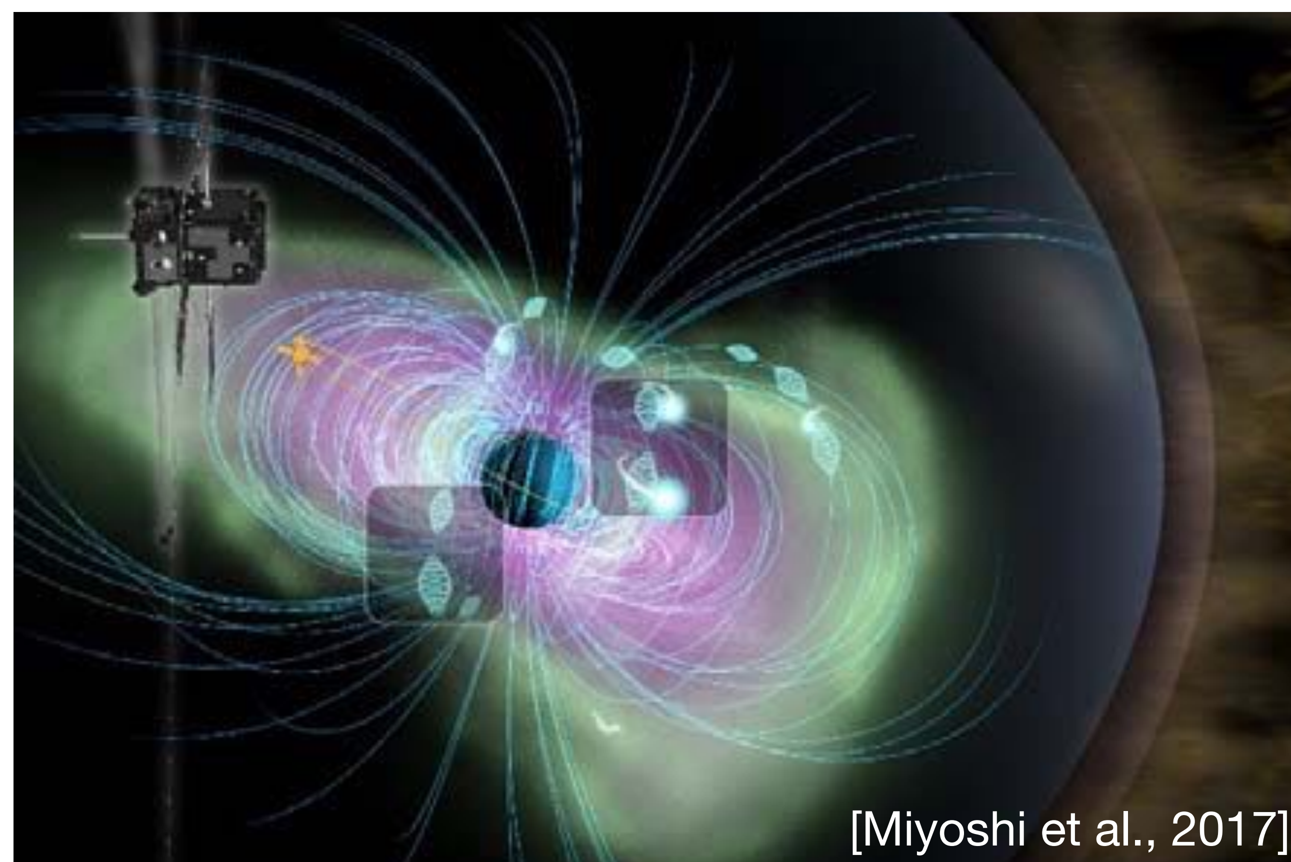

Mitani et al., 2018

- Oxygen ions are diffused by the drift-bounce resonance with convection electric field (simulation).
- Drift-bounce resonance of $O^+$ ion contributes to the acceleration or deceleration of $O^+$ ions [e.g., Li et al., 1993; Yang et al., 2011].
- Mitani et al. (2018) proposed that the drift-bounce resonance contribute to the deeper penetration of > 200 keV $O^+$ ions into the inner magnetosphere.

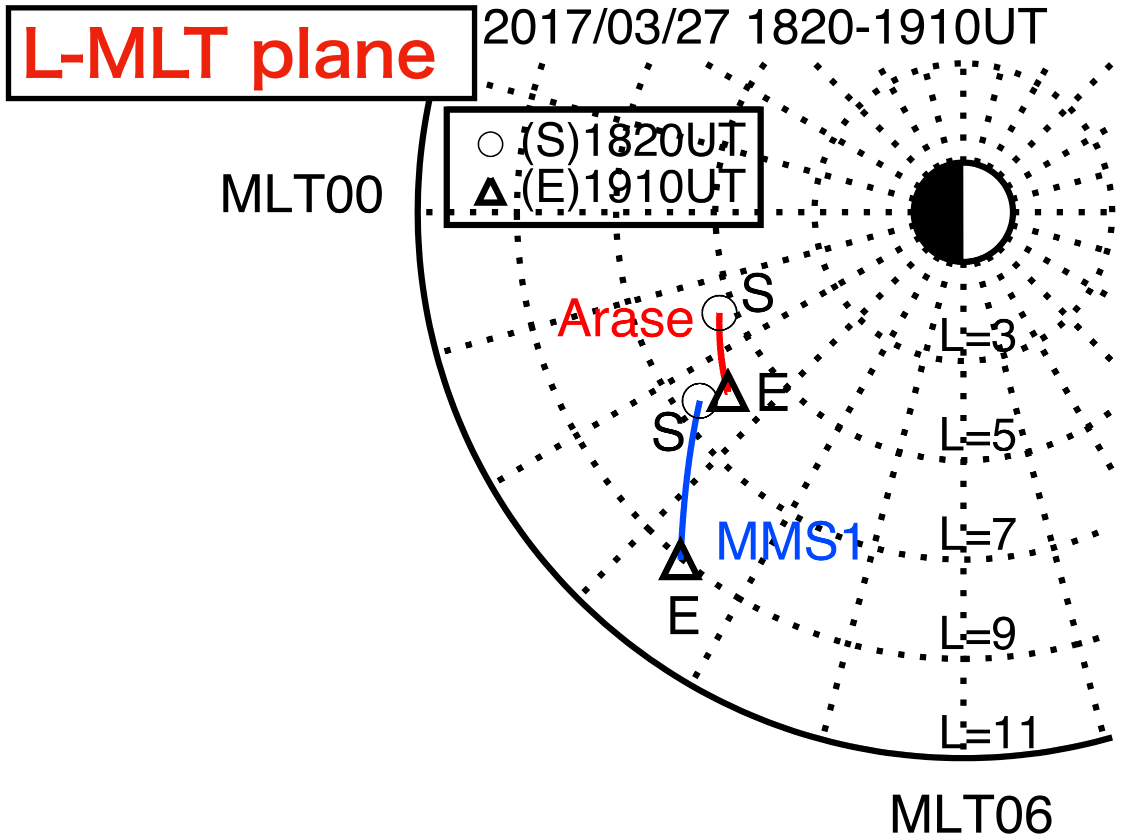
# Data

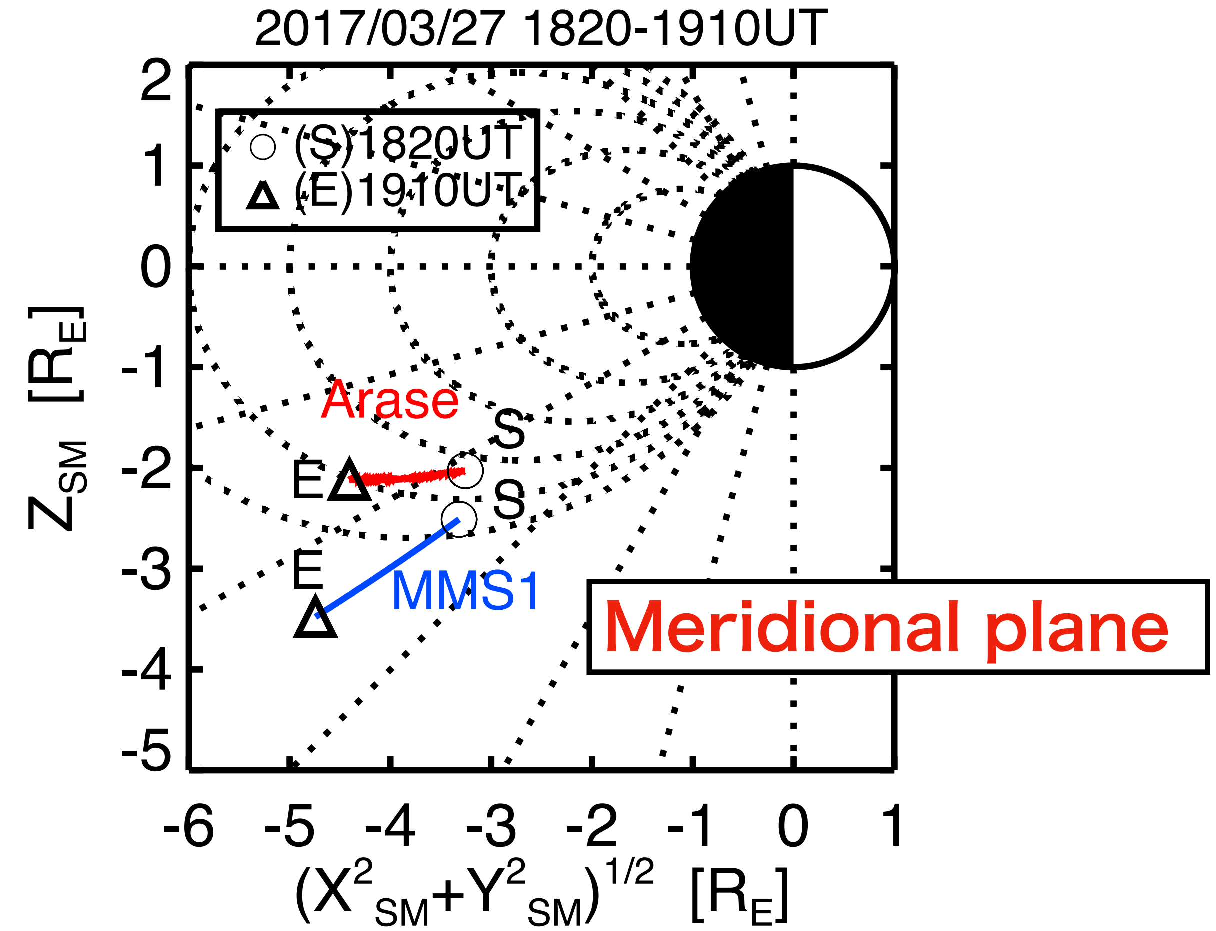
- **Arase satellite**
  - **MGF**
    - 8-s magnetic field
  - **MEP-i**
    - 16-s data (NML mode)
    - $H^{+}$, $He^{++}$, $He^{+}$, $O^{+}$, $O^{+2}$, $O_2^{+}$
    - Energy range: 5.1 ~109.6 keV
  - **MEP-e**
    - 8-s data
    - Electron ($e^{-}$)
    - Energy range: 7.0~87.5 keV
- **MMS1 satellite**
  - **FGM** - Magnetic field
  - **EDP** - Electric field
- **Ground stations** (TIK, PBK…)
  - Magnetic field

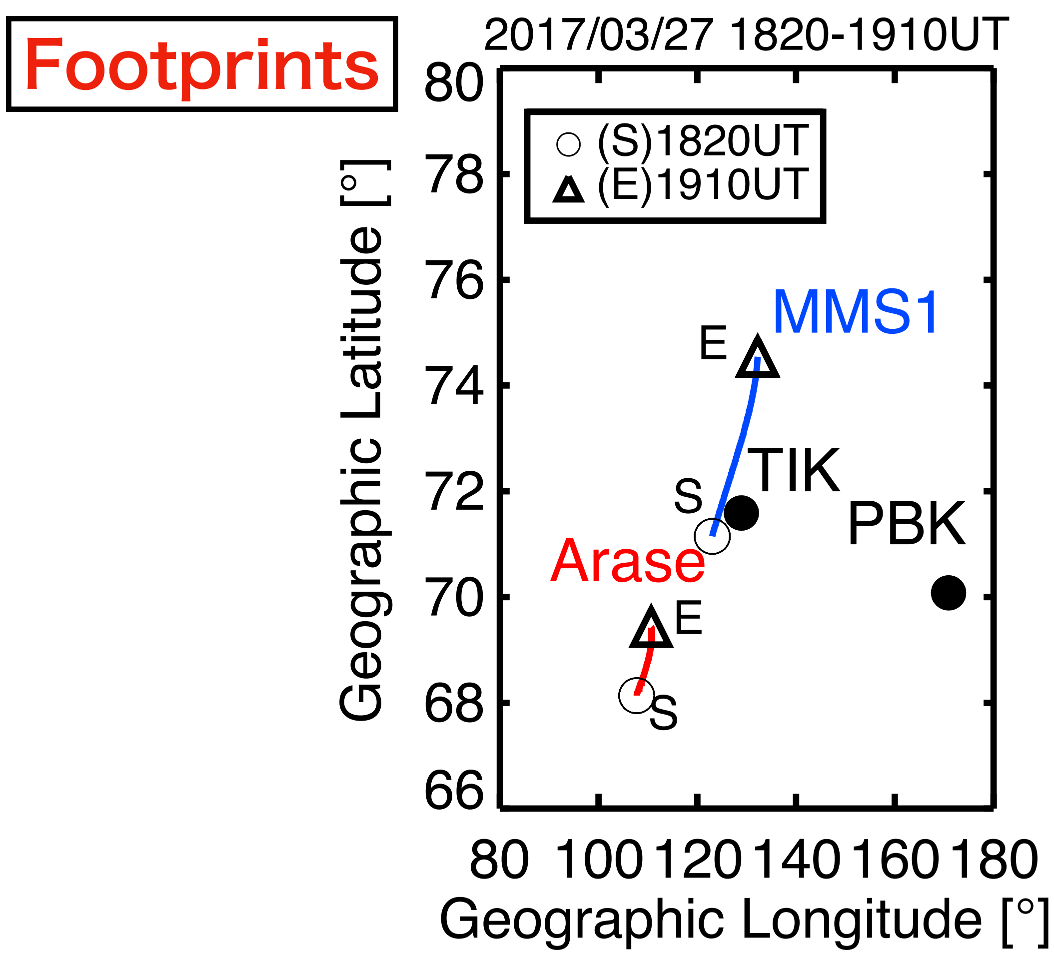
| | | |
|---|---|---|
| Launch | Date | December 20, 2016 |
| Orbit | Altitude | Perigee: ~460 km<br>Apogee: ~6 Re |
| | Inclination | < ~31° |
| | Type of Orbit | Elliptical orbit |
| | Period | ~8 hours |
| | Spin period | ~8 sec |


[Miyoshi et al., 2017]

# Case study : 27 March 2017

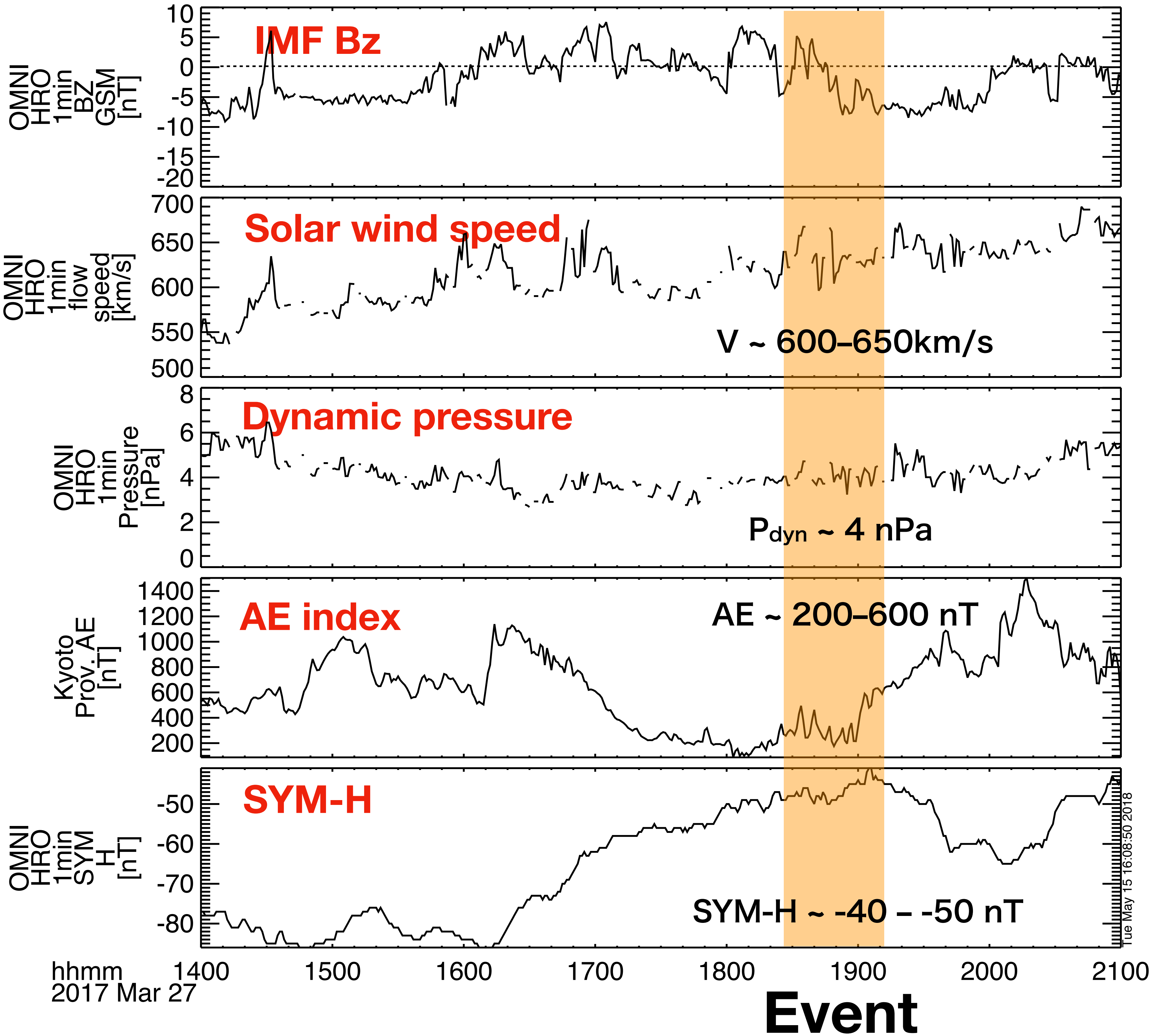


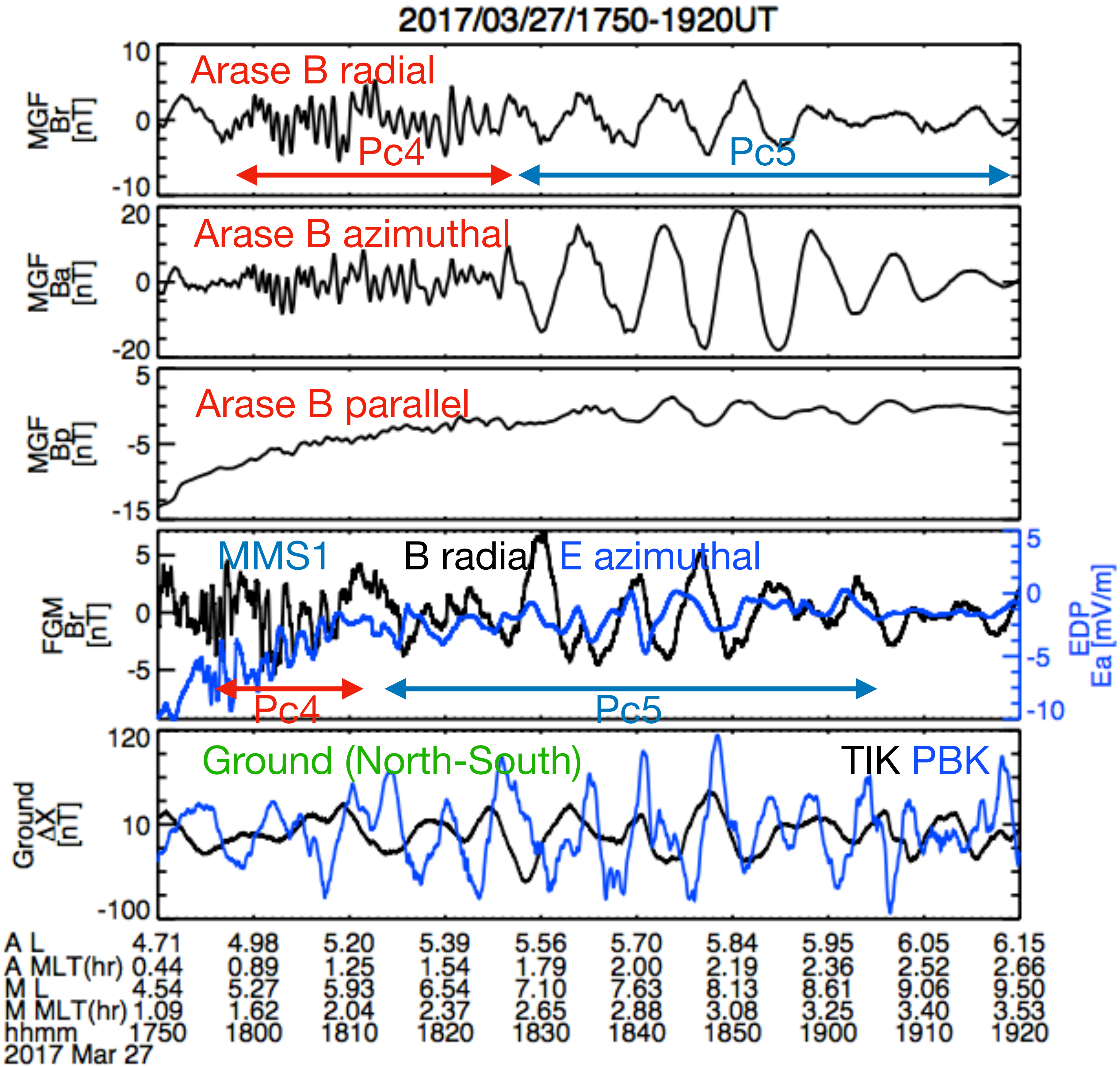




| | L | MLT(hr) | MLAT |
|---|---|---|---|
| **Arase** | 5–6 | 1.5–2.5 | -30° |
| **MMS1** | 7–9 | 2.5–3.5 | -35° |

# Solar wind conditions



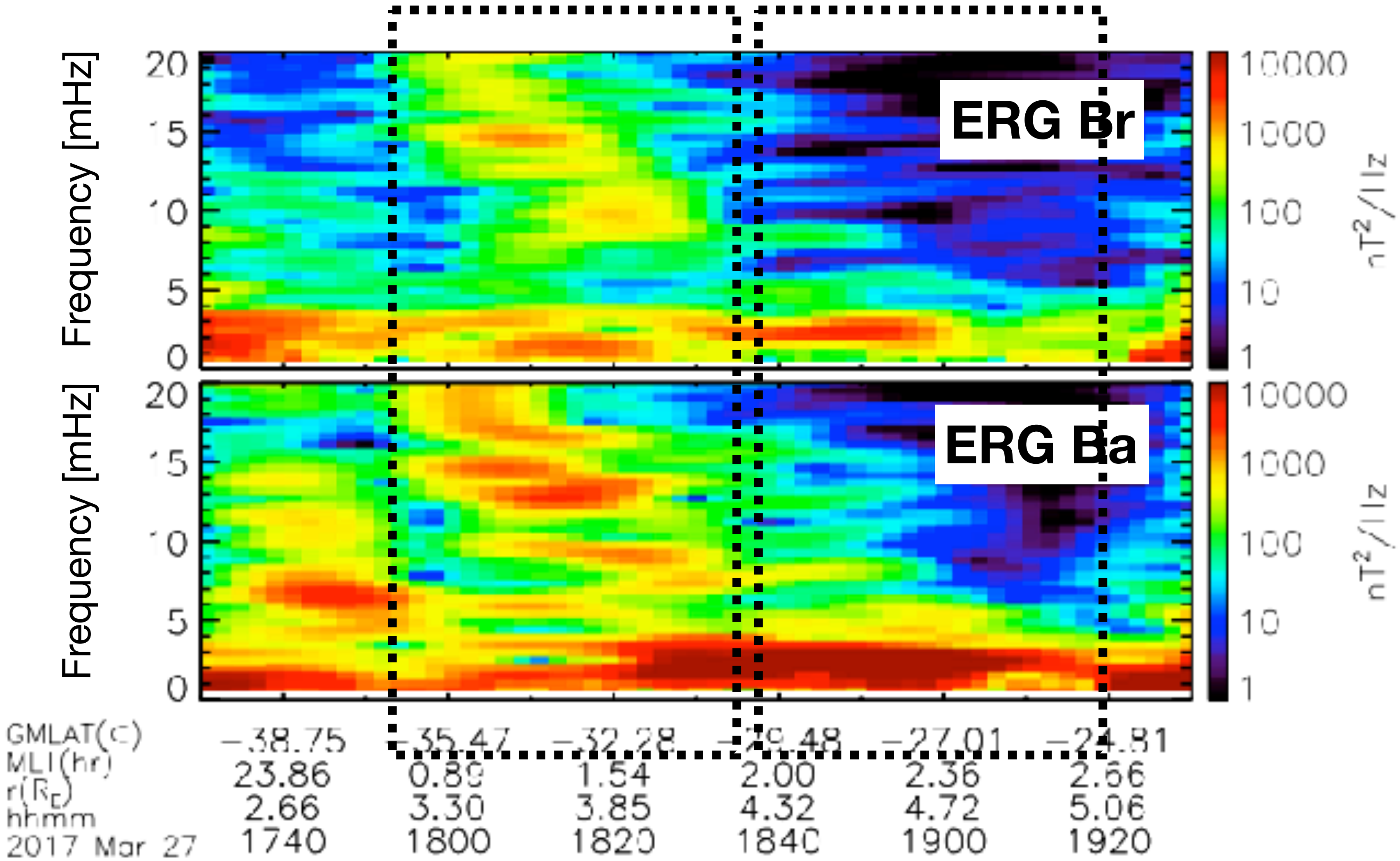
# Observation of ULF waves



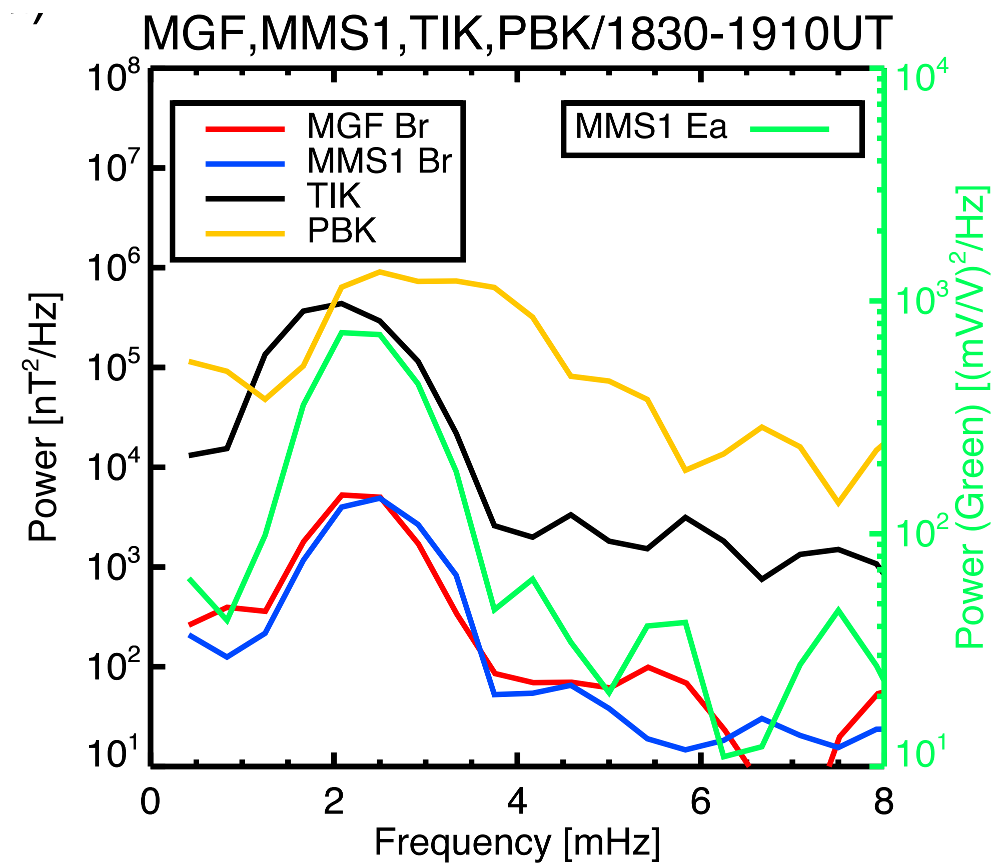

- Arase, MMS1, and ground magnetometers observed Pc4 and Pc5 waves.
- The wave amplitude of the Pc5 is largest in the azimuthal direction.
- The Pc5 wave is observed on the ground.
- Wave period of the Pc5 wave is ~450 s.
- Ea leads Br in the southern hemisphere.

  → Fundamental mode.

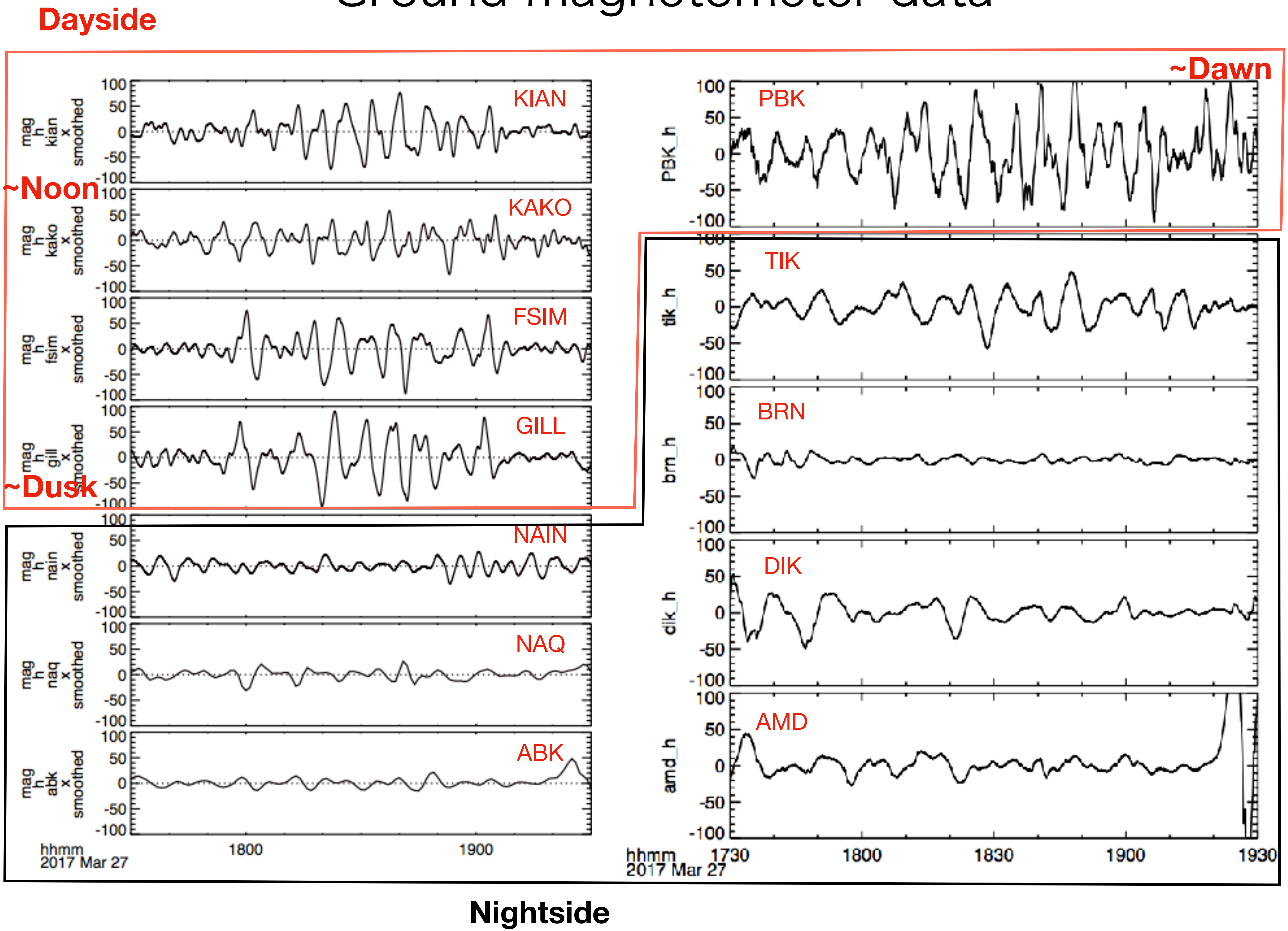
# Power spectrum




Pc4 Pc5



# Ground magnetometer data



# Observational estimation of m-number

$$m = \frac{\Delta\theta}{\Delta\varphi}$$

$\Delta\theta$ : Phase difference

$\Delta\varphi$ : Longitudinal separation

We determine $\Delta\theta$ which provides the maximum cross-correlation coefficient at 1830–1910 UT.

**(1) Arase - MMS1**

$\Delta\theta = -192^\circ$

$\Delta\varphi = 13^\circ$

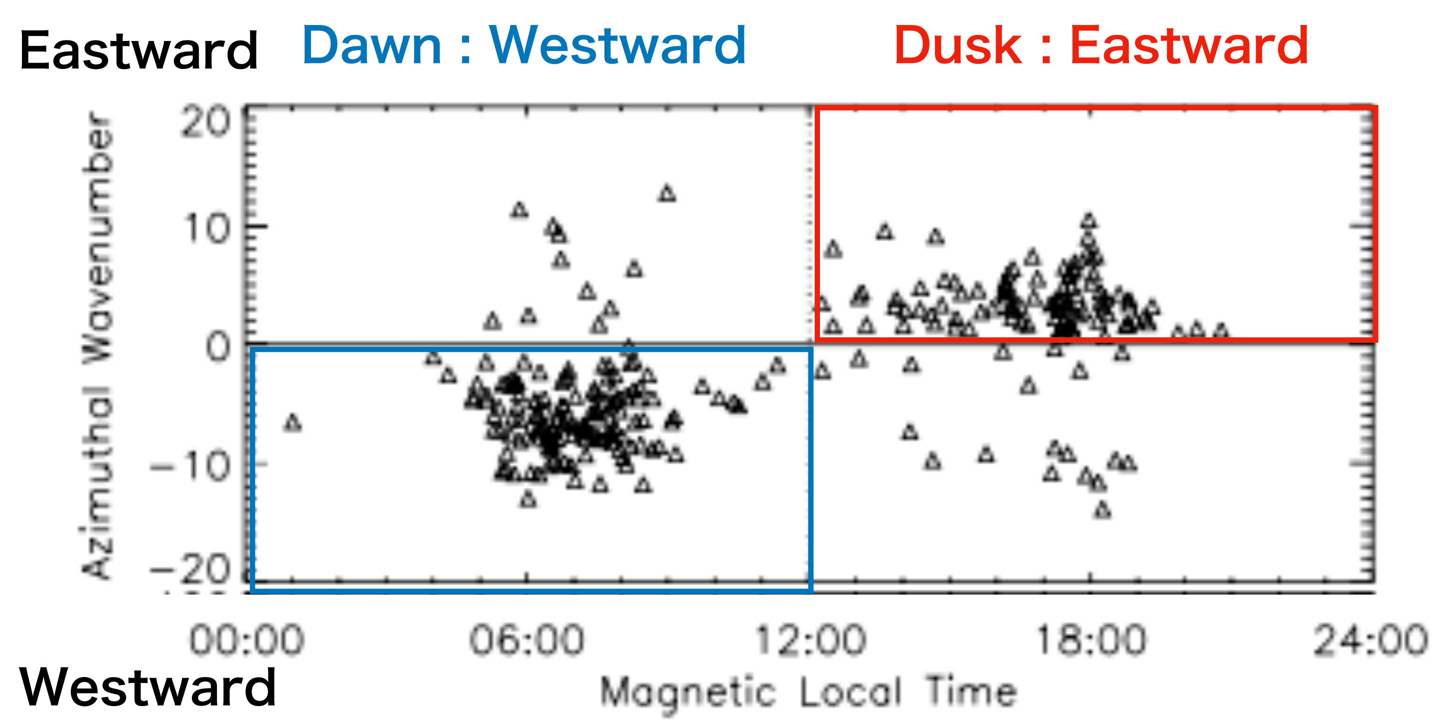
➡ **m ~ -15**

**(2) TIK - PBK**

$\Delta\theta = -316^\circ$

$\Delta\varphi = 30.4^\circ$

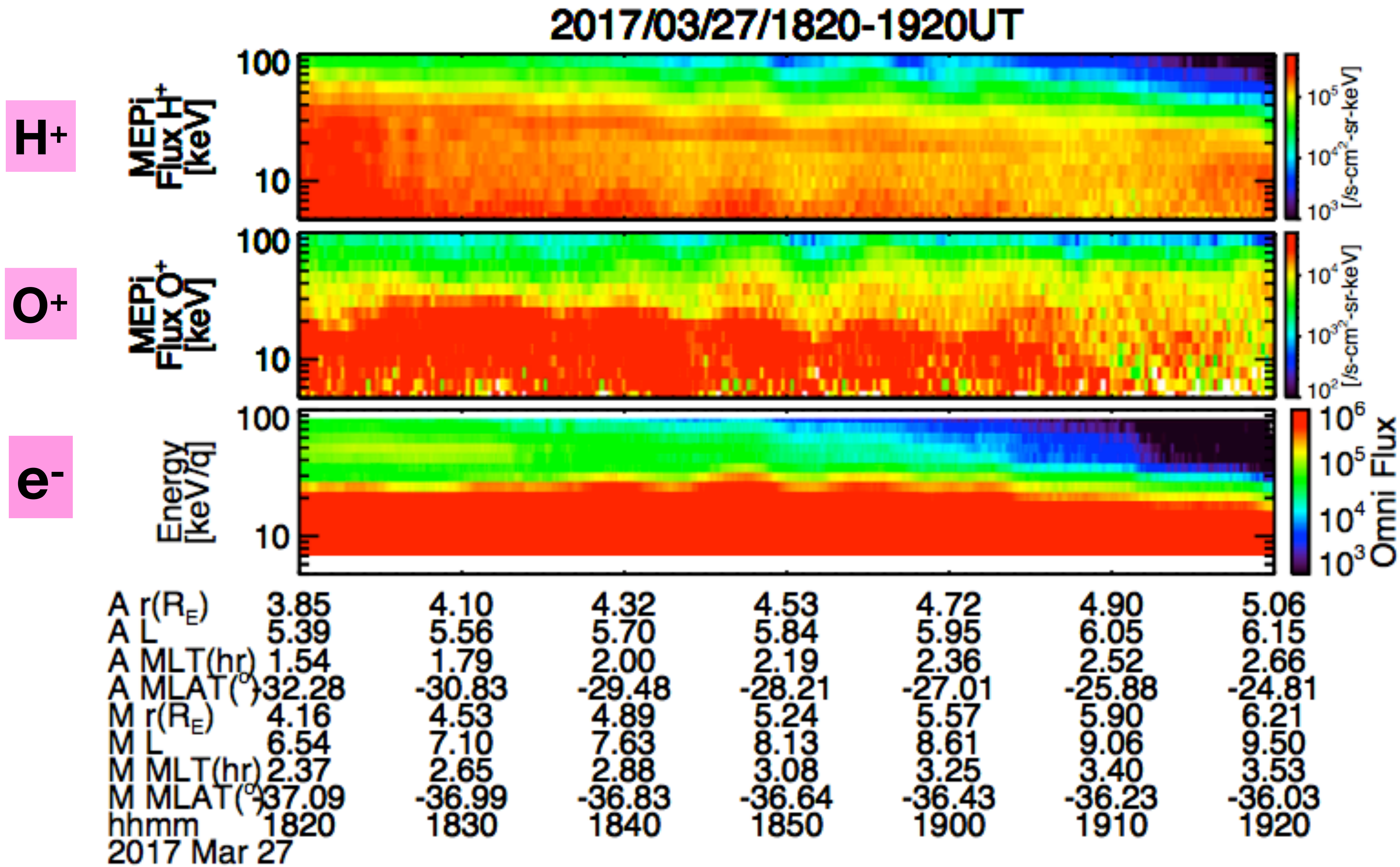
➡ **m ~ -10**




Baker et al., 2003

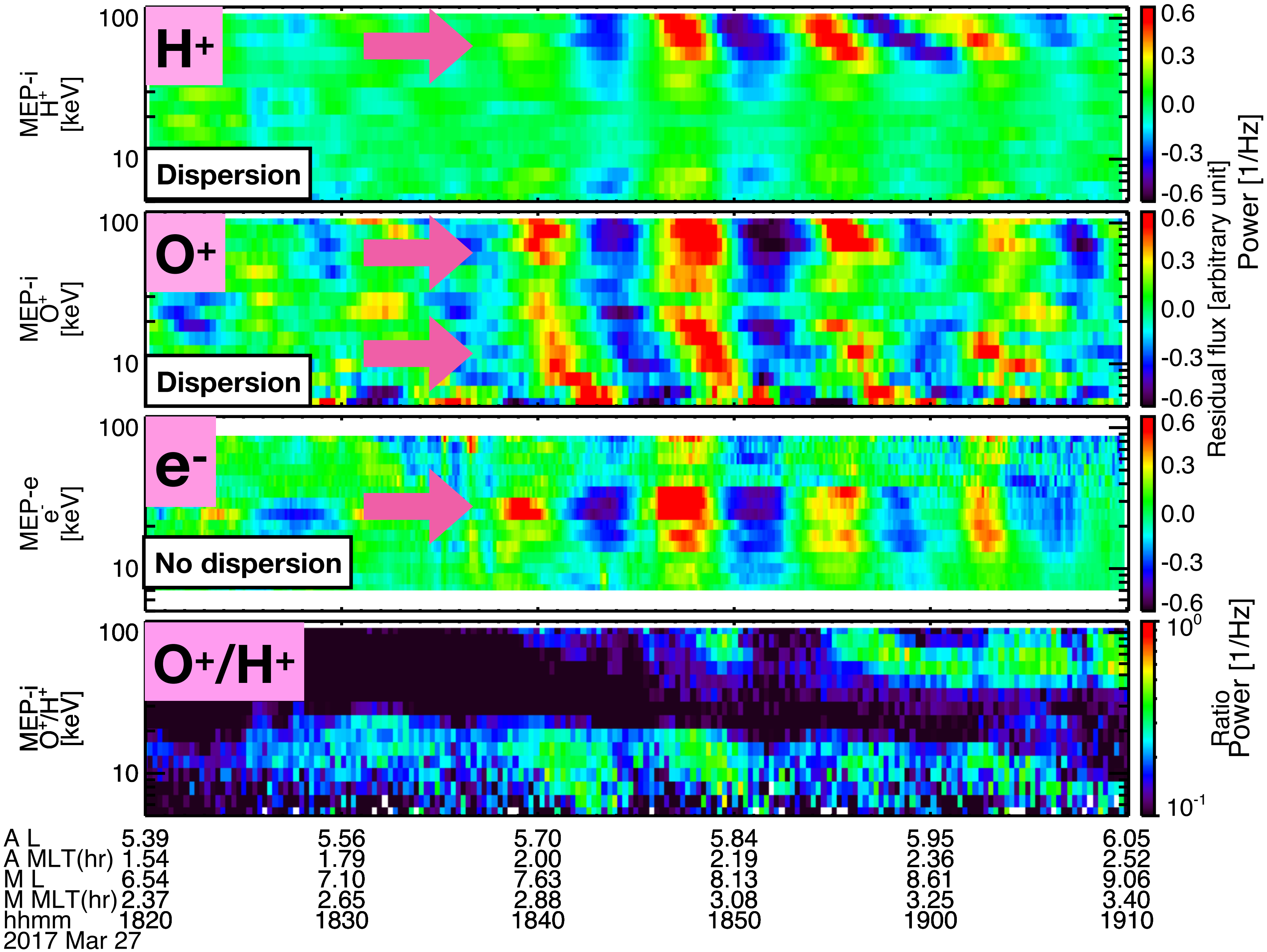
- Estimated values are consistent with the ground observation.

# E-T diagram



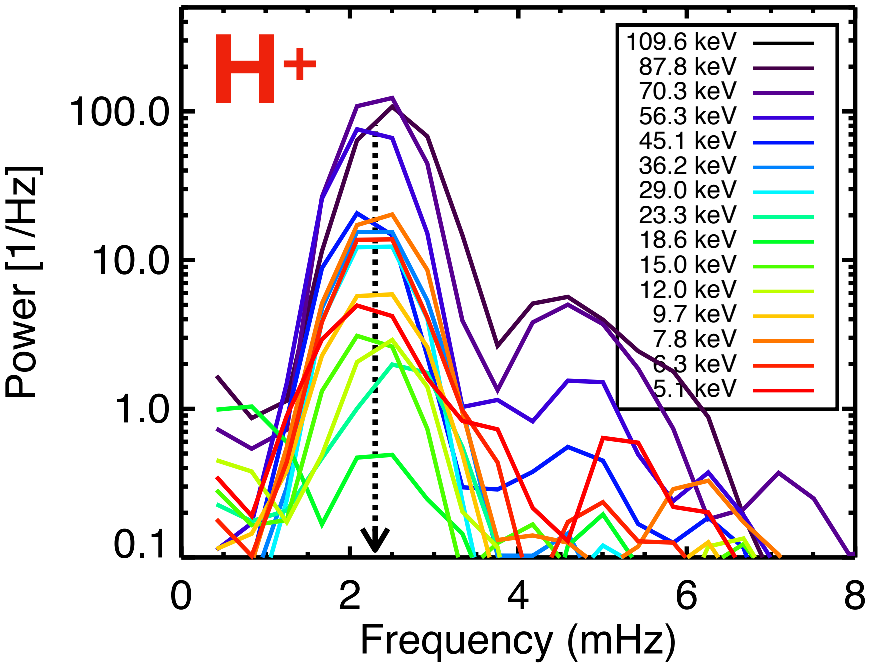
2017/03/27/1820-1920UT
H+
O+
e-
MEPi Flux H+ [keV]
MEPi Flux O+ [keV]
Energy [keV/q]
100
10
[/s-cm²-sr-keV]
Omni Flux
A r(RE) 3.85 4.10 4.32 4.53 4.72 4.90 5.06
A L 5.39 5.56 5.70 5.84 5.95 6.05 6.15
A MLT(hr) 1.54 1.79 2.00 2.19 2.36 2.52 2.66
A MLAT(°) -32.28 -30.83 -29.48 -28.21 -27.01 -25.88 -24.81
M r(RE) 4.16 4.53 4.89 5.24 5.57 5.90 6.21
M L 6.54 7.10 7.63 8.13 8.61 9.06 9.50
M MLT(hr) 2.37 2.65 2.88 3.08 3.25 3.40 3.53
M MLAT(°) -37.09 -36.99 -36.83 -36.64 -36.43 -36.23 -36.03
hhmm 1820 1830 1840 1850 1900 1910 1920
2017 Mar 27

# Residual fluxes

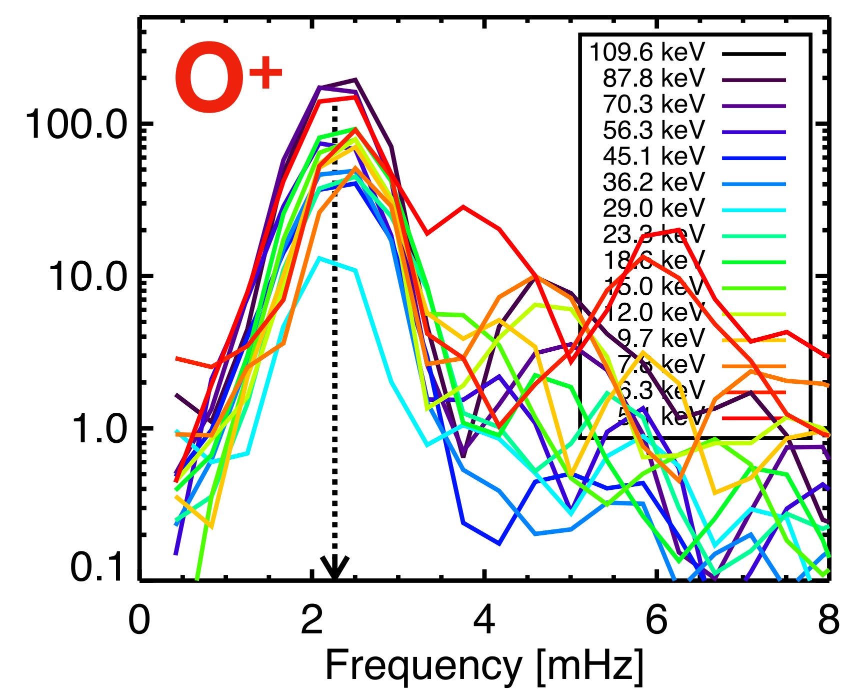



## Power spectra

MEP-i/$H^+$/1830-1910UT



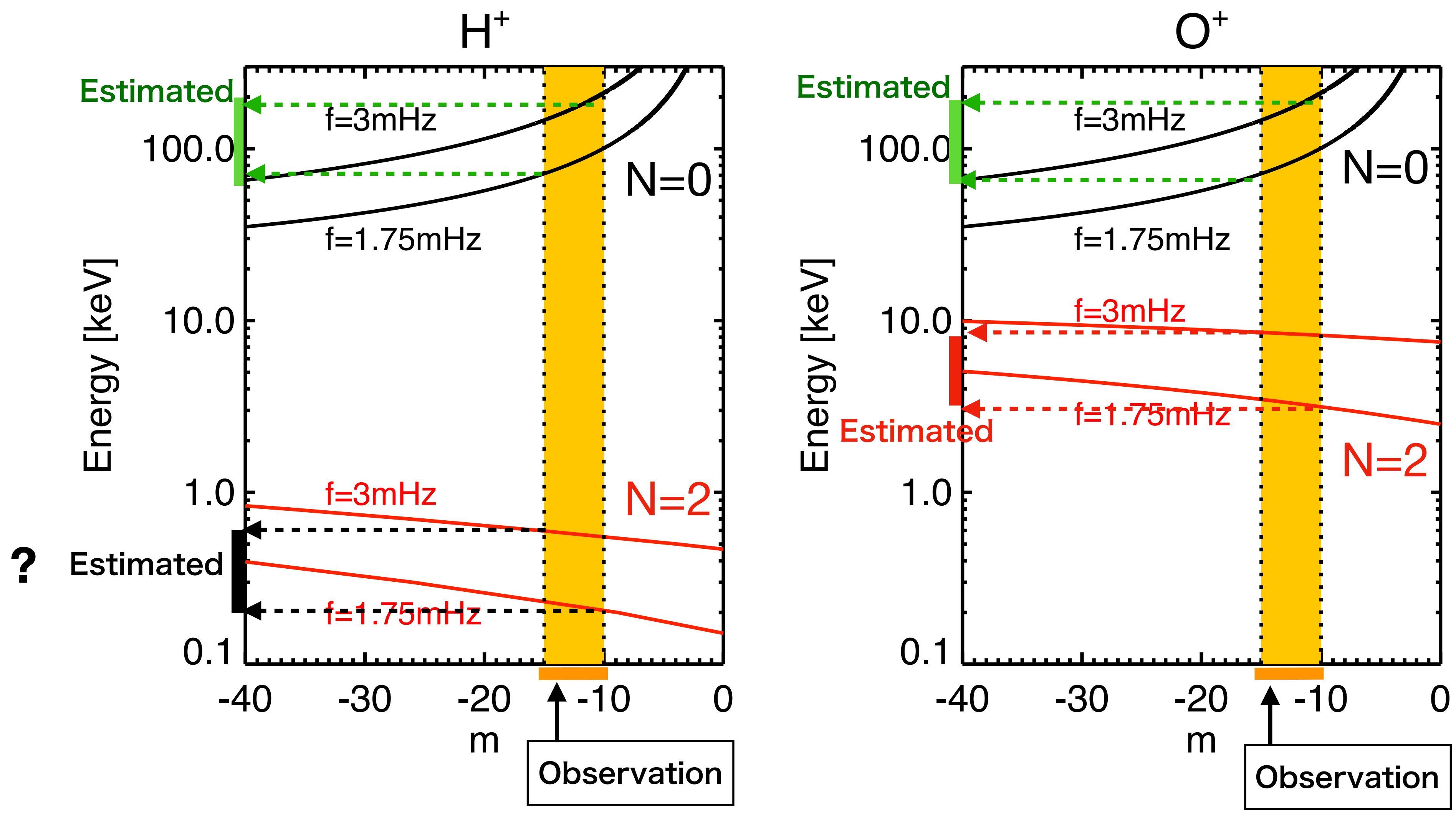

MEP-i/$O^+$/1830-1910UT




Residual flux : $\Delta J=(J-J_1)/J_1$
($J_1$: 10-min moving average)

- Large flux oscillations of $H^+$ fluxes at > 50 keV, and that of $O^+$ fluxes at > 50 keV and < 20 keV.
- $O^+/H^+$ flux ratio show the enhancements corresponding to the $O^+$ flux oscillations.

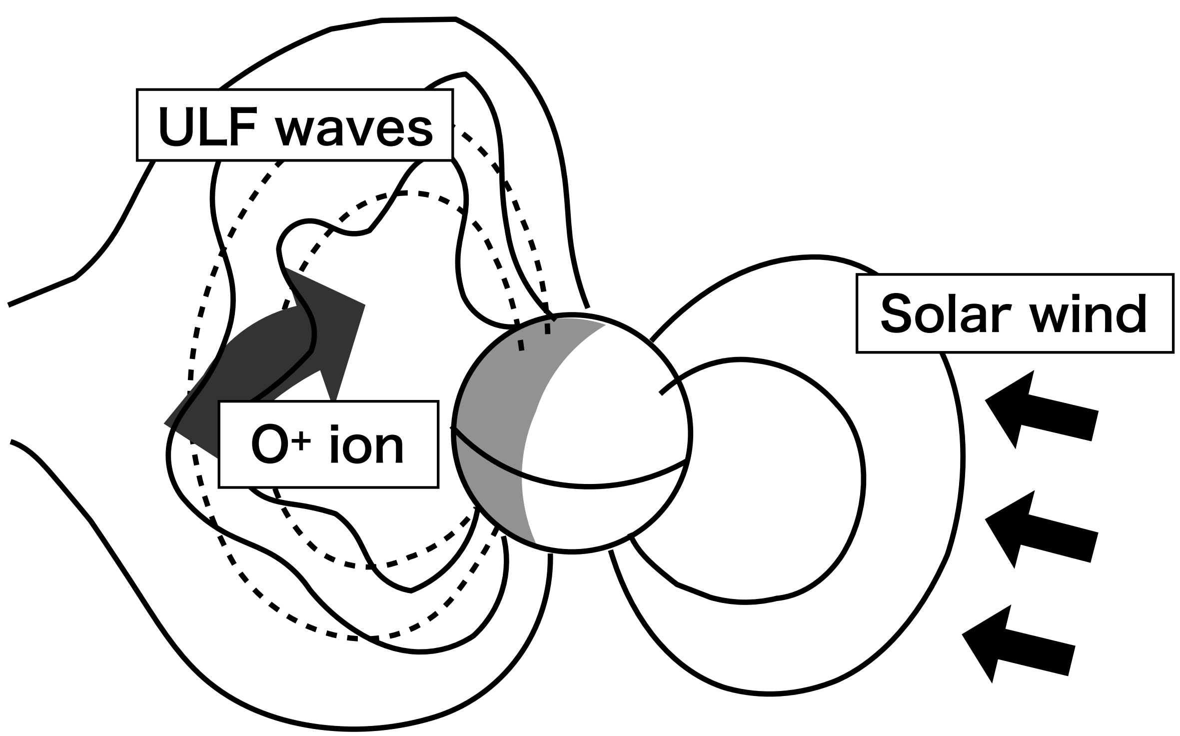
# Theoretical resonance energy in a dipole field




| | Resonance mode | Theoryetical resonance energy | Observational energy of large flux oscillations | Consistency (Theory vs observation) |
|---|---|---|---|---|
| $H^+$ | N=0 Drift resonance ($\omega \sim m\omega_d$) | ~70-200 keV | > 56 keV | ○ |
| | N=2 Bounce resonance ($\omega \sim 2\omega_b$) | 0.2-0.6 keV | Out of energy range of MEP-i | ? |
| $O^+$ | N=0 Drift resonance ($\omega \sim m\omega_d$) | ~70-200 keV | > 56 keV | ○ |
| | N=2 Bounce resonance ($\omega \sim 2\omega_b$) | ~3-9 keV | ~5–18 keV | ○ |

# Discussion on the flux oscillations

- Flux oscillations of $H^+$ and $O^+$ ions at > 50 keV are caused by drift resonance and those of $O^+$ ions at < 20 keV are caused by bounce resonance.
- We simultaneously found the drift resonance and bounce resonance of $O^+$ ions at multiple energies in the nightside inner magnetosphere.
- The enhancement of $O^+/H^+$ flux ratio at low-energy band (≤ 23.3 keV) is mainly caused by selective acceleration of $O^+$ ions due to the bounce resonance for $O^+$ ions (≤ 18.6 keV)
- Mitani et al. (2018) proposed that the drift-bounce resonance contribute to the deeper penetration of > 200 keV $O^+$ ions into the inner magnetosphere.
- The solar wind may generate the Pc5 wave through K-H instability and it feeds energy to the $O^+$ ions through the bounce resonance.

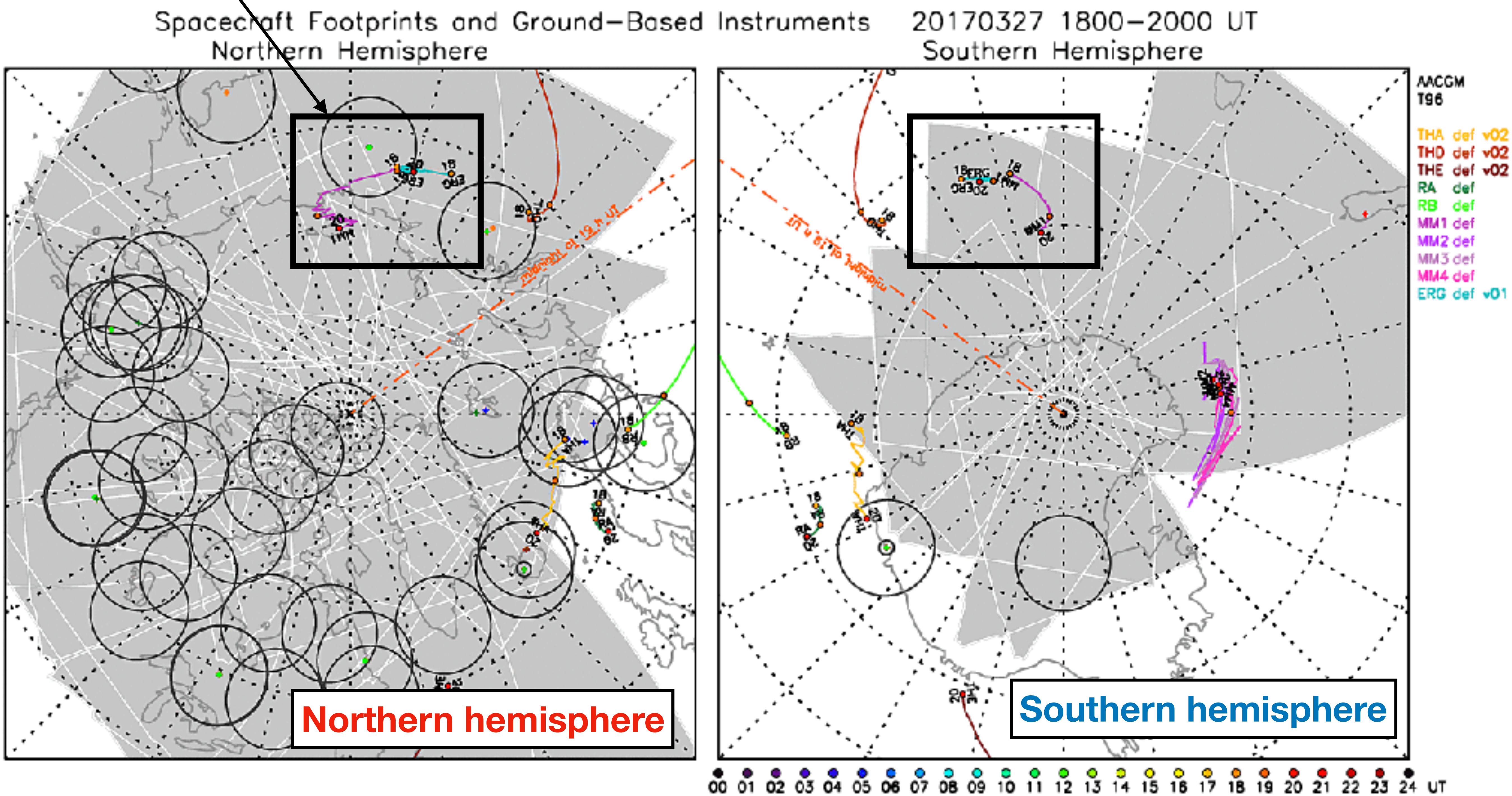



Energy transfer

**Solar wind →ULF waves →Resonance→$O^+$ ions ?**

# Conjunction of SuperDARN data

**Footprint is in Russia**




https://ergsc.isee.nagoya-u.ac.jp/data/ergsc/cef/orbit/

**Can I use any SuperDARN data?**

# Summary

- Fundamental Pc5 wave and a Pc4 wave were observed by Arase, MMS1, and ground stations (TIK and PBK) in the postmidnight region in the storm recovery phase on 27 March 2017.
- The Pc5 waves is considered to be excited by solar wind.
- m-number of the Pc5 wave is estimated by satellite observation and ground observation to be m=-10 to -15.
- The $e^-$ flux oscillation is not caused by the drift-bounce resonance, while, large ion flux oscillations are attributed to the drift resonance for $H^+$ and $O^+$ ion (> 50 keV), and to the bounce resonance for $O^+$ ion (< 20 keV).
- $O^+/H^+$ flux ratio shows enhancements corresponding to the $O^+$ ion flux oscillations, which suggest the selective acceleration of $O^+$ ions.