# Properties and Generation of Oblique Whistler-Mode Chorus Waves

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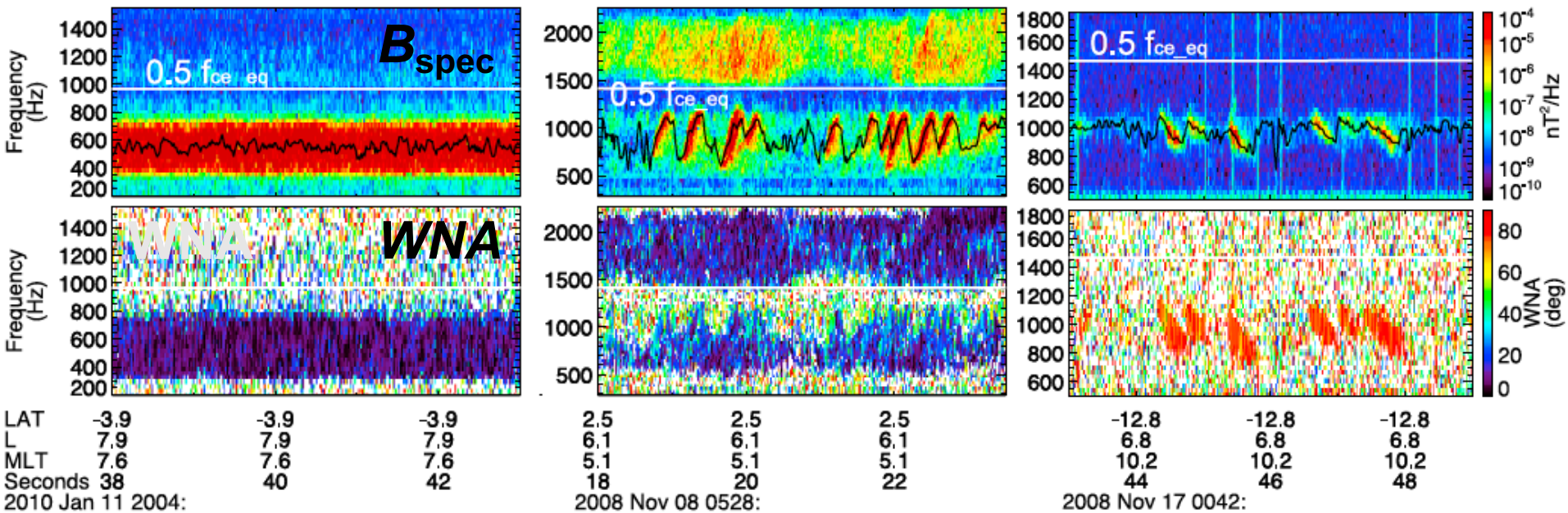
# Motivation

- The rate of electron scattering caused by chorus is dependent on various parameters
  - wave intensity
  - wave normal direction
  - wave frequency spectrum

- Improve our understanding of
  - chorus wave generation and propagation
  - chorus quantitative scattering effects on energetic electrons

# Chorus wave normal distribution

- Typically quasi field-aligned [e.g., *Bolton and Holzer,* 1974; *Goldstein and Tsurutani,* 1984; *Santolik et al.,* 2014]
- In some cases very oblique [*Cattell et al.,* 2008; *Santolik et al.,* 2009; *Li et al.,* 2011, 2013; *Agapitov et al.,* 2013; *Taubenschuss et al.,* 2014]




**What is the chorus wave normal distribution in different regions under various geomagnetic activities?**

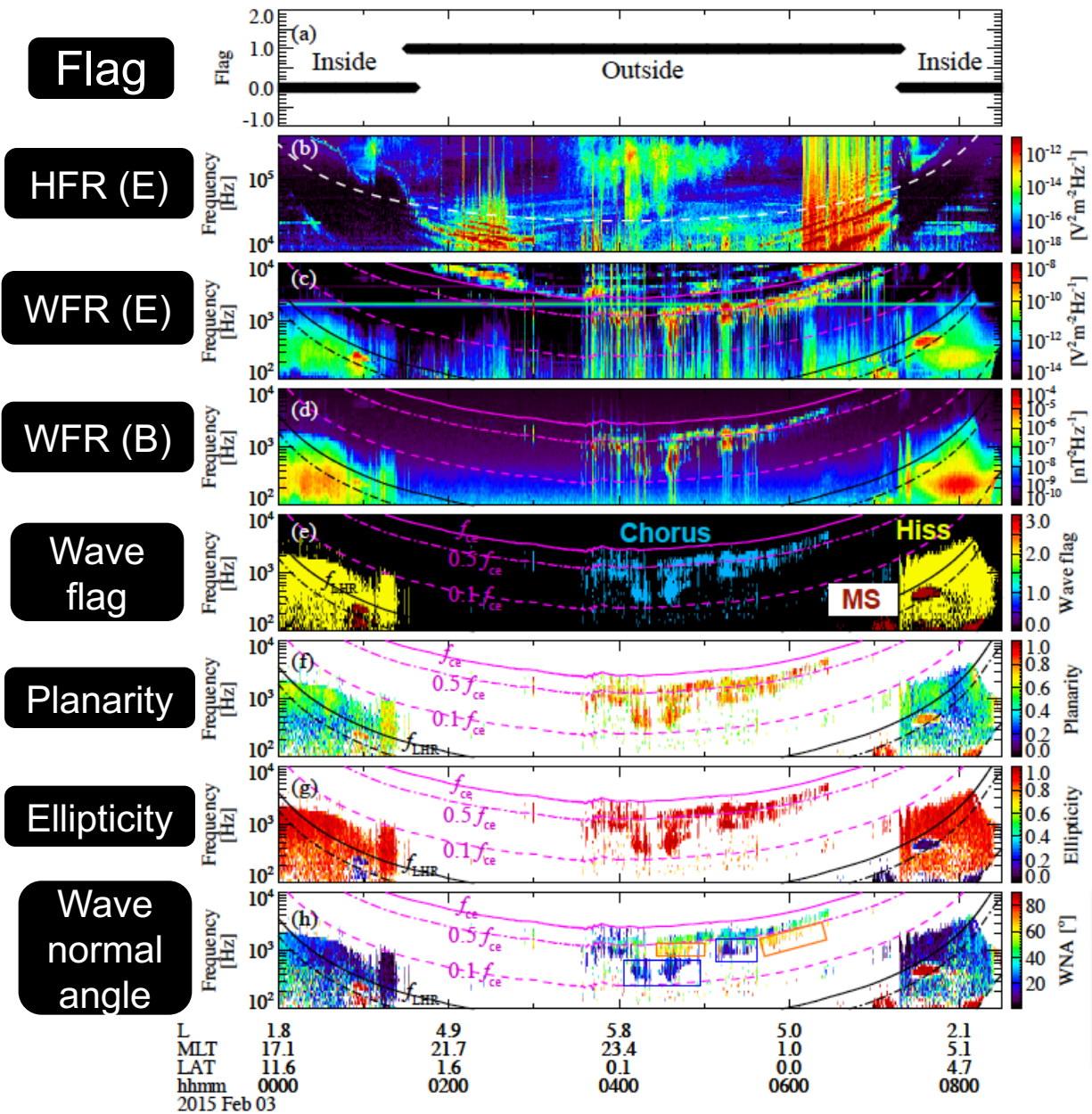
# Objective

- Evaluate chorus wave normal directions near wave source region (|MLAT| < 10º)
- Understand the generation mechanism of oblique chorus

# Methodology

- Statistically analyze chorus polarization properties obtained from Van Allen Probes EMFISIS wave data over >3 years (2012/10/01–2015/12/01)
- Perform linear wave instability analysis for oblique chorus events using simultaneous electron and wave data from Van Allen Probes

# Overview of EMFISIS wave observations



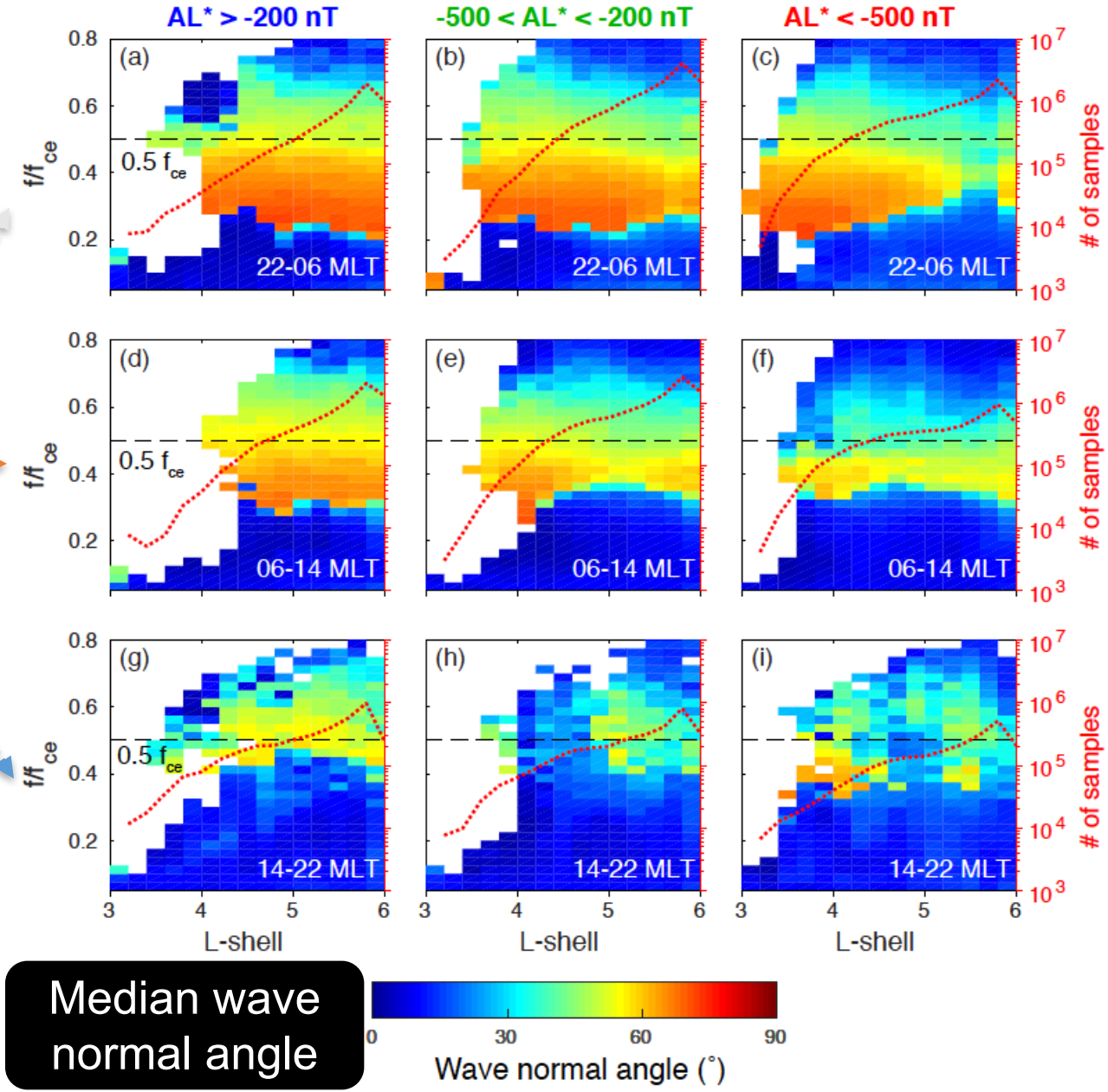

**Identification of chorus:**

- Outside plasmapause $N_e < 124 \times (3/L)^4$
- 0.05–1 $f_{ce}$
- Planarity > 0.6
- Ellipticity > 0.7

Wave polarization properties are obtained from the SVD method [*Santolik et al.*, 2003]

LB chorus is either quasi-parallel or very oblique, whereas UB has intermediate WNAs.

# Statistical results of chorus wave normal angles

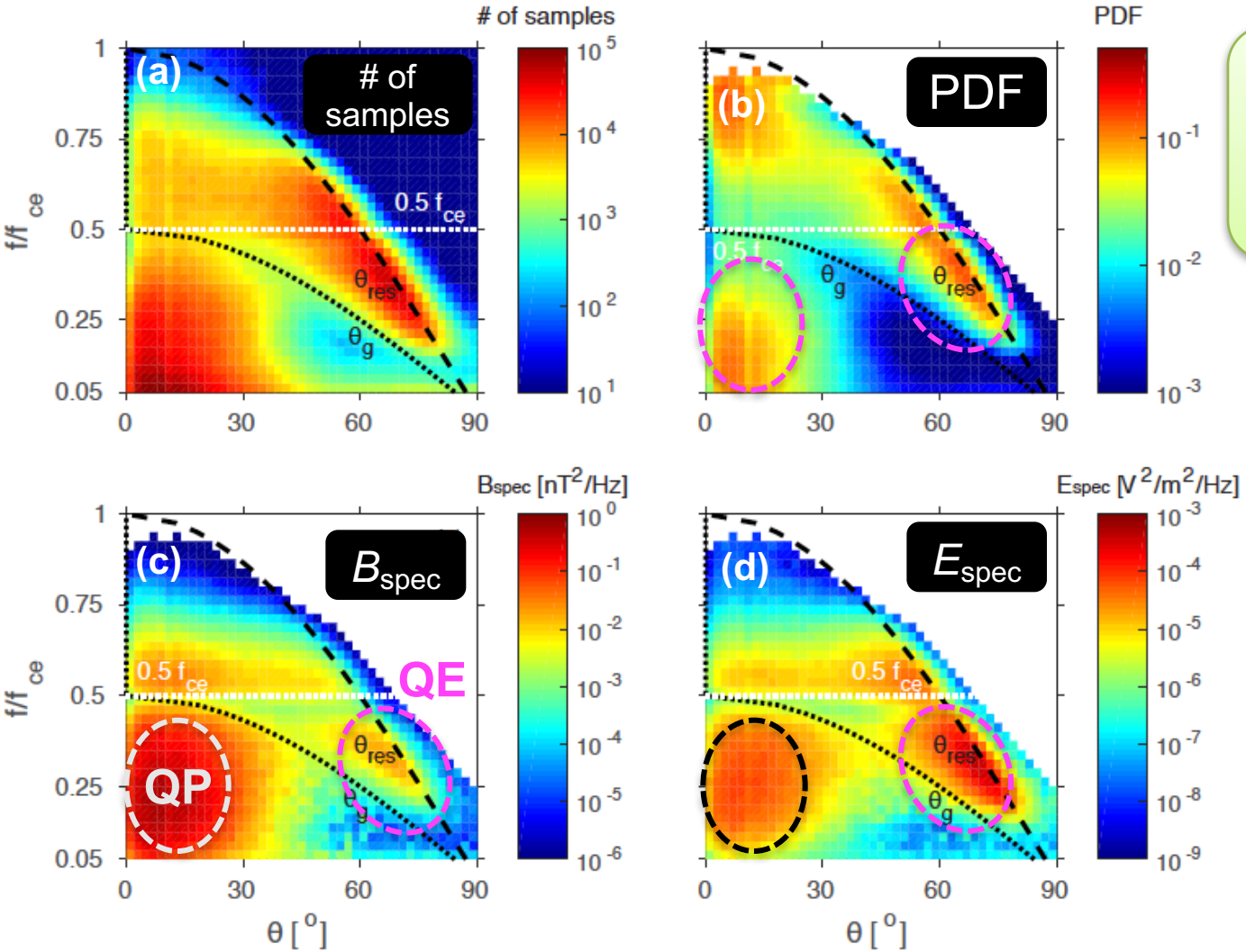



**AL***: minimum AL in preceding three hours

2012/10/01–2015/12/01
3–6 $R_E$, in all MLT sectors
7.3 x $10^8$ wave samples

- A separation frequency exists for LB at 0.2–0.4 $f_{ce}$.
- LB tends to be more quasi-parallel at stronger activity and higher *L*-shell on the nightside and dayside.
- Duskside LB is more quasi-parallel.
- UB wave normal angles have modest values.

# Chorus properties as functions of $\theta$ and $f/f_{ce}$




**PDF**: normalized wave normal distribution in each frequency bin.

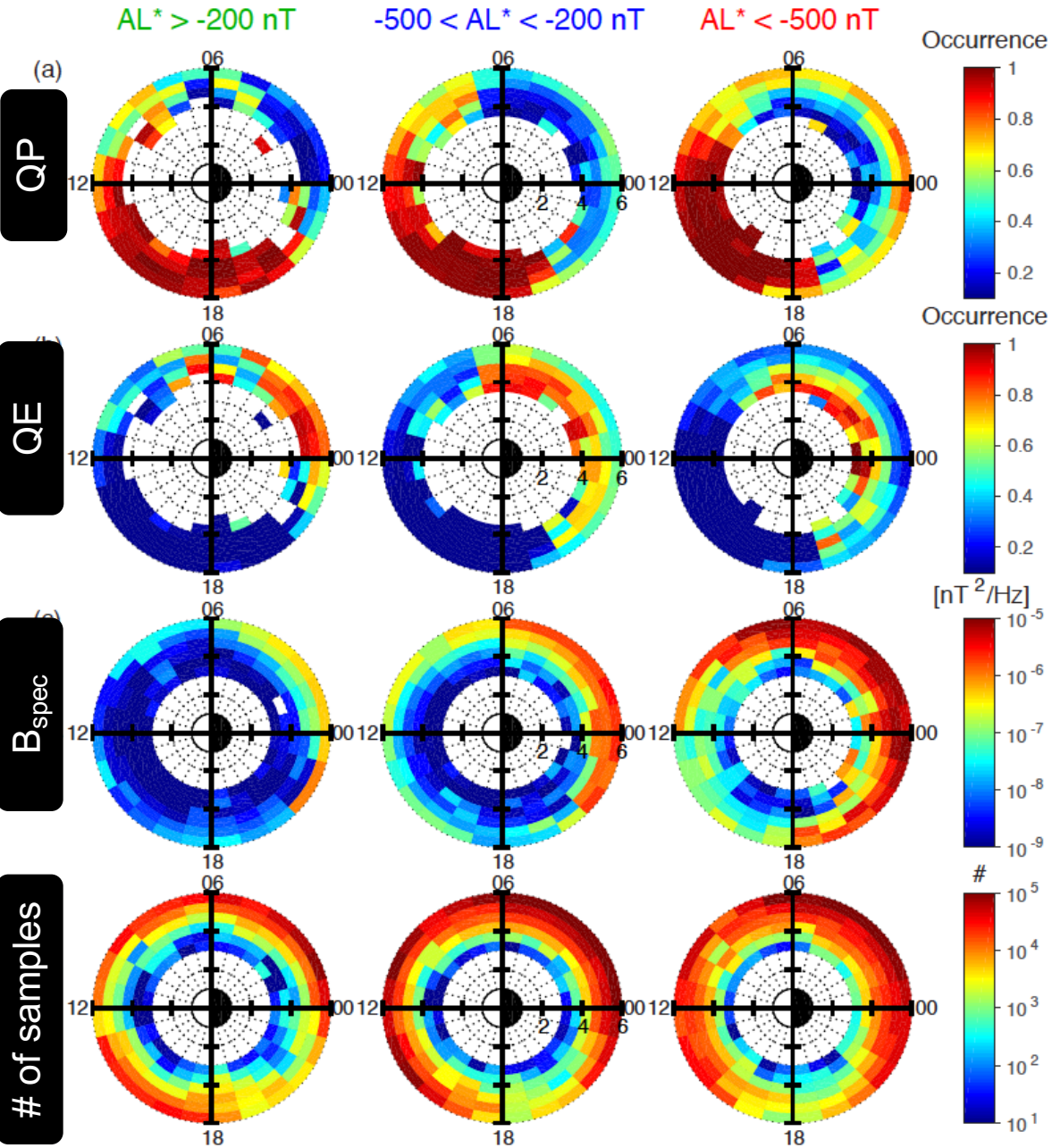
**Lower-band** has two distinctive modes:

- Quasi-parallel
- Quasi-electrostatic

Quasi-parallel mode has strong wave power in both *B* and *E*, while the oblique mode has strong *E* but weaker *B*.

**Upper-band** exhibits a smooth profile peaking near the resonance cone.

[*Li, W. et al., GRL*, 2016a]

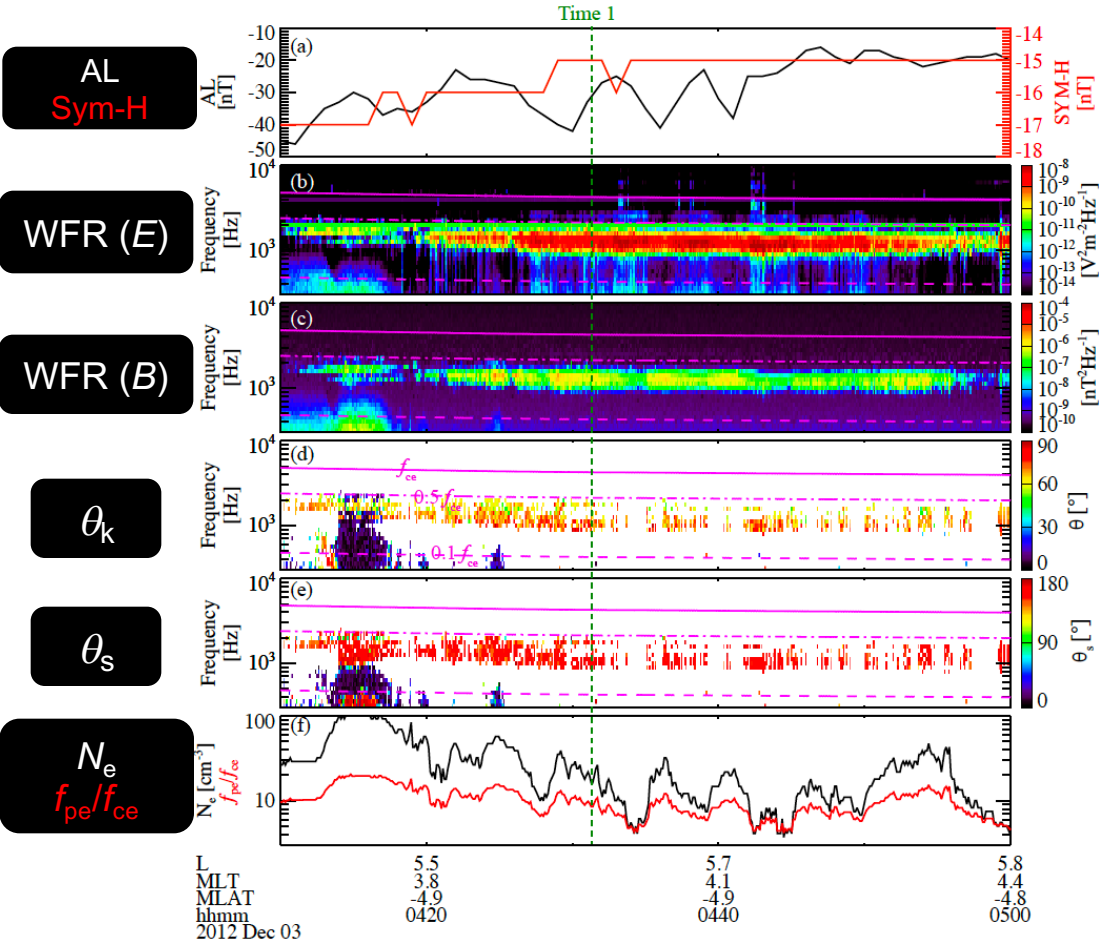



# Relative occurrence of quasi-parallel (QP) and quasi-electrostatic (QE) modes

- QP ($\theta$ < 30º); QE ($\theta$ > 40º)
- During quiet times, QE is dominant from midnight to dawn.
- As activity increases, QP becomes dominant especially at higher *L*-shell.
- QP appears to be dominant from prenoon to dusk, but its wave intensity is weak.

[*Li, W. et al., GRL*, 2016a]

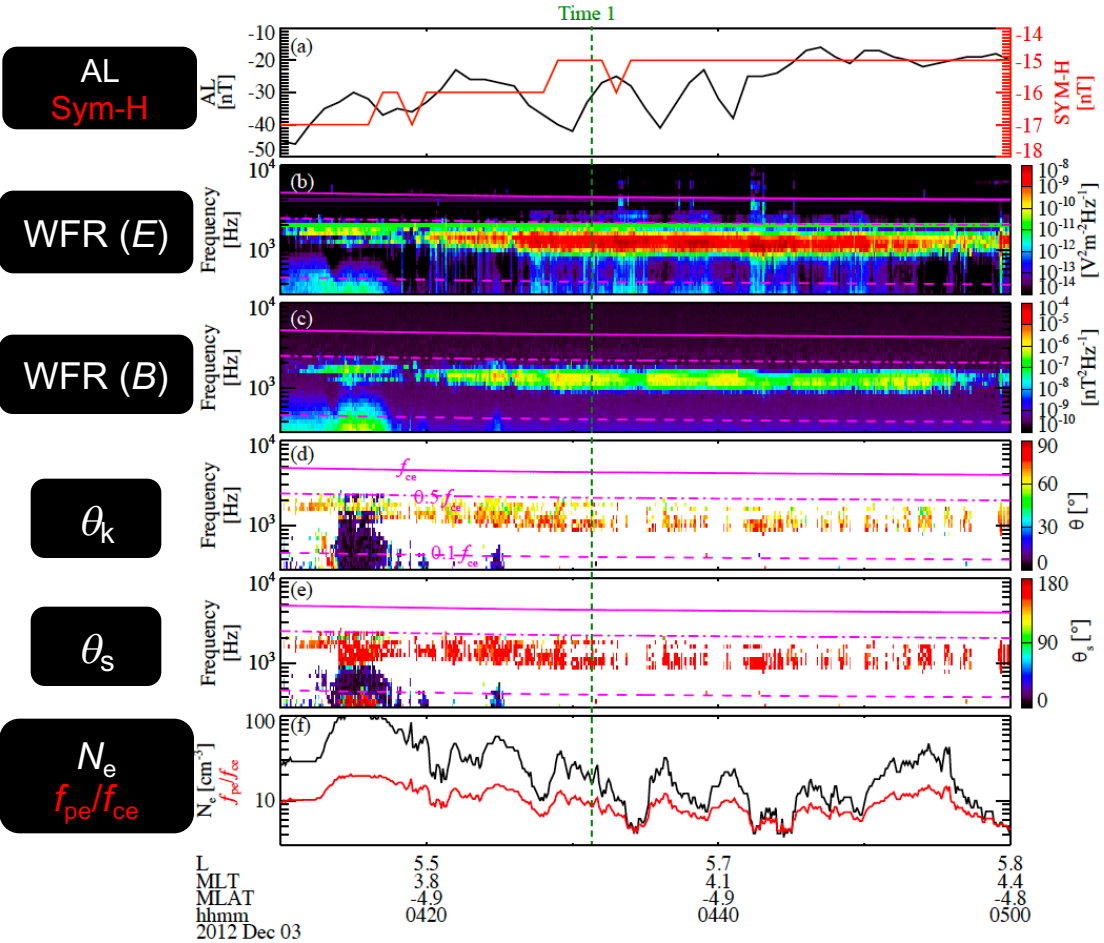
# Generation of oblique chorus: Event 1



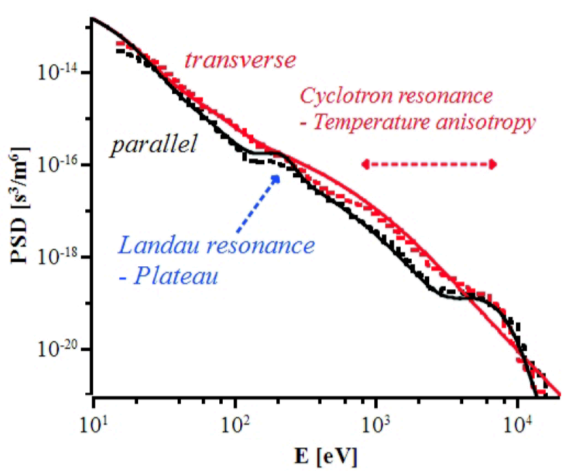

- Geomagnetic activity remained very quiet.
- Intense LB was observed at ~4 MLT, MLAT ~ -5º
- $\theta_s$ ~ 180º, generated near the equator
- $\theta_k$: 60º–80º

[*Li, W. et al., GRL*, 2016b]

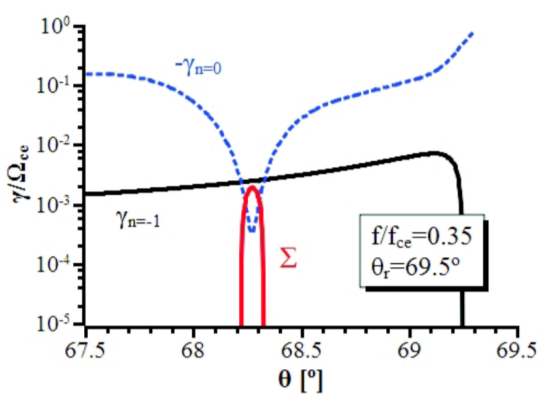
# Generation of oblique chorus: Event 1

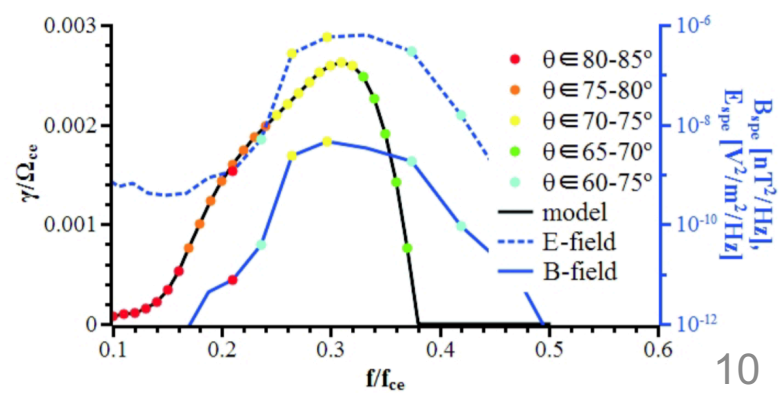



- Electron PSD was fitted using a sum of 4–6 Maxwellian and power-law distributions
- A small beam-like component at 100–300 eV
- Calculate wave linear growth rates using *Kennel*, [1966]
  - Cyclotron growth: $\gamma_{n=-1}$
  - Landau damping: $-\gamma_{n=0}$
  - $\Sigma = \gamma_{n=-1} - \gamma_{n=0}$
- Calculated wave growth rate agrees well with observed wave frequency spectra.

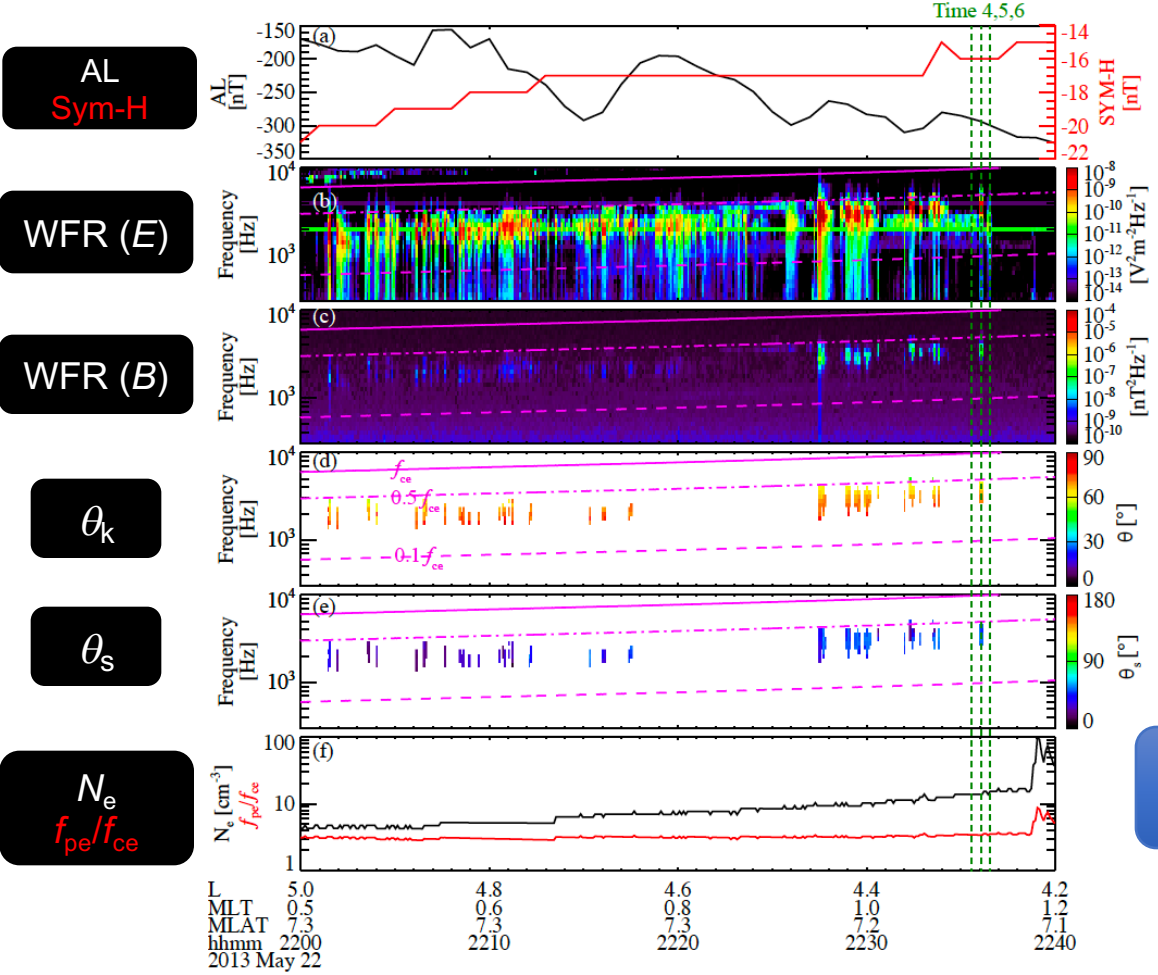



Time 1: 2012.12.03 04:31:18 UT



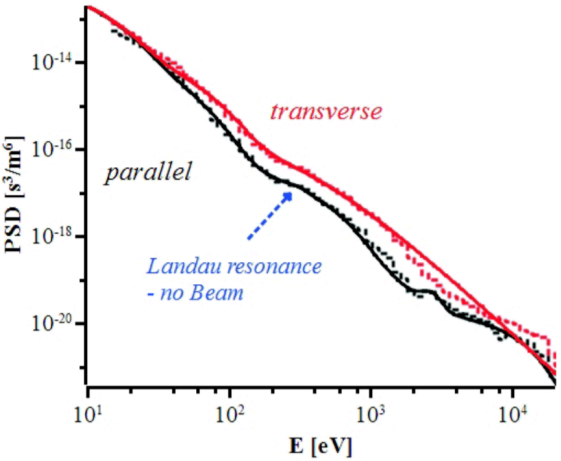
# Generation of oblique chorus: Event 2

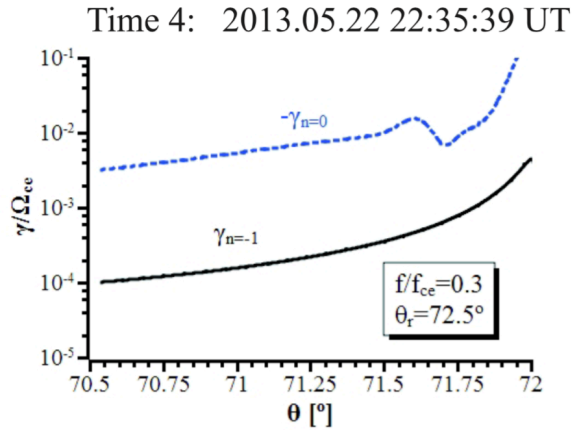


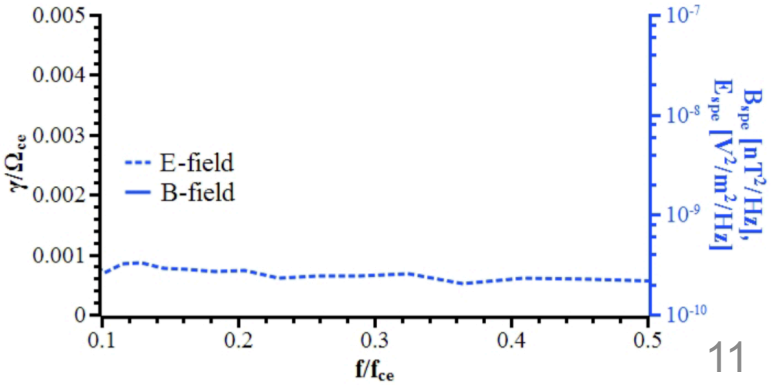

- Isolated bursts of oblique chorus
- Over successive 48 sec
  - Time 4: Chorus "off"
  - Time 5: Chorus "on"
  - Time 6: Chorus "off"

**Time 4**: No beam or plateau

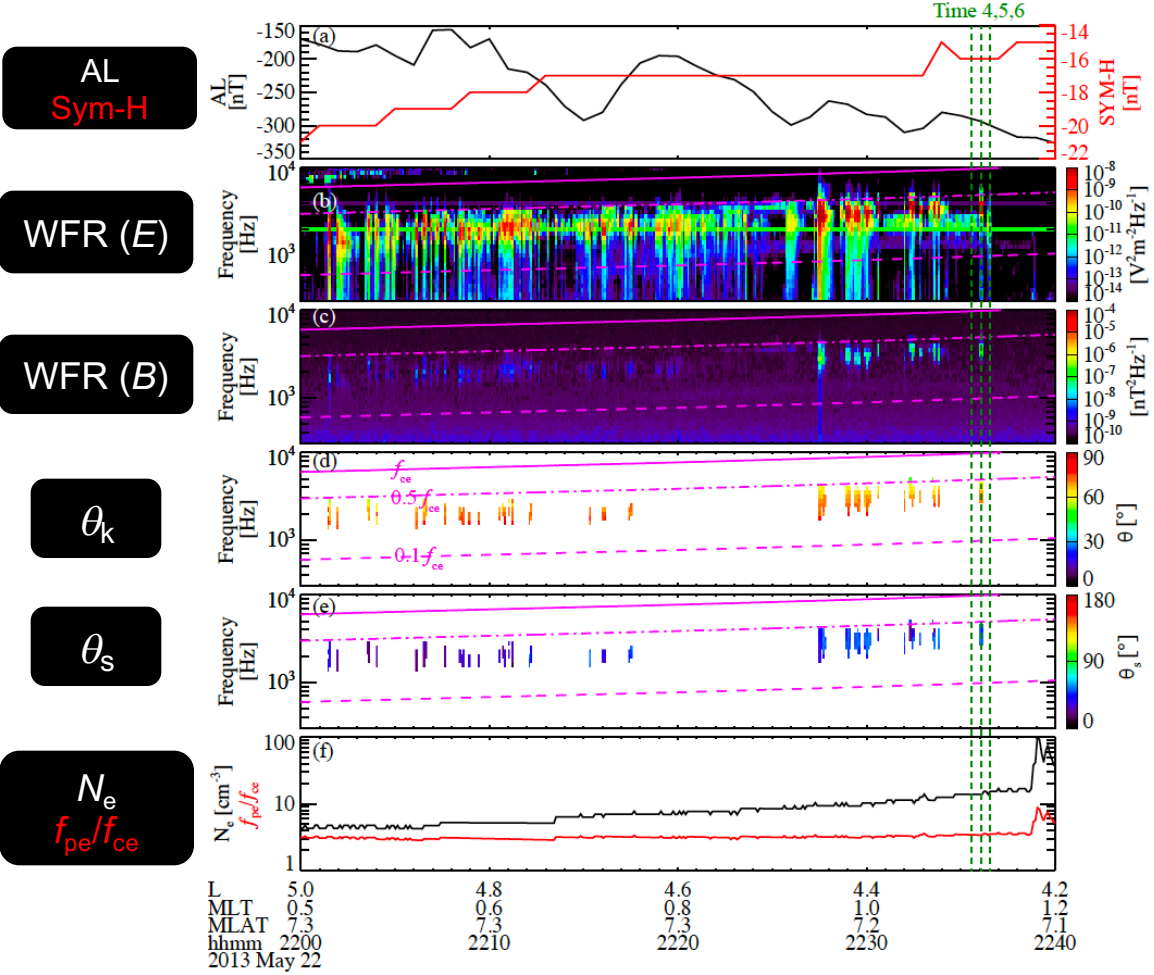
[*Li, W. et al., GRL*, 2016b]



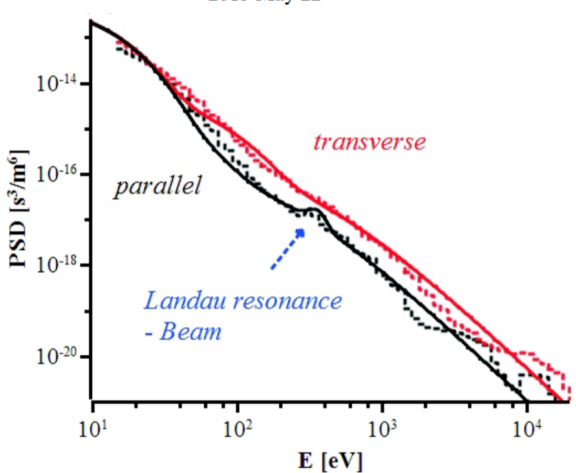
# Generation of oblique chorus: Event 2

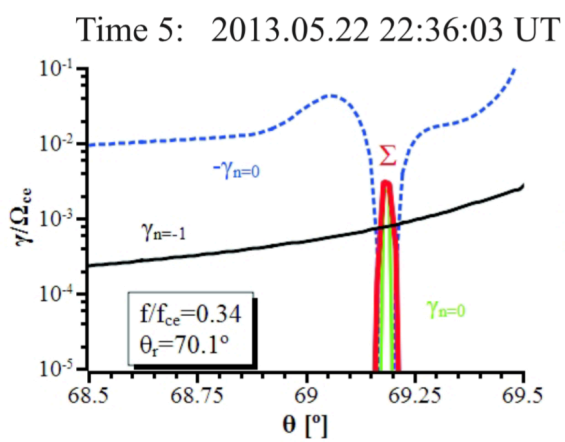


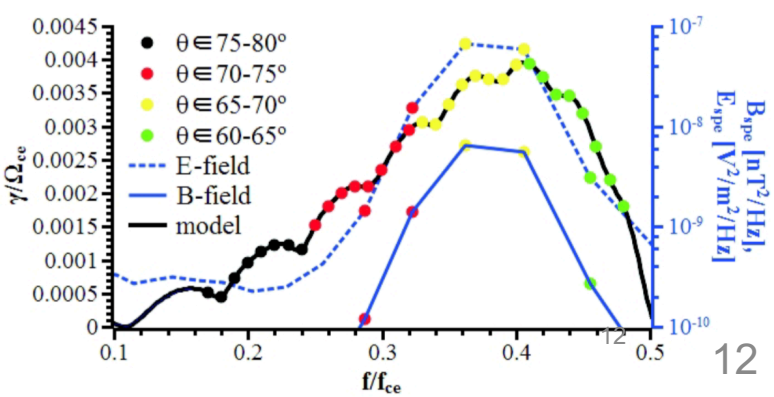

- Isolated bursts of oblique chorus
- Over successive 48 sec
  - Time 4: Chorus "off"
  - Time 5: Chorus "on"
  - Time 6: Chorus "off"

**Time 5**: clear beam feature

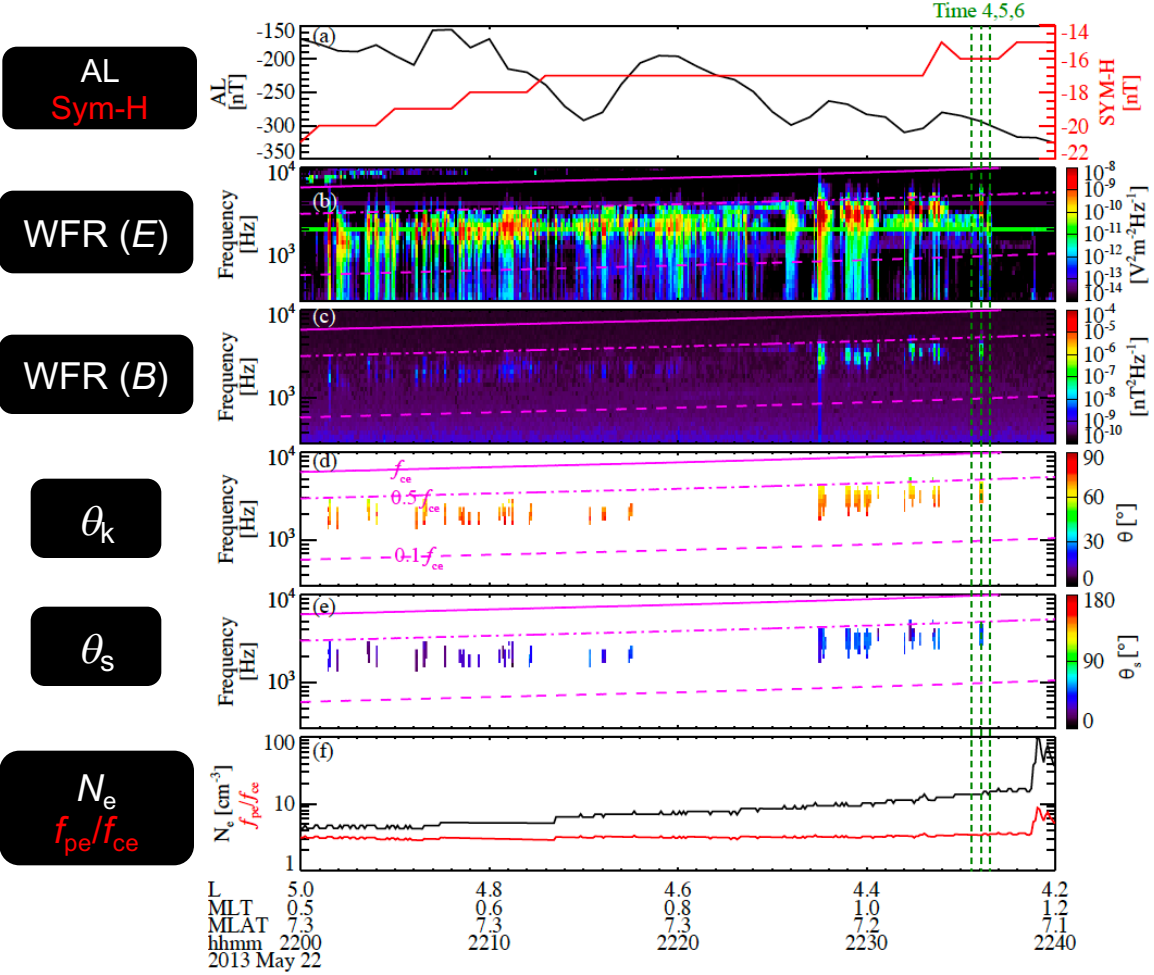
[*Li, W. et al., GRL*, 2016b]



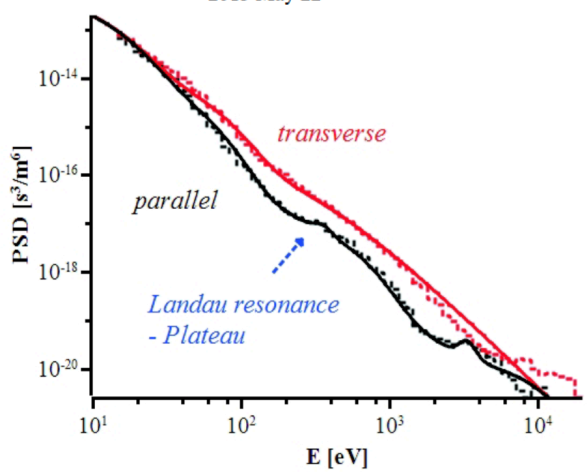
# Generation of oblique chorus: Event 2

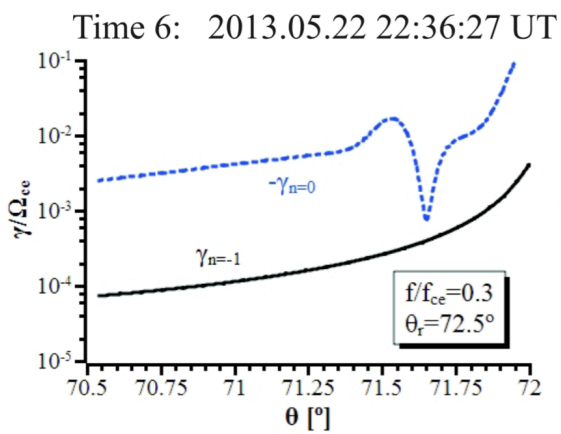


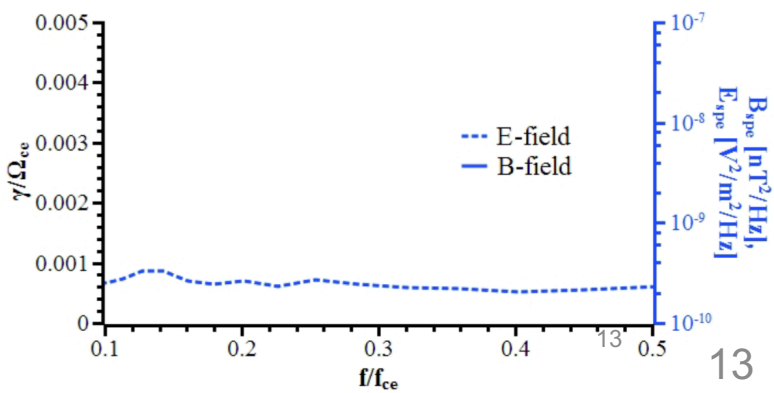

- Isolated bursts of oblique chorus
- Over successive 48 sec
  - Time 4: Chorus "off"
  - Time 5: Chorus "on"
  - Time 6: Chorus "off"

**Time 6**: tiny plateau

[*Li, W. et al., GRL*, 2016b]



# Summary

- **Wave normal distribution of chorus**
  - Our statistical results clearly demonstrate the two distinctive modes (QP and QE) for lower-band chorus.
  - Relative dominance of QP and QE mode depends on *L*-shell, MLT, geomagnetic activity, and wave frequency.
- **Generation of oblique LB chorus**
  - A small beam-like feature over 100–300 eV is a crucial component for the excitation of highly oblique LB chorus through reduced Landau damping or Landau growth.


**References**

- Li, W., O. Santolik, J. Bortnik, R. M. Thorne, C. A. Kletzing, W. S. Kurth, and G. B. Hospodarsky (2016a), New chorus wave properties near the equator from Van Allen Probes wave observations, *Geophys. Res. Lett., 43*, 4725–4735, doi:10.1002/2016GL068780.
- Li, W. et al. (2016b), Unraveling the generation mechanism of very oblique lower-band chorus waves, *Geophys. Res. Lett., 43*, 8867–8875, doi:10.1002/2016GL070386.