Properties and Generation of Oblique Whistler-Mode Chorus Waves

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.

Median wave normal angle
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 ($\theta < 30^\circ$); QE ($\theta > 40^\circ$)
- 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
- $\theta_s \sim 180^\circ$, 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.
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"

[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”
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Time 5: clear beam feature

[Li, W. et al., GRL, 2016b]
Generation of oblique chorus: Event 2

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[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