Orientation of Whistler-Mode Chorus Wave Vectors and the Implications for the Chorus-to-Hiss Mechanism

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EMFISIS Observations

Identify Lower Band Chorus Waves:

$0.075\ f_{ce} < f < 0.50\ f_{ce}$

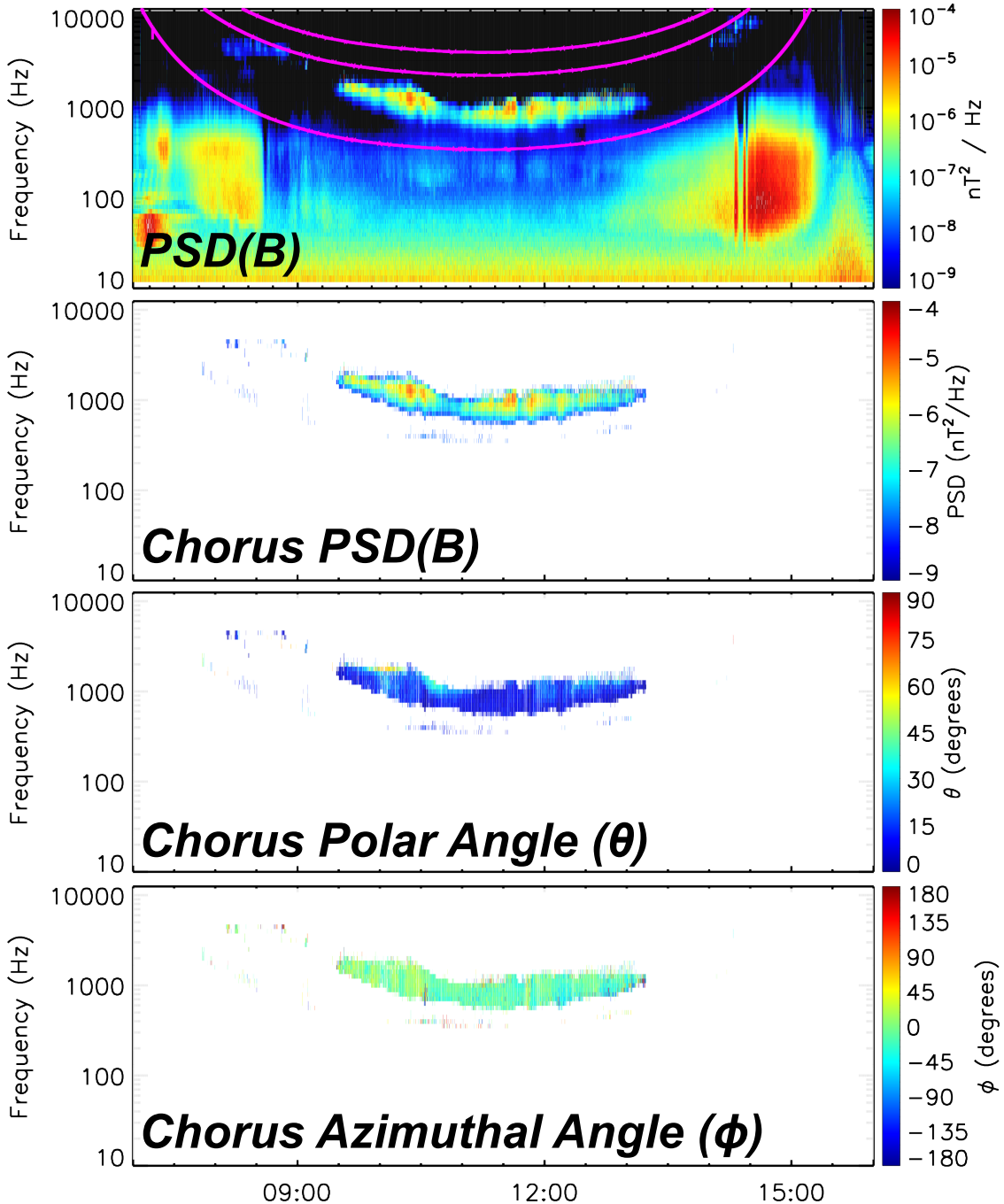
Density less than the minimum of: $10 \times (6.6/L)^4$ or $30\ cm^{-3}$ (whichever is smaller)

PSD(B) > $10^{-7} nT^2/Hz$

Ellipticity > 0.5

Polarization > 0.5

Planarity > 0.6



10th December 2013

Lower Band Chorus WNA Statistics

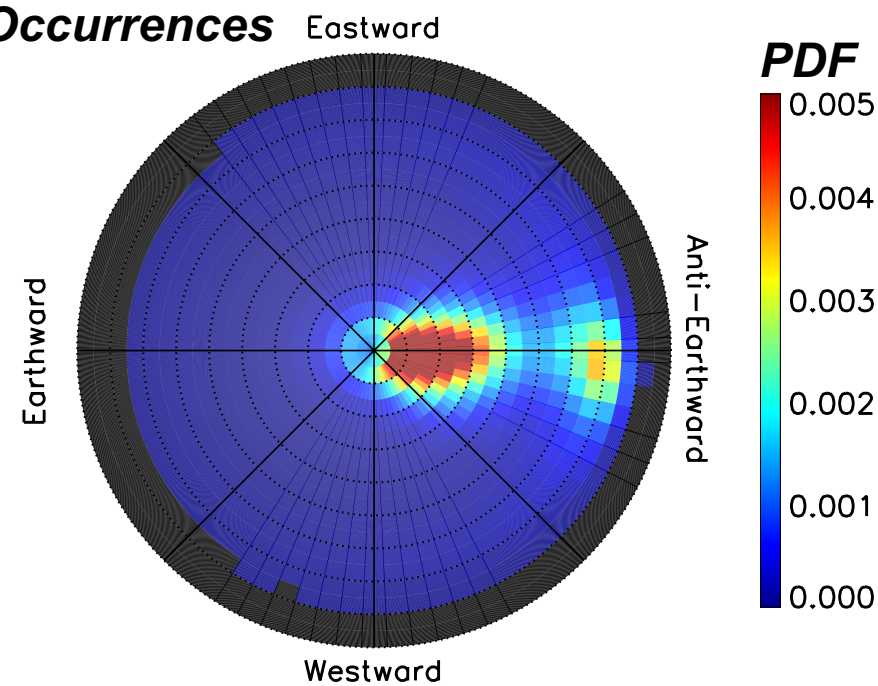
Statistics of Occurrences and Power

Most waves are near field-aligned ($\theta < 30°$)

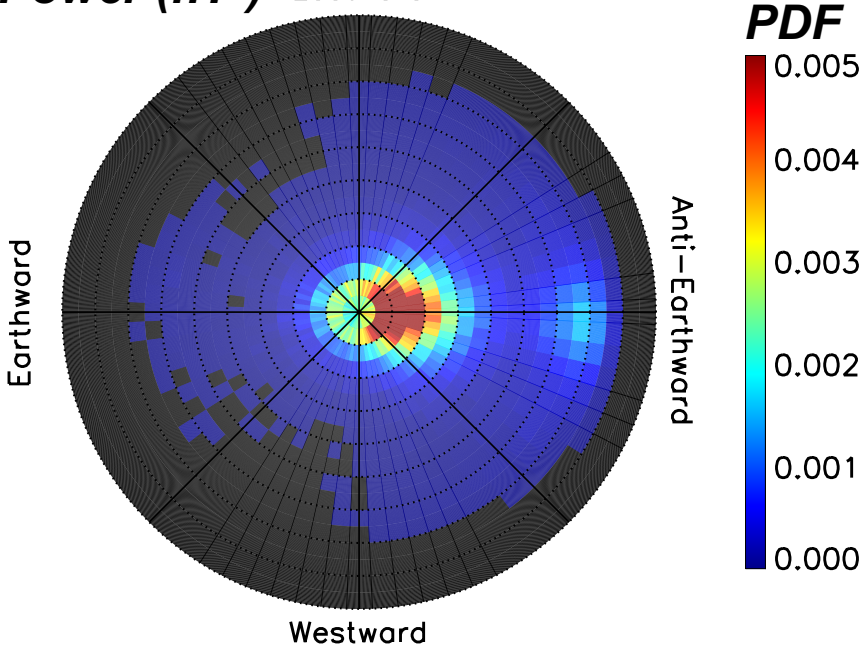
Small population of oblique waves ($\theta > 50°$)

Almost all wave vectors are oriented in the anti-Earthward direction ($-30° < \phi < 30°$)

Occurrences



Power (nT^2)



Most wave power is contained in the approximately field-aligned population

More oblique waves are substantially less intense

Most wave power is in the anti-Earthward direction, very little oriented Earthwards

Why is this important for the chorus-to-hiss mechanism?

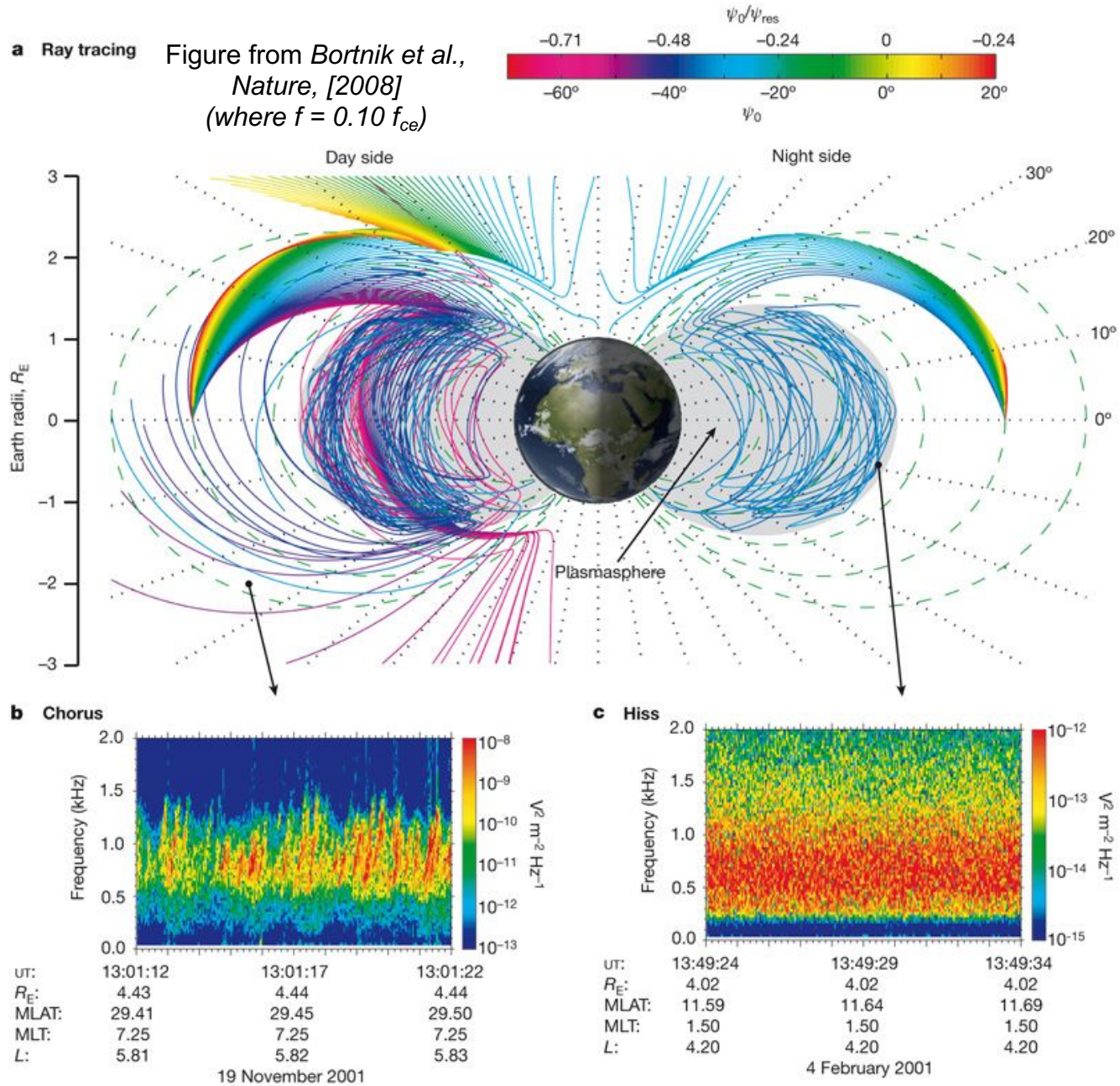
The Chorus-to-Hiss Mechanism

Ray tracing simulations have shown that chorus waves can propagate into the plasmasphere and evolve into hiss

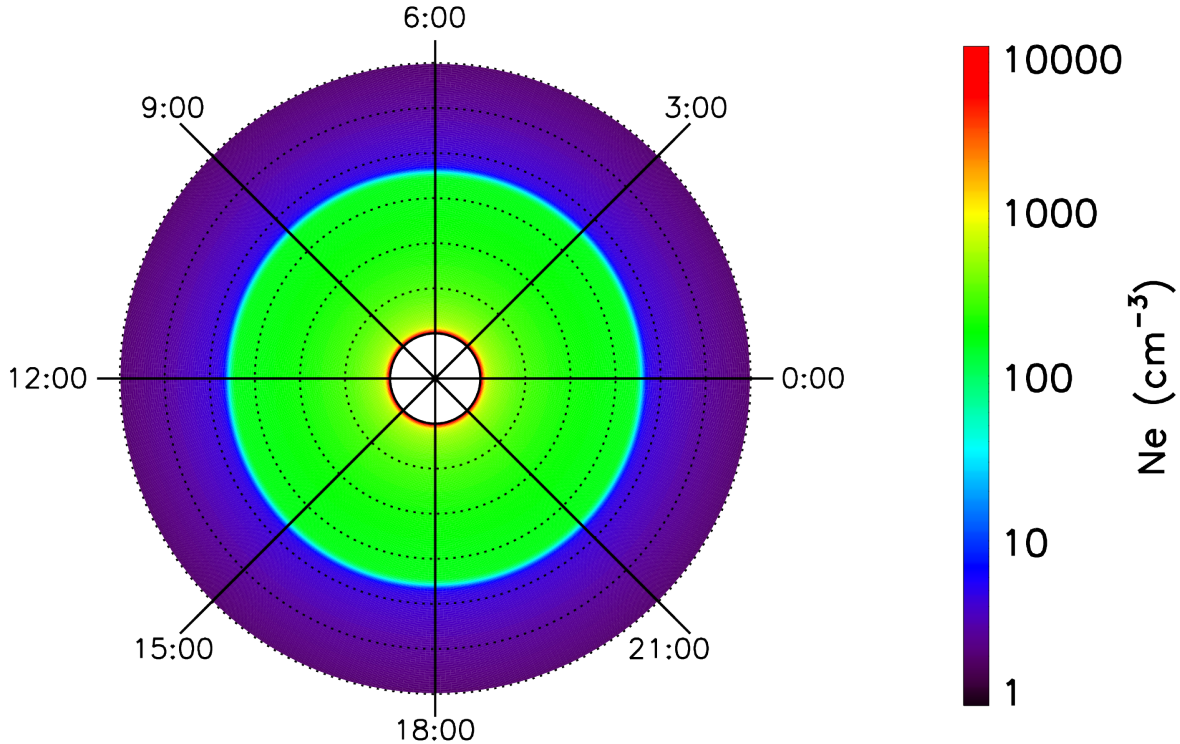
However, this only occurs for specific initial WNA (~ *-60°* to *-40°*), source locations (within ~ *3* R_E of p/pause), and wave frequencies (~ *0.05 to 0.25* f_{ce})

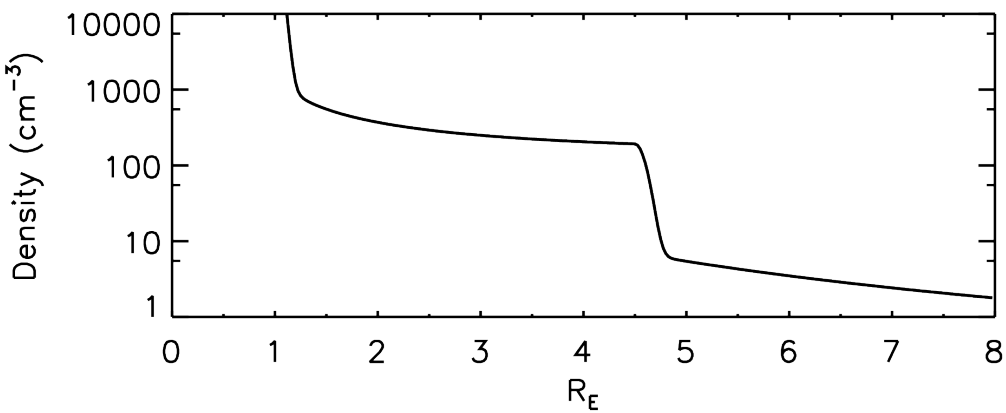
How often do we observe chorus with these required conditions?

Figure from *Bortnik et al., Nature, [2008]* *(where f = 0.10* f_{ce}*)*



Ray Tracing in Azimuthally Symmetric Diffusive Equilibrium Density Model





Diffusive equilibrium density model with p/pause at 4.5

Cold plasma ray tracing, damping rate not calculated

Ray trace full range of WNA for 2 seconds from:

L = 5.0, 6.0

MagLat = 0°, 10°, 20°,

f/f_{ce} = 0.10, 0.15, 0.20

Determine which ϕ and θ values result in rays gaining access to p/sphere and compare with observations

Since density model is azimuthally symmetric, data are not sorted by MLT sector

Azimuthally Symmetric Density Model

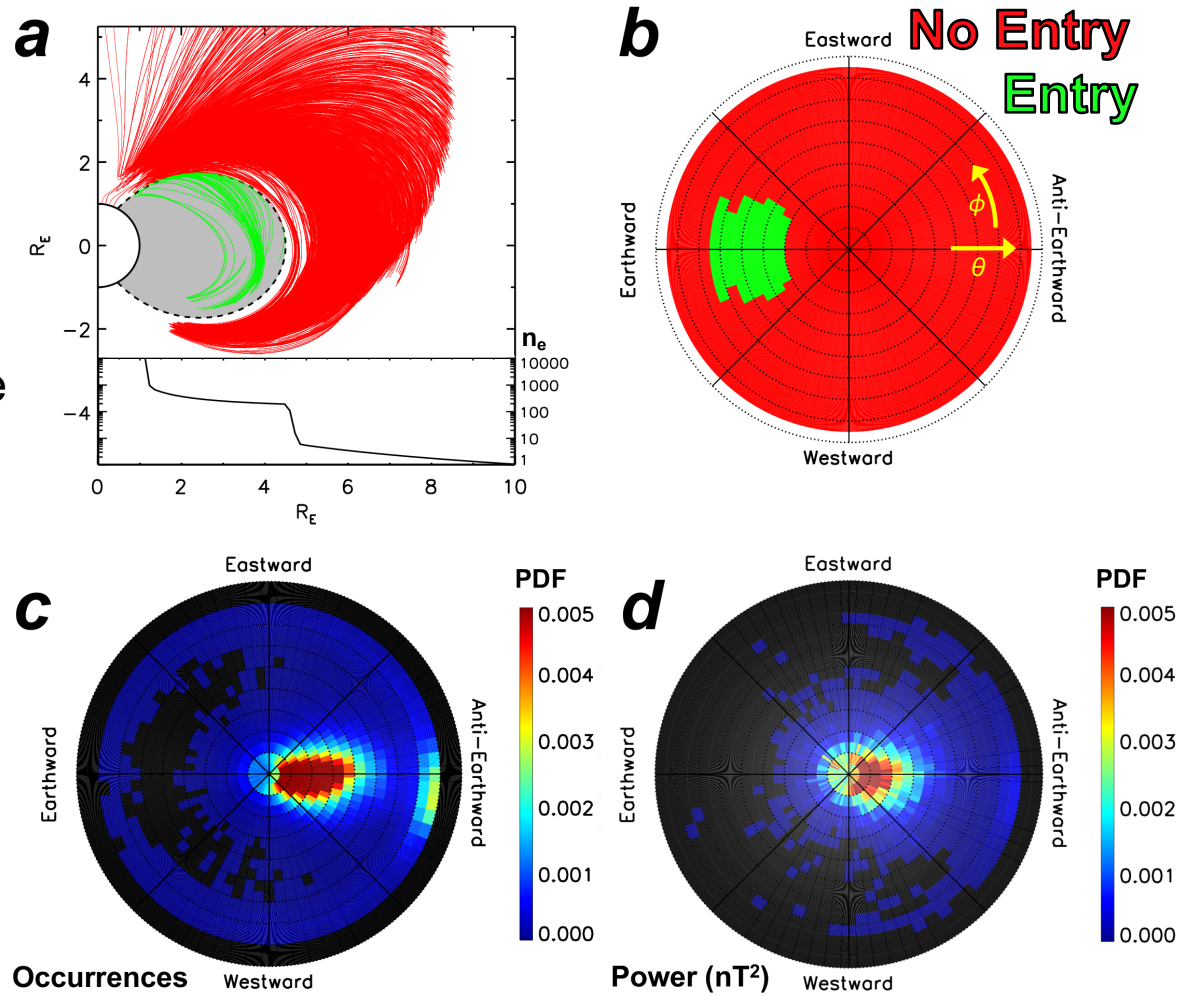
Initial Conditions: f/f_{ce} = 0.20, MagLat = 0°, 10°, 20°, L = 6

Ray tracing provides WNA that can access p/sphere (green)

WNA is shown in green if ray enters p/sphere from any source latitude (*0°, 10°,* or *20°*)

Calculate occurrences, and wave power, that exist with these crucial WNA values

In this case, only:
0.12% of occurrences
0.094% of wave power
exist with the conditions required to access p/sphere



Only very small fraction of chorus can enter p/sphere!
What about other source locations and wave frequencies?

Azimuthally Symmetric Density Model

Repeat analysis for all source locations and frequencies

e	Occurrences		Wave Power (nT^2)	
	L = 5	L = 6	L = 5	L = 6
0.10 f_{ce}	0.37%	0.16%	0.35%	0.15%
0.15 f_{ce}	0.32%	0.13%	0.49%	0.098%
0.20 f_{ce}	0.31%	0.12%	0.56%	0.094%

Similar results are obtained under all conditions

Maximum percentage of occurrences is *0.37%* for wave frequencies of *0.10* f_{ce} and a source location of *L = 5*

Maximum wave power percentage being *0.56%* for wave frequencies of *0.20* f_{ce} and a source location of *L = 5*

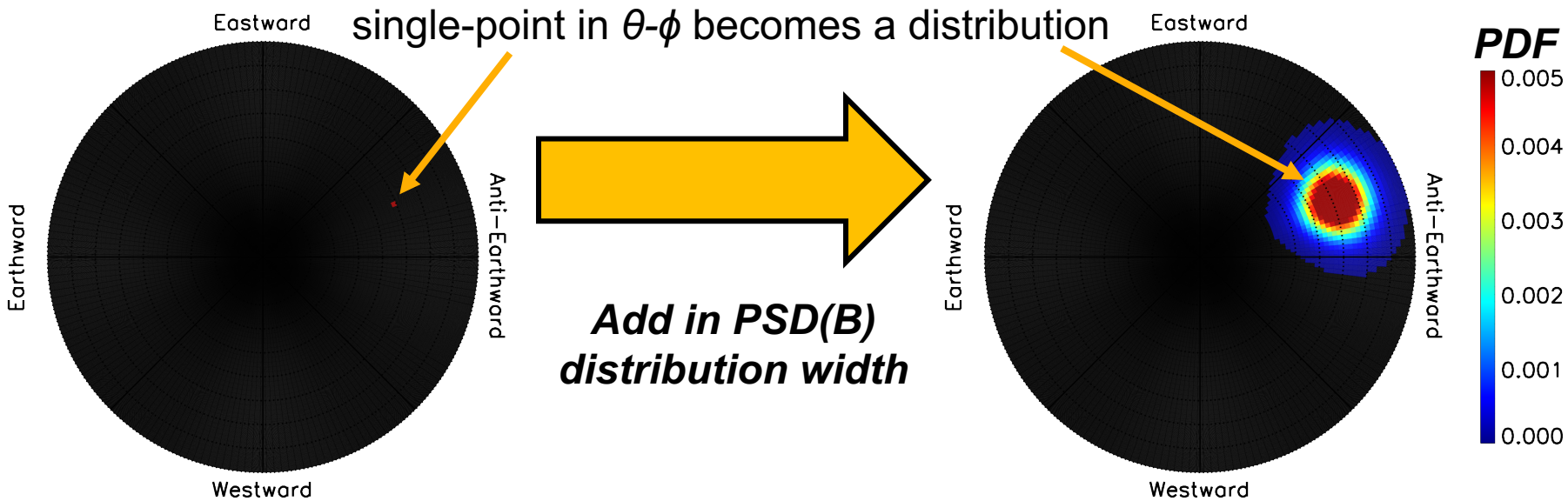
Still, only very small fraction of chorus waves exist with the conditions required to access the plasmasphere!

Width of Power Spectral Density in θ-ϕ

So far, we assumed that *PSD(B)* occurs with a single WNA based on *SVD* analysis, when in actuality, *PSD(B)* is distributed over range of WNA, peaked at *SVD* values

Distribution width can be incorporated into analysis by modeling power spectral density as a Gaussian function with a polar, $\Delta\theta$, and azimuthal, $\Delta\phi$, width (*FWHM*)

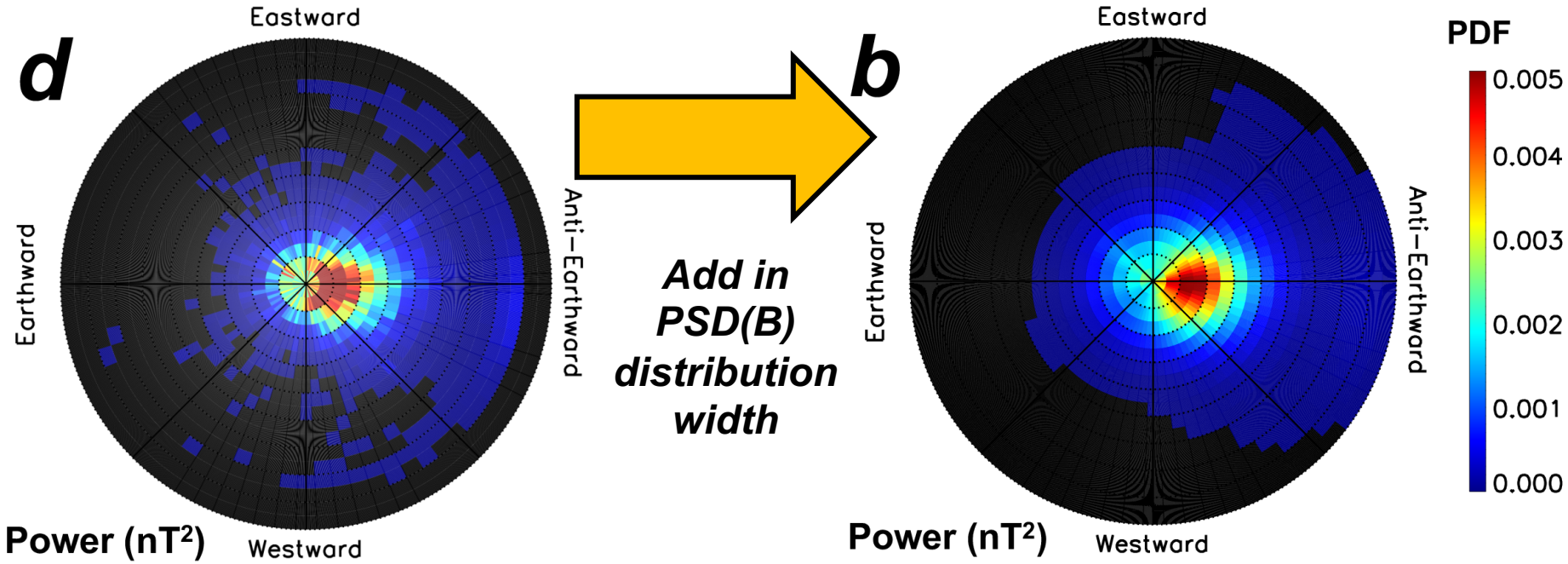
$\Delta\theta = \Delta\phi = 20°$ is used as an approximation based on the average planarity of the waves (e.g. *Santolík et al., [2003], Taubenschuss and Santolík [2018]*)



Apply this distribution width to each observation and recalculate the wave power that exists with the wave vector orientation required to propagate into the plasmasphere

Width of Power Spectral Density in θ-ϕ

Initial Conditions: f/f_{ce} = 0.20, L = 6

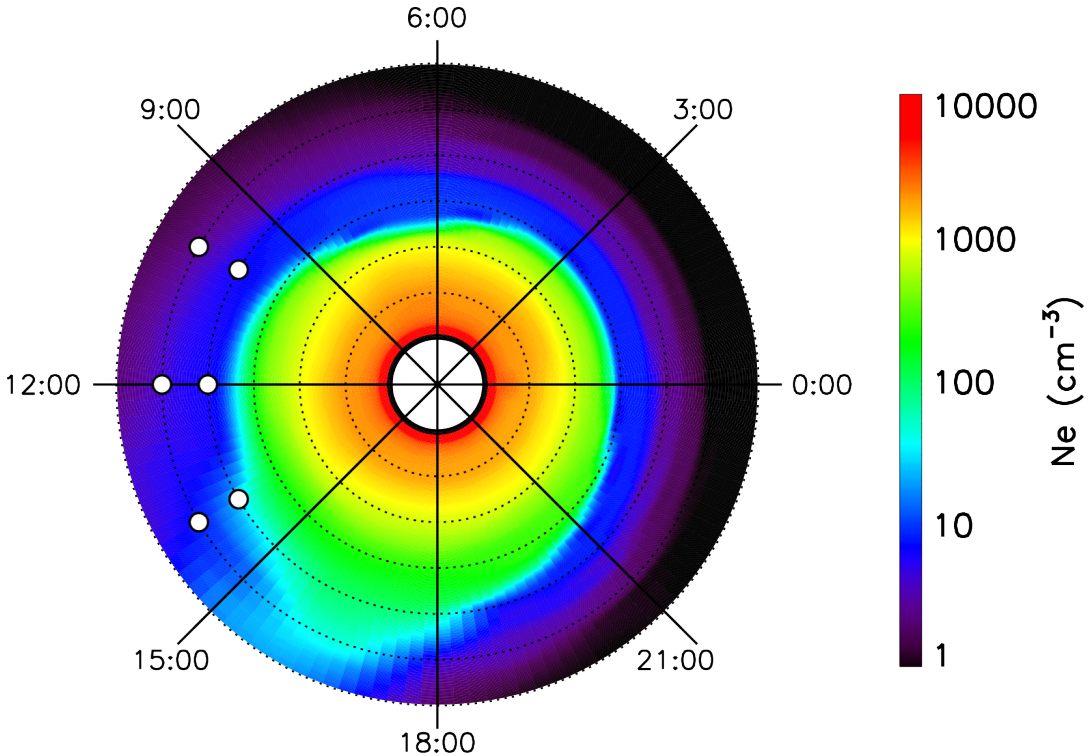


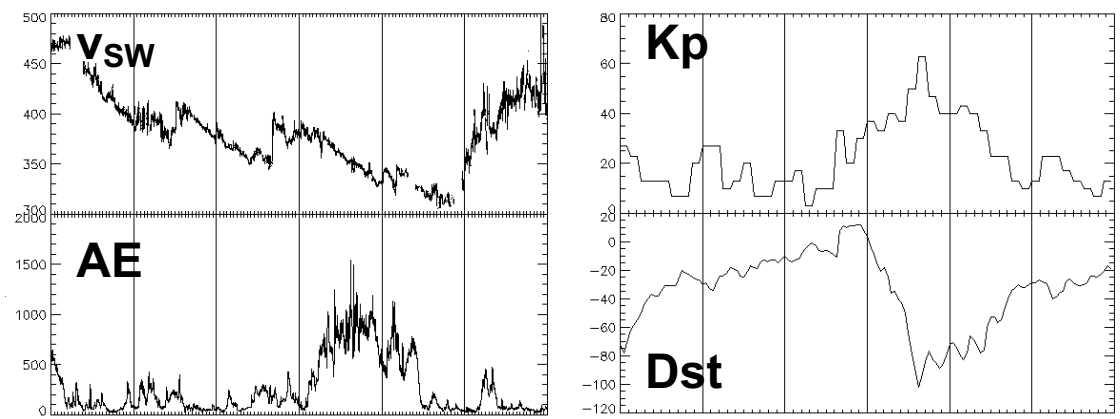
c	Wave Power (nT²)	
	L = 5	L = 6
0.10 f_{ce}	0.91%	0.53%
0.15 f_{ce}	0.95%	0.38%
0.20 f_{ce}	0.87%	0.31%

Add in distribution width for all source locations and wave frequencies

Percentages are increased by accounting for distribution width, but are still not substantial (<1%)

Asymmetric Density Model (Plume)





April 19 – April 24, 2001

Use ray tracing results from *Chen et al., [2009]* who implemented an asymmetric density model to account for storm-time plume

Model driven by electric field from Rice Convection Model (RCM) for main phase of April 21, 2001 storm

CRRES data for *AE > 300 nT* used to model the suprathermal electron distribution – damping rates explicitly calculated

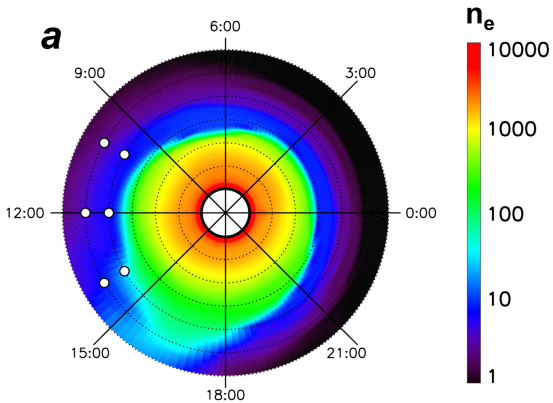
Ray trace for all azimuthal (ϕ) and polar angles (θ) from:

L = 5.0, 6.0 MagLat = 0°

f/f_{ce} = 0.10, 0.15, 0.20

MLT = 10, 12, 14

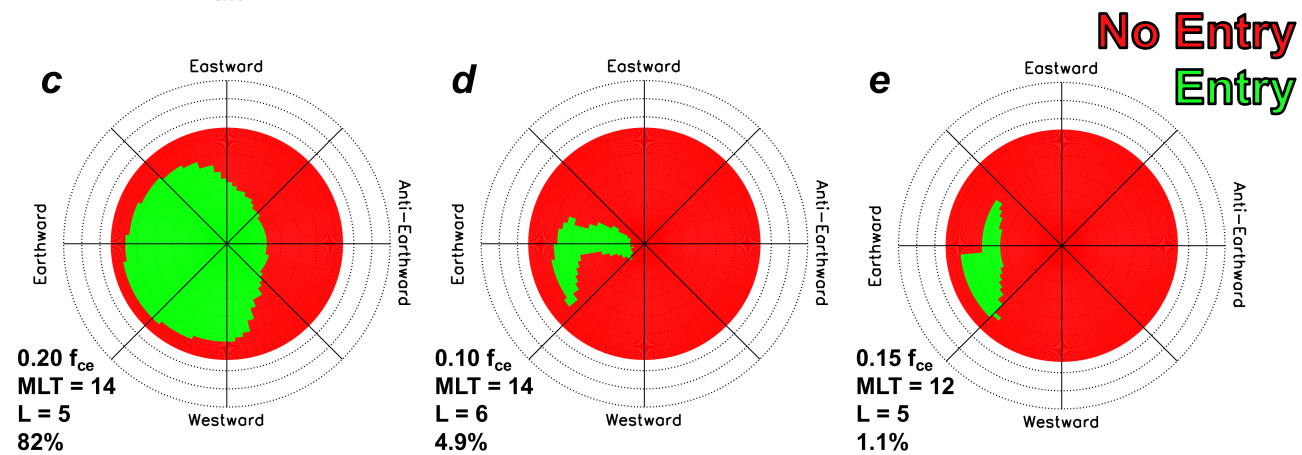
Ray Tracing with Asymmetric Density



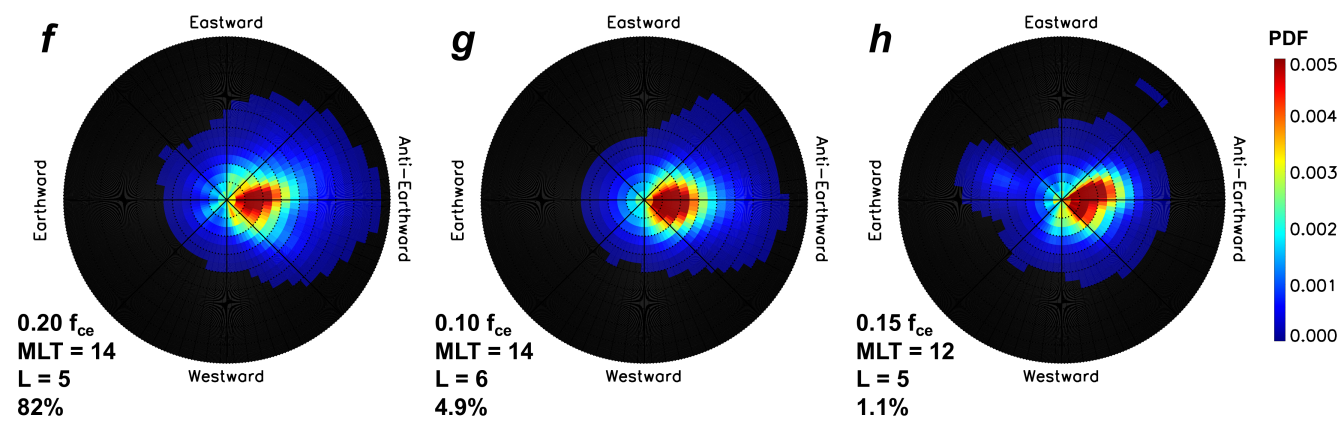
b	Wave Power (nT^2)					
	L = 5			L = 6		
	MLT = 10	MLT = 12	MLT = 14	MLT = 10	MLT = 12	MLT = 14
0.10 f_{ce}	0.00045%	0.16%	94%	0.034%	0%	4.9%
0.15 f_{ce}	0.020%	1.1%	86%	0%	0%	0.0058%
0.20 f_{ce}	0.037%	0.42%	82%	0%	0%	0.0013%

Increased range of WNA can enter p/sphere in the presence of azimuthal density gradients

Highest percentage is observed for *0.10 f_{ce}* at *L = 5* and *MLT = 14*



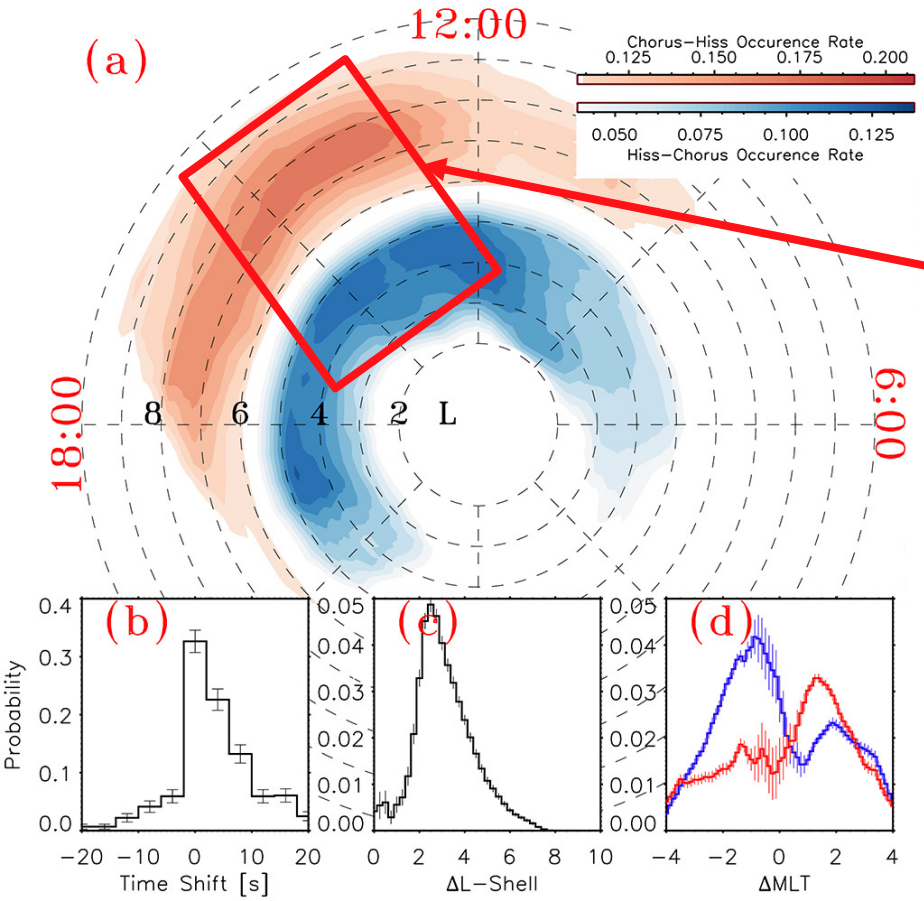
If source location is moved away from the strong azimuthal density gradients (azimuthally or radially), percentages decrease substantially



Strong azimuthal density gradients (plumes) are required if a significant fraction of chorus waves are to enter p/sphere in line with the chorus-to-hiss mechanism

Correlation between Chorus and Hiss

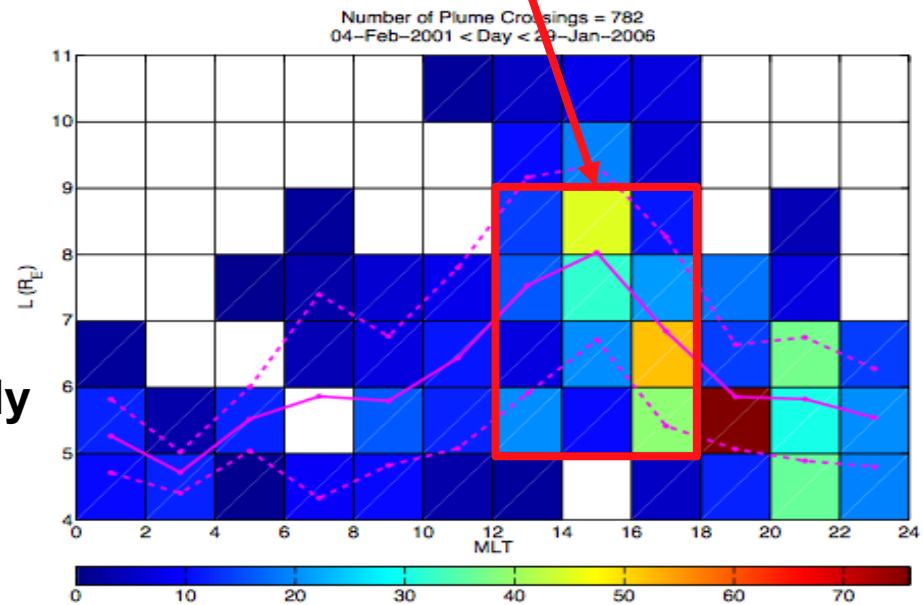
Agapitov et al., JGR, [2018]



Percentage of time that concurrent observations of chorus and hiss wave power are highly correlated (>0.7) from THEMIS

Correlation between chorus and hiss is observed most frequently in the post-noon sector (between 12 and 16 MLT)

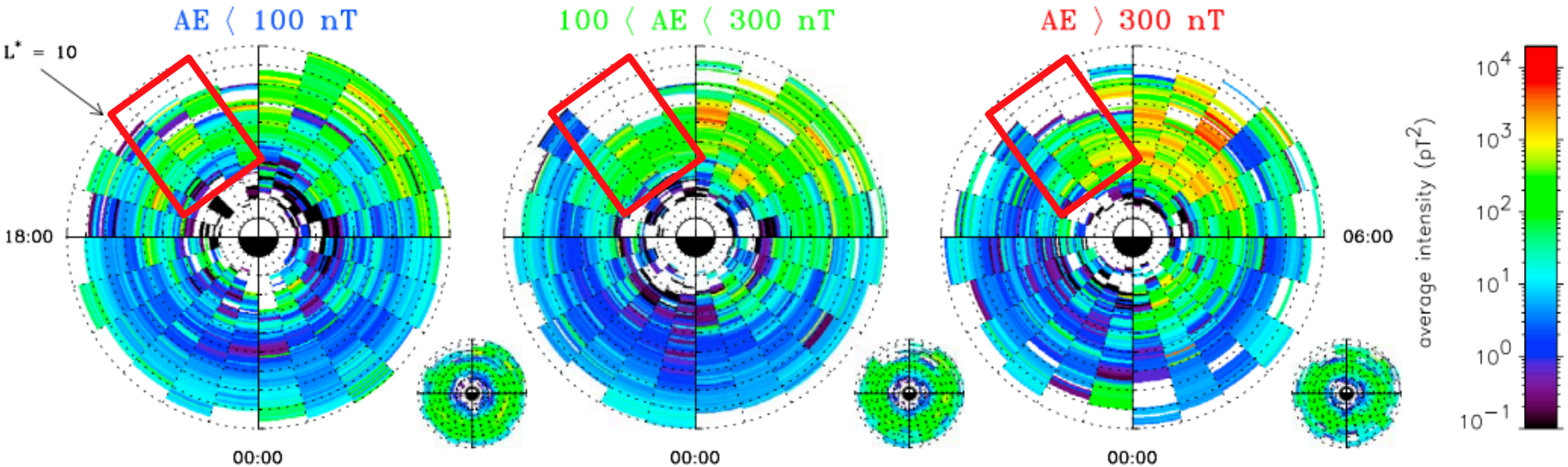
Darrouzet et al et al., Annales, [2008]



Strong azimuthal density gradients (likely in the form of plumes) are required for chorus waves to enter p/sphere in line with the chorus-to-hiss mechanism

Comparison to Chorus Wave Power Map

Lower Band Chorus Intensity from Meredith et al., JGR, [2012]

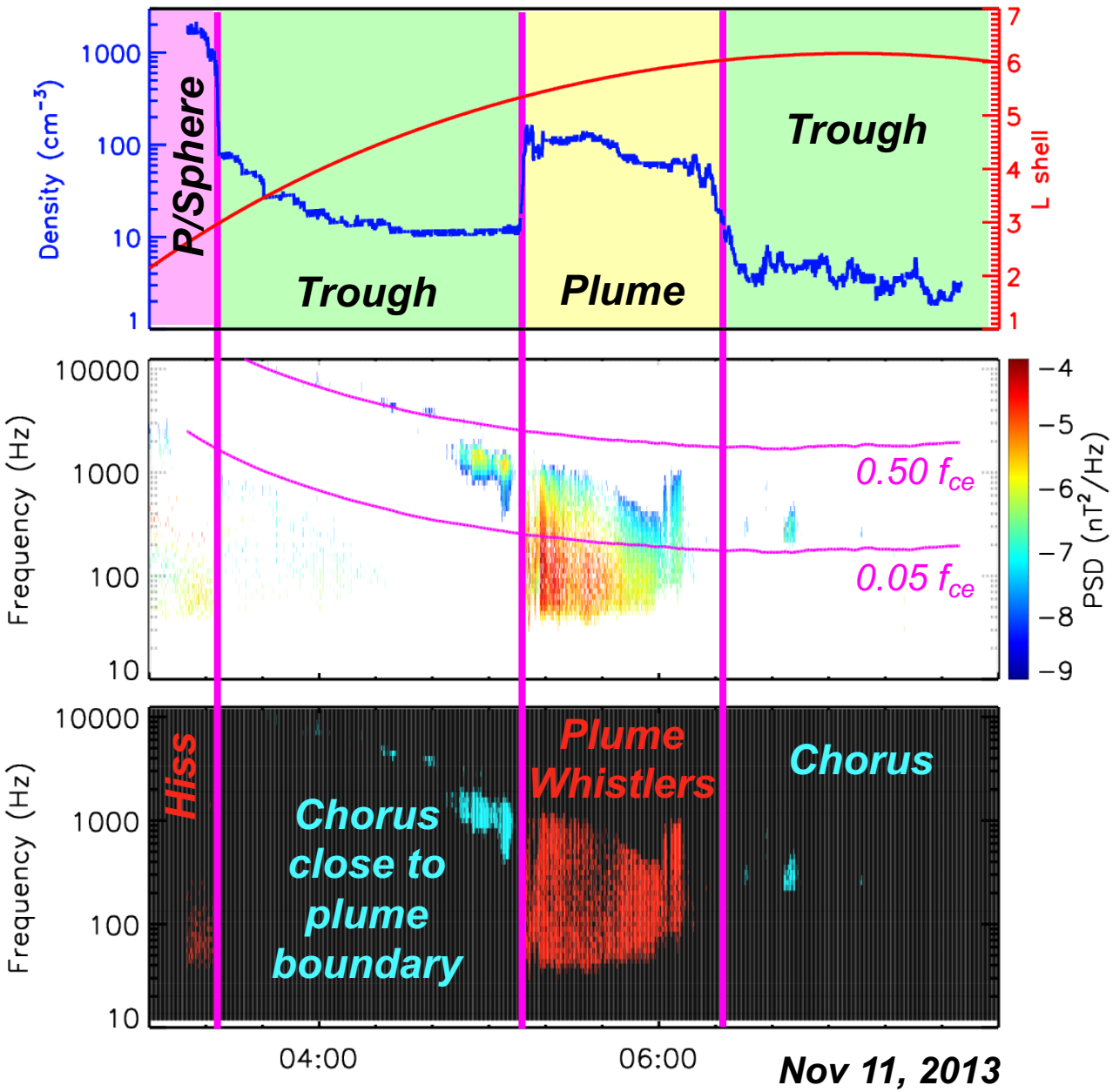


In dawn region, where the statistical peak in chorus wave power is observed, azimuthal density gradients are generally weak (chorus-to-hiss mechanism does not work here!)

It is only in a region on the dusk side (close to a plume), where the average chorus wave power is significantly lower, that chorus waves can enter the p/sphere in line with the chorus-to-hiss mechanism

Result qualitatively indicates that the overall contribution of chorus to hiss may be small – additional mechanisms for generating/amplifying hiss may be required

Future Work: Chorus Near Plumes



So far, we sorted by MLT/L, but plumes are the dictating factor

Why not look specifically at chorus waves in the vicinity of plasmaspheric plumes?

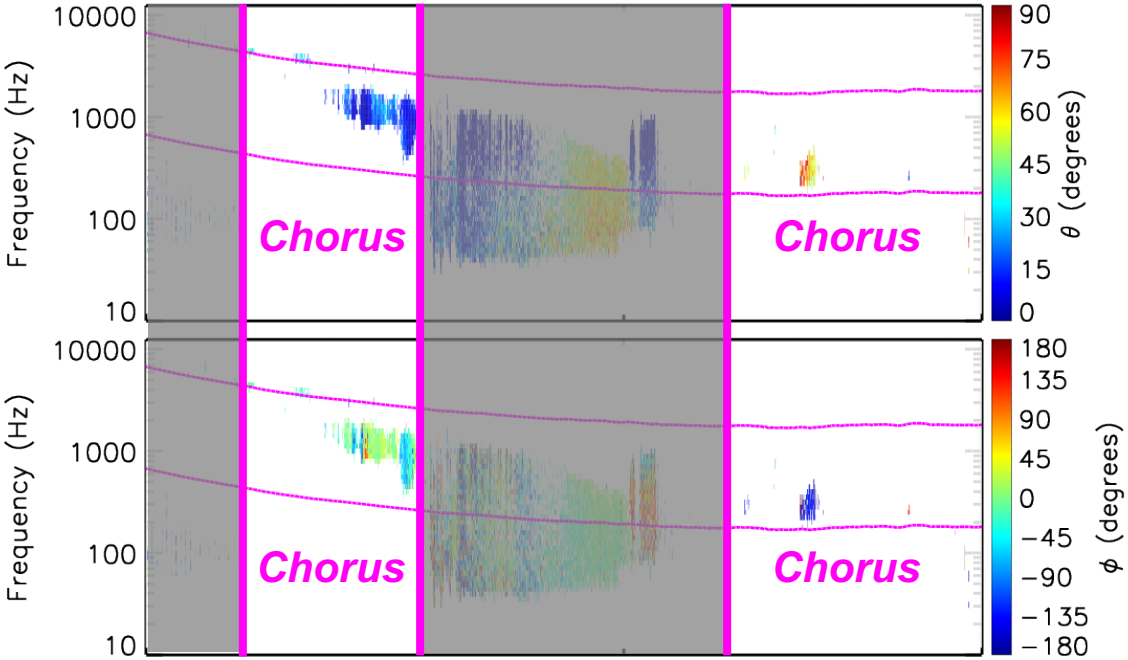
Plan to evaluate the angular distribution of chorus close to plumes

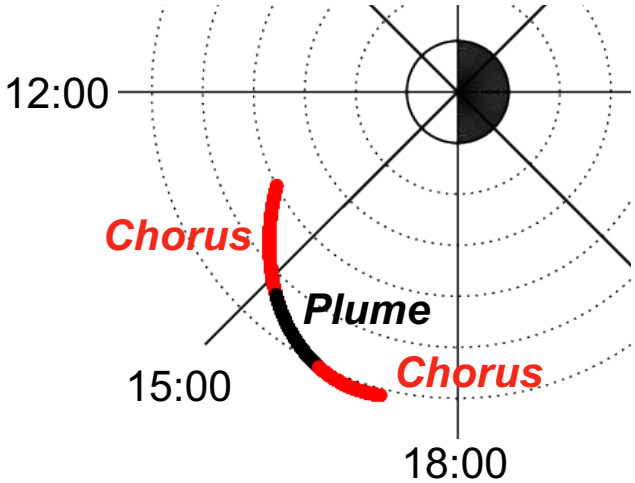
What does this angular distribution look like?

How does it vary with separation distance from the plume?

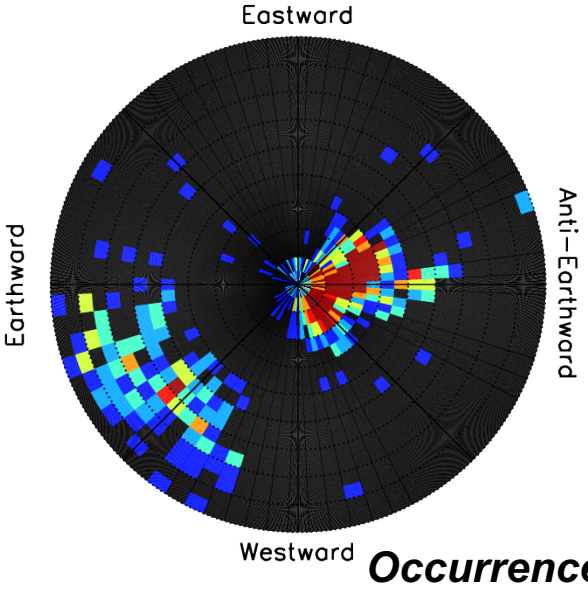
How much wave power can enter the plume or the plasmasphere?

Preliminary Case Study Example

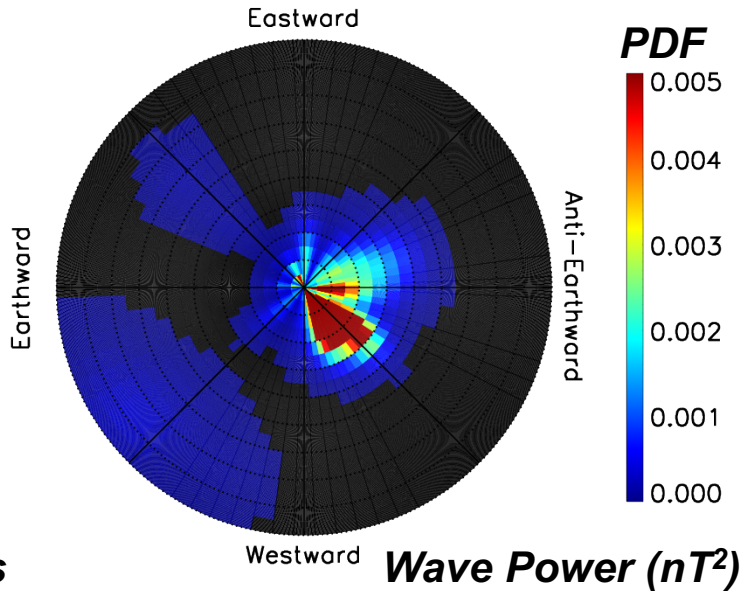




Small sample from a case study of angular distribution of chorus waves in the vicinity of a plume



Occurrences



Wave Power (nT²)

Majority of wave power is in the field-aligned direction

First time we have seen a fraction of chorus wave power with a wave vector oriented Earthward