Global Model of Low Frequency Chorus from Multiple Satellite Observations

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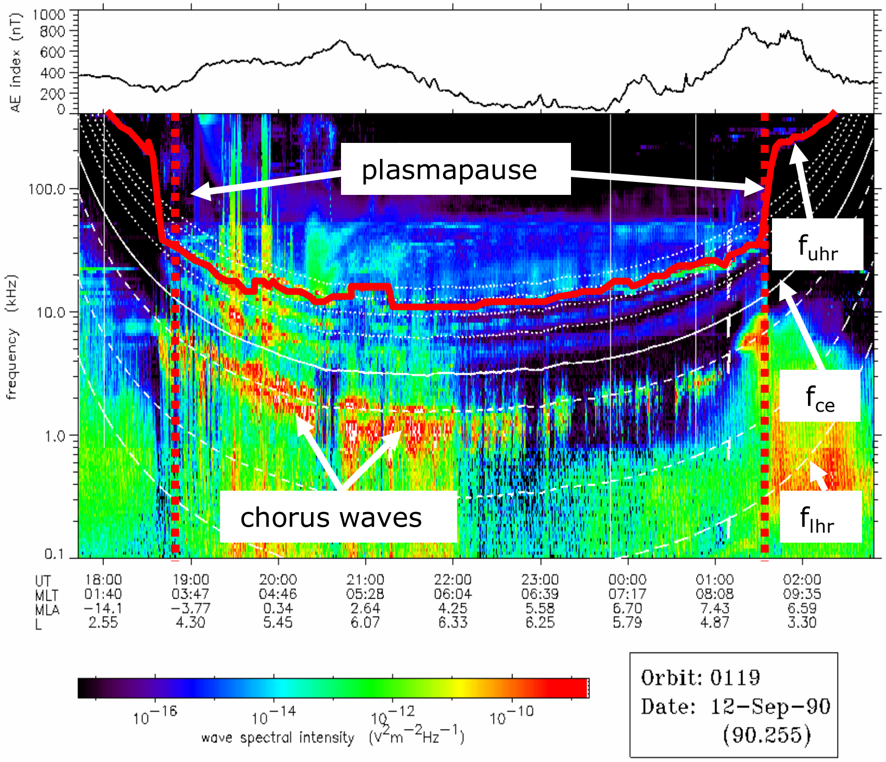
Whistler Mode Chorus

- Chorus is a discrete, naturally occurring emission that is generated in two bands with a gap at 0.5fce, separating the emissions into so-called lower band and upper band chorus

- The waves are generated outside the plasmapause near the magnetic equator by plasma sheet electrons injected into the magnetosphere during substorms and/or enhanced convection



Wave Particle Interactions

- Gyroresonant wave particle interactions with whistler mode chorus play a key role in radiation belt dynamics

- They are thought to be largely responsible for the gradual build up of radiation belt electrons that occurs on a timescale of 1-2 days following geoeffective geomagnetic storms [Horne *et al*., 2005]

- In contrast, storm time chorus at mid to high latitudes causes microburst precipitation and may lead to losses of radiation belt electrons on the timescale of the order 1 day [Thorne *et al*., 2005]

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Introduction

- There are several global models of the radiation belts which are based on diffusion models
- They require diffusion rates which are based on the wave magnetic field intensity.
- Horne *et al*., [2012] recently computed energy and pitch angle diffusion rates for use in radiation belt codes using plasma wave observations of chorus in the frequency range 0.1-0.8f_{ce} from seven satellites, including the effects of upper and lower band chorus
- The new diffusion coefficients have been incorporated into the BAS radiation belt model showing significant pitch angle and energy diffusion extends well beyond GEO [Glauert *et al*., 2014a; 2014b]

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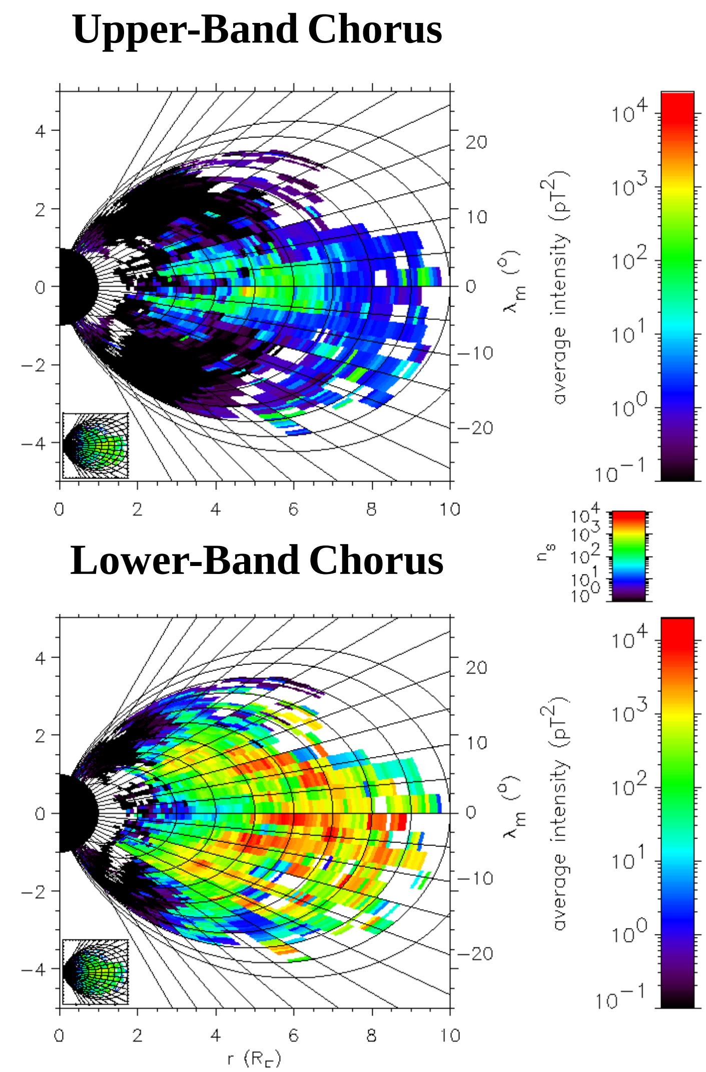
Upper and Lower Band Chorus

- Upper band chorus tends to be tightly confined to the magnetic equator
- Lower band chorus can propagate to higher latitudes on the dayside
- Significant power can fall below 0.1fce due to the increasing magnetic field strength



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Normalisation of the Wave Frequency

- In our studies we normalise the wave frequencies to the local electron gyrofrequency as opposed to an estimate of the equatorial gyrofrequency

- This avoids the use of a magnetic field model to estimate the equatorial gyrofrequency and makes no assumptions about the ray paths

- Lower band chorus waves generated near the equator fall to lower relative frequencies as they propagate to higher latitudes and may fall below 0.1fce

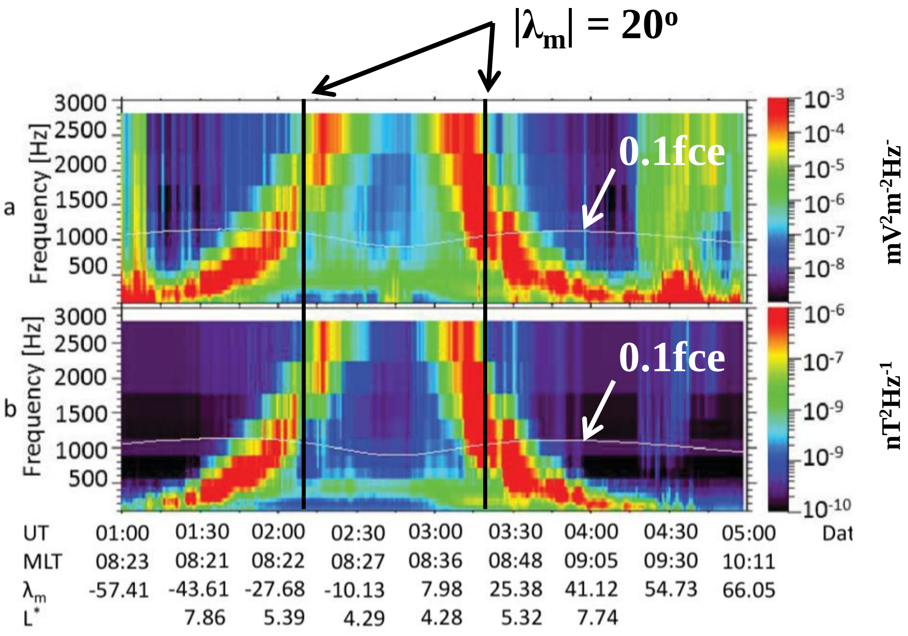
Motivation

- Chorus wave power below $0.1f_{ce}$ is largely omitted in radiation belt models
- To investigate the global distribution of this wave power and to improve the inputs to radiation belt models we develop a global model of chorus below $0.1f_{ce}$, in the frequency range $f_{LHR} < f < 0.1f_{ce}$
- We refer to the chorus wave power in this band as *low-frequency chorus*

Example of Low-Frequency Chorus

- Strong low frequency chorus is seen at absolute magnetic latitudes greater than 20º both north and south of the magnetic equator

- Closer to the equator the wave power is largely above 0.1fce, illustrating that chorus wave power falls below 0.1fce at mid-latitudes



Cluster-1, STAFF
29th Oct 2001

Wave Database

- To construct a comprehensive database of low-frequency chorus in the inner magnetosphere we combined data from six satellites:
  - Dynamics Explorer 1
  - Cluster 1
  - Double Star TC1
  - THEMIS A, D & E

- We binned the average low-frequency chorus wave intensity as a function of:
  - L*
  - MLT
  - MLAT
  - magnetic activity
  - position with respect to the plasmapause

Statistical Analysis

- We then accessed the database to conduct a statistical analysis of the average wave intensities of low-frequency chorus ($f_{LHR} < f < 0.1fce$) as a function of spatial location and geomagnetic activity

- We split the magnetic activity into three levels which we define as
  - Quiet AE < 100 nT
  - Moderate 100 < AE < 300 nT
  - Active AE > 300 nT

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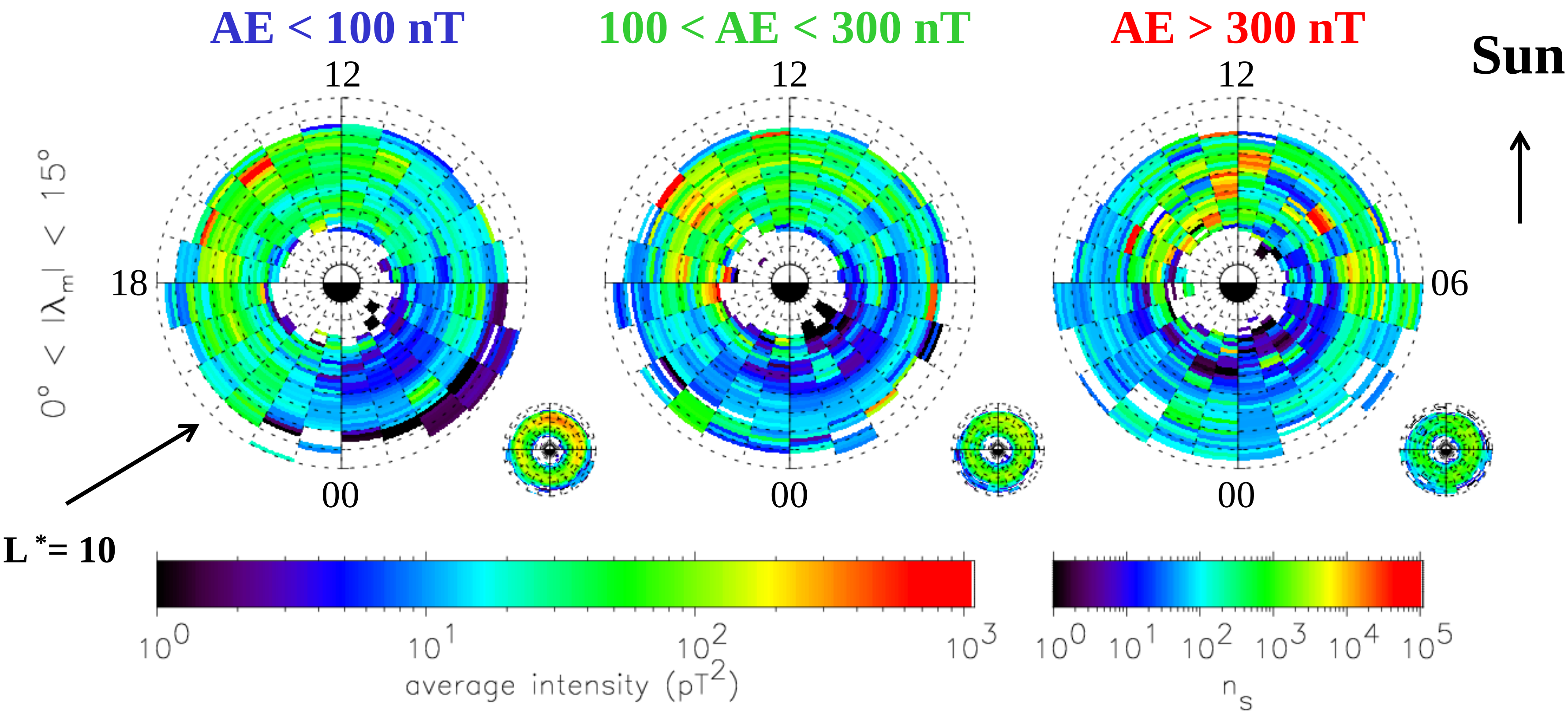
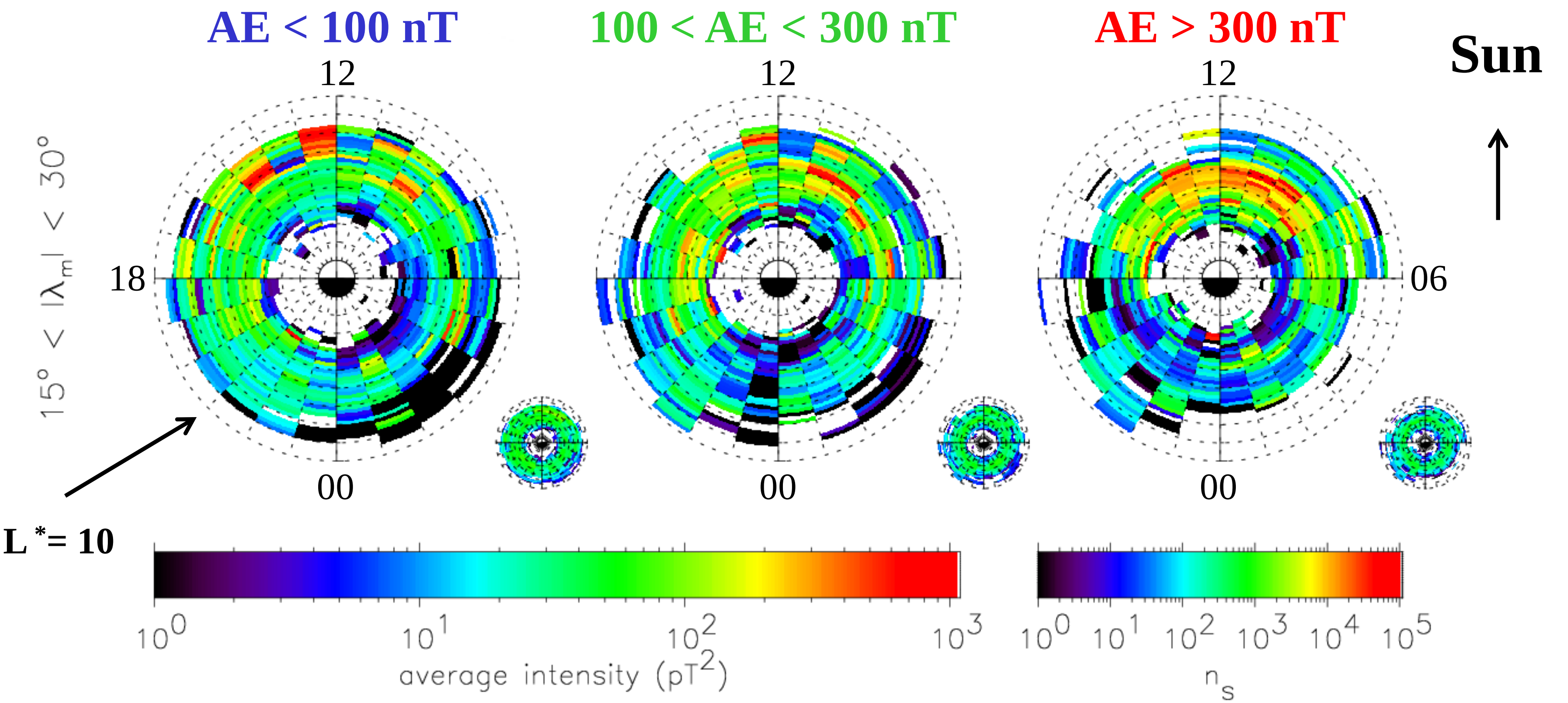
MLT Dependence: $0^o < |\lambda_m| < 15^o$



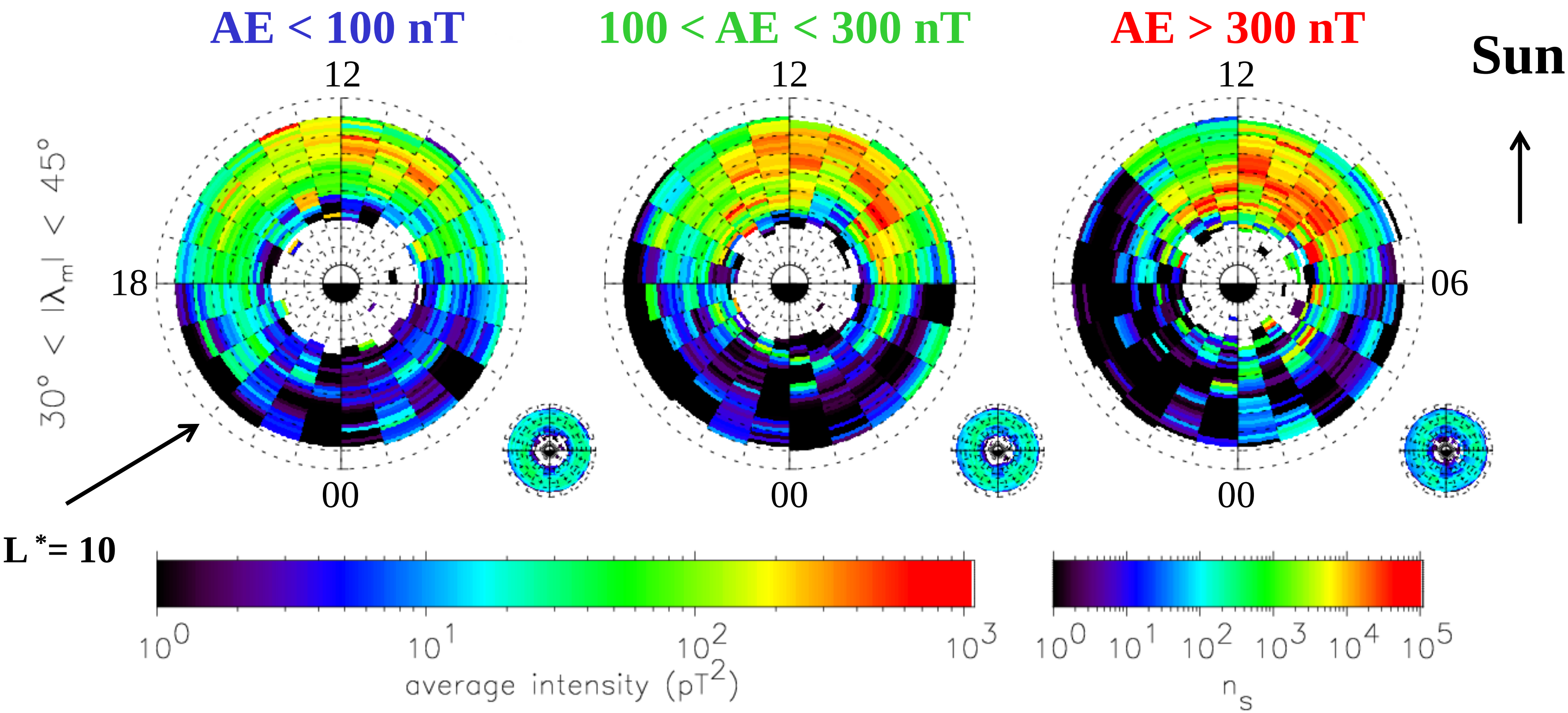
- Low frequency chorus tends to be rather weak in the equatorial region with typical intensities of the order tens of pT^2

MLT Dependence: $15^o < |\lambda_m| < 30^o$



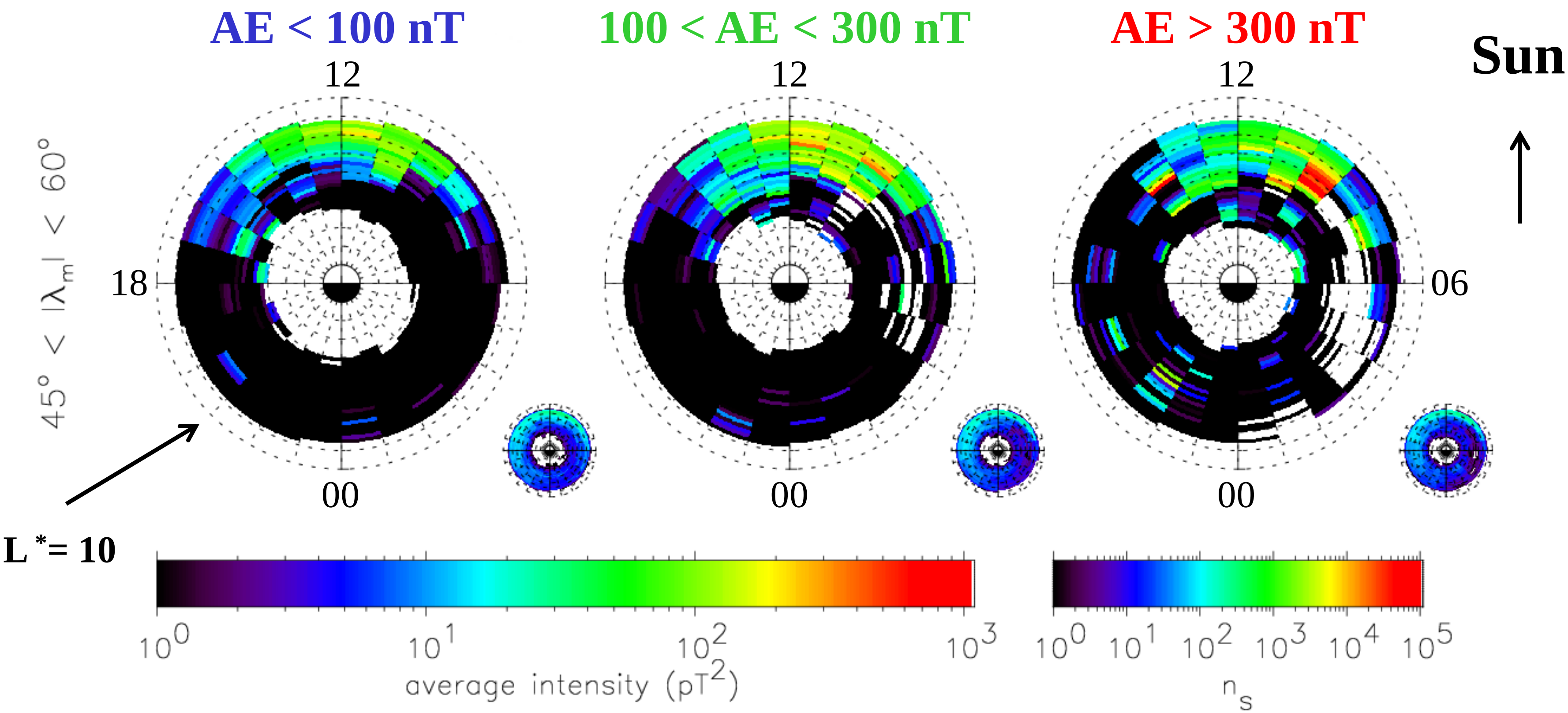
- At mid-latitudes significant wave power is observed but only on the dayside
- Wave power peaks during active conditions with intensities of the order several hundred pT^2 in the region $4 < L^* < 7$ from 07-15 MLT

MLT Dependence: 30° < $|\lambda_m|$ < 45°



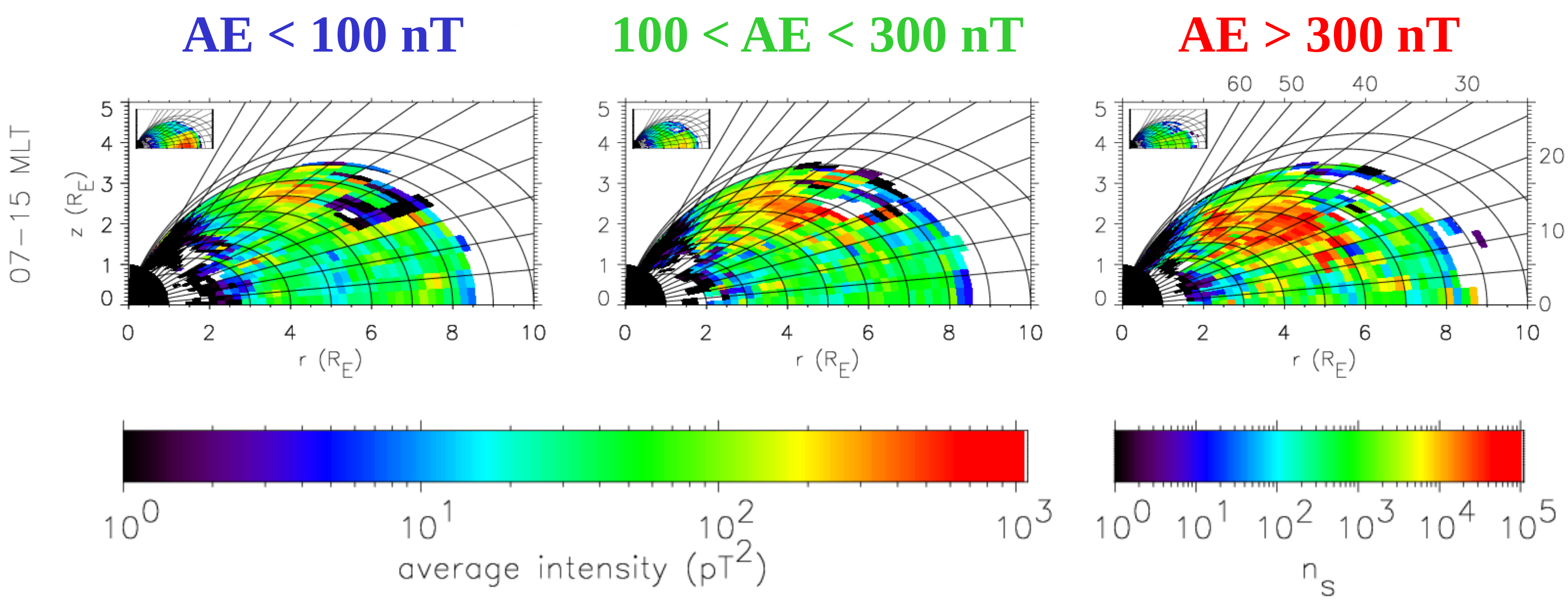
- At higher mid-latitudes wave power is again strongest and most extensive on the dayside during active conditions with intensities of the order several hundred pT^2 in the region 4 < L* < 8 from 07-15 MLT

MLT Dependence: $45^o < |\lambda_m| < 60^o$



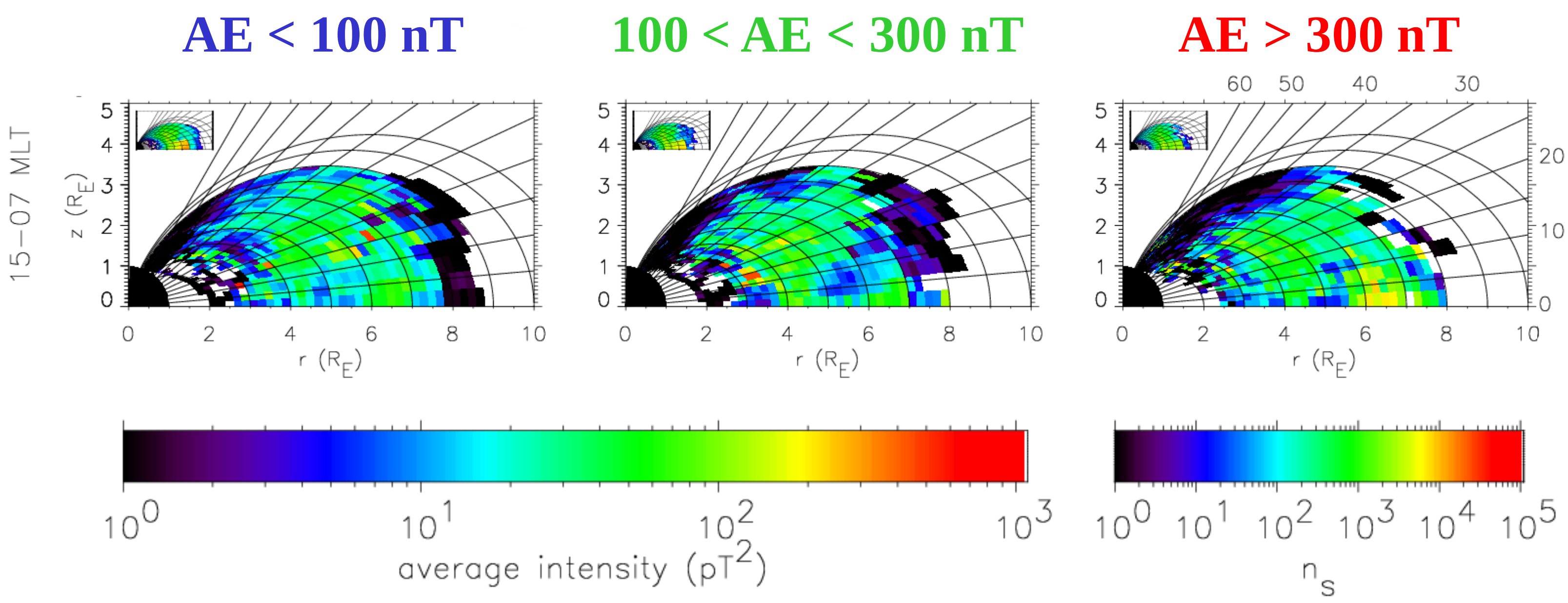
- The low-frequency chorus wave power drops off in both magnitude and extent at high latitudes.
- Here weak power of the order of tens of pT^2 is restricted to the noon sector beyond L* = 7

Latitudinal Dependence: 07-15 MLT



- Strong low frequency chorus in the region 07-15 MLT from L* = 4-8 typically extends from 20º to 50º with an average intensity of 240 pT^2
- In contrast there is little wave power in the equatorial region below about 20º, confirming that these waves are a mid-latitude phenomenon

Latitudinal Dependence: 15-07 MLT



- Low-frequency chorus tends to be largely absent from 15-07 MLT at all magnetic latitudes and for all levels of magnetic activity

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Discussion

- Low-frequency chorus is not observed on the nightside because waves at higher relative frequencies generated near the equator are confined to latitudes below 15 [Meredith *et al*., 2012] due to strong Landau damping by suprathermal electrons [Bortnik *et al*., 2007]

- On the dayside the flux of suprathermal electrons is much lower and chorus generated near the equator in the lower band propagates to higher latitudes and lower relative frequencies where it may be observed as low-frequency chorus

- Low-frequency chorus at high latitudes on the dayside can propagate into the plasmasphere and evolve into plasmaspheric hiss [Bortnik *et al*., 2008]

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Implications

- Significant wave power extends below 0.1fce particularly at mid-latitudes in the pre-noon sector where it may have a significant effect on radiation belt dynamics

- For example, mid-latitude chorus at latitudes greater than 30º can cause significant scattering near the loss cone for relativistic energies.

- For medium to high energy electrons, mid-latitude chorus at absolute magnetic latitudes greater than 20º is likely to extend the range of pitch angles over which energisation is possible and extend the range of energisation to higher energies, but only at intermediate pitch angles

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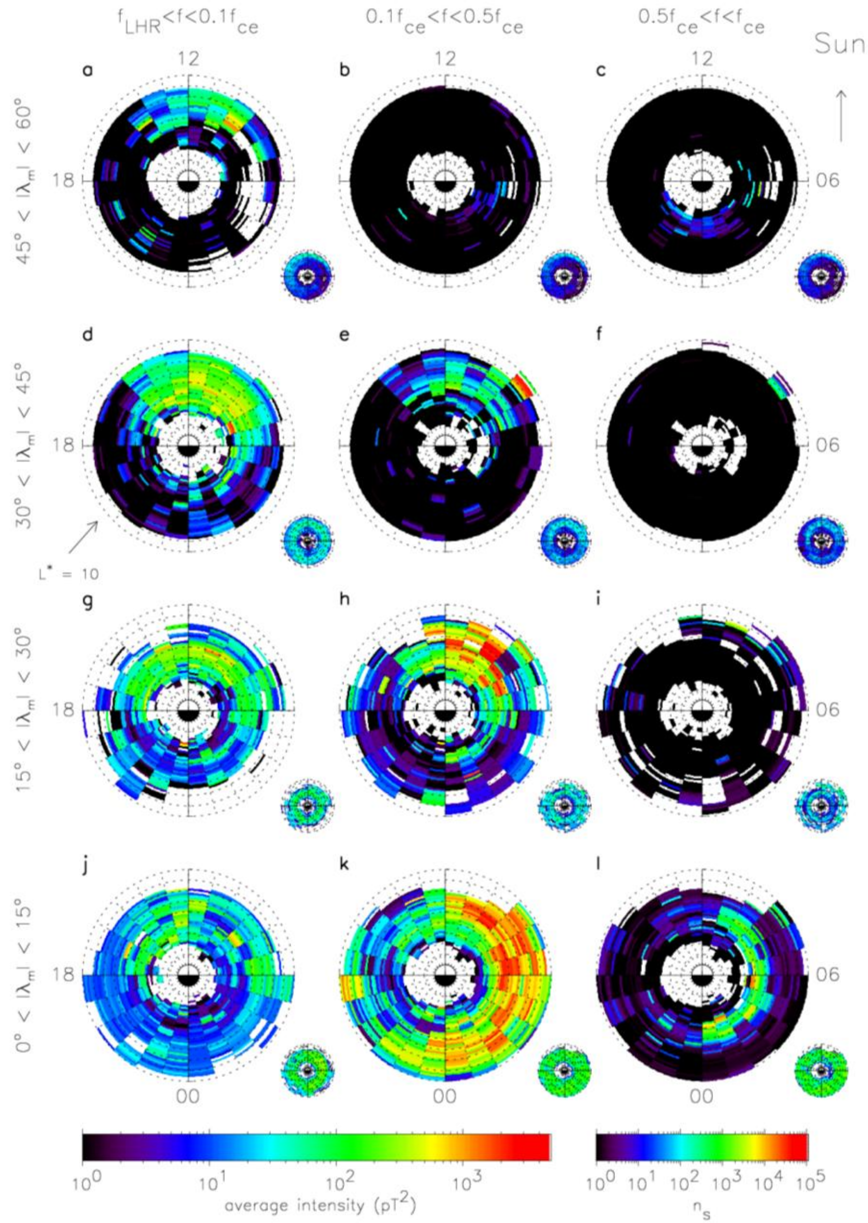
Global Chorus Model

- We can combine the model of low frequency chorus with our model of upper and lower band chorus to produce a comprehensive global model of the chorus waves



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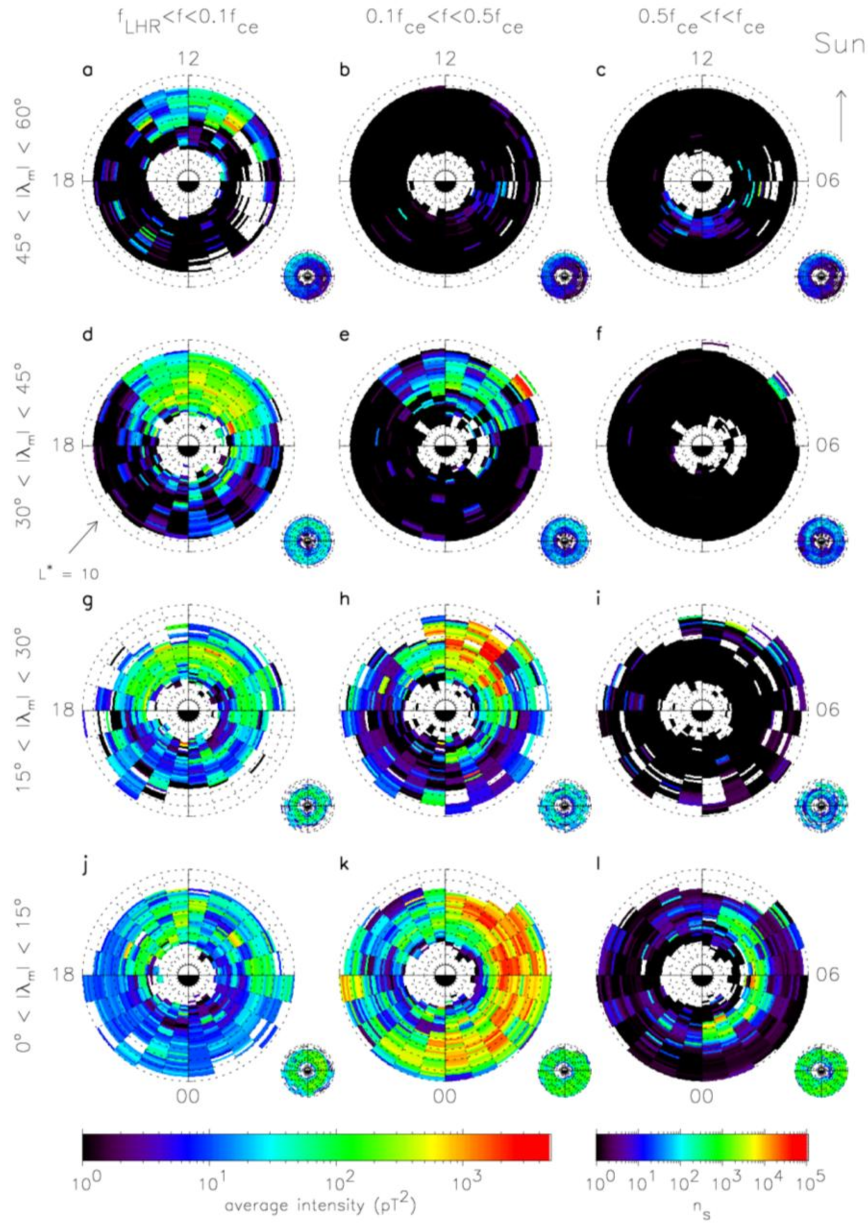
Global Chorus Model

- Equatorial lower band chorus is primarily observed on the dawnside from L* = 4-9
- Mid latitude lower band chorus is primarily observed in the pre-noon sector from L* =4-9
- Upper band chorus is tightly confined to the equatorial region over a narrow range of L*



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Conclusions

- Low-frequency chorus is substorm-dependent with the strongest intensities during active conditions

- The waves are strongest on the dayside with an average intensity of 240 pT^2 during active conditions at mid-latitudes ($20 <|\lambda_m|< 50^o$) from 7-15 MLT for $4 < L^* < 8$.

- Low-frequency chorus tends to be absent on the night-side at all magnetic latitudes and for all levels of magnetic activity

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Conclusions

- Significant low-frequency chorus power is observed during active conditions over a wide range of geospace
- Such waves will contribute to the acceleration and loss of relativistic electrons and should be included in radiation belt models

Acknowledgements

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