Radiation Belt Wave Observations on the Van Allen Probes and Opportunities for Lab Experiments

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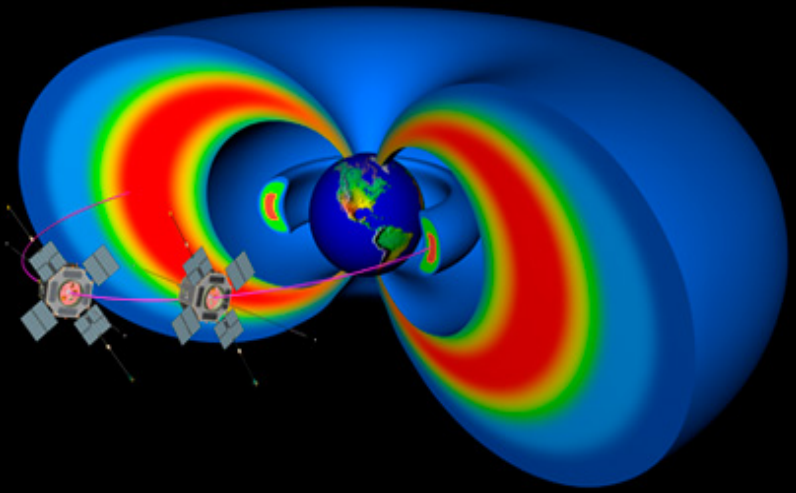

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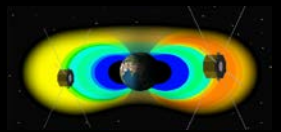
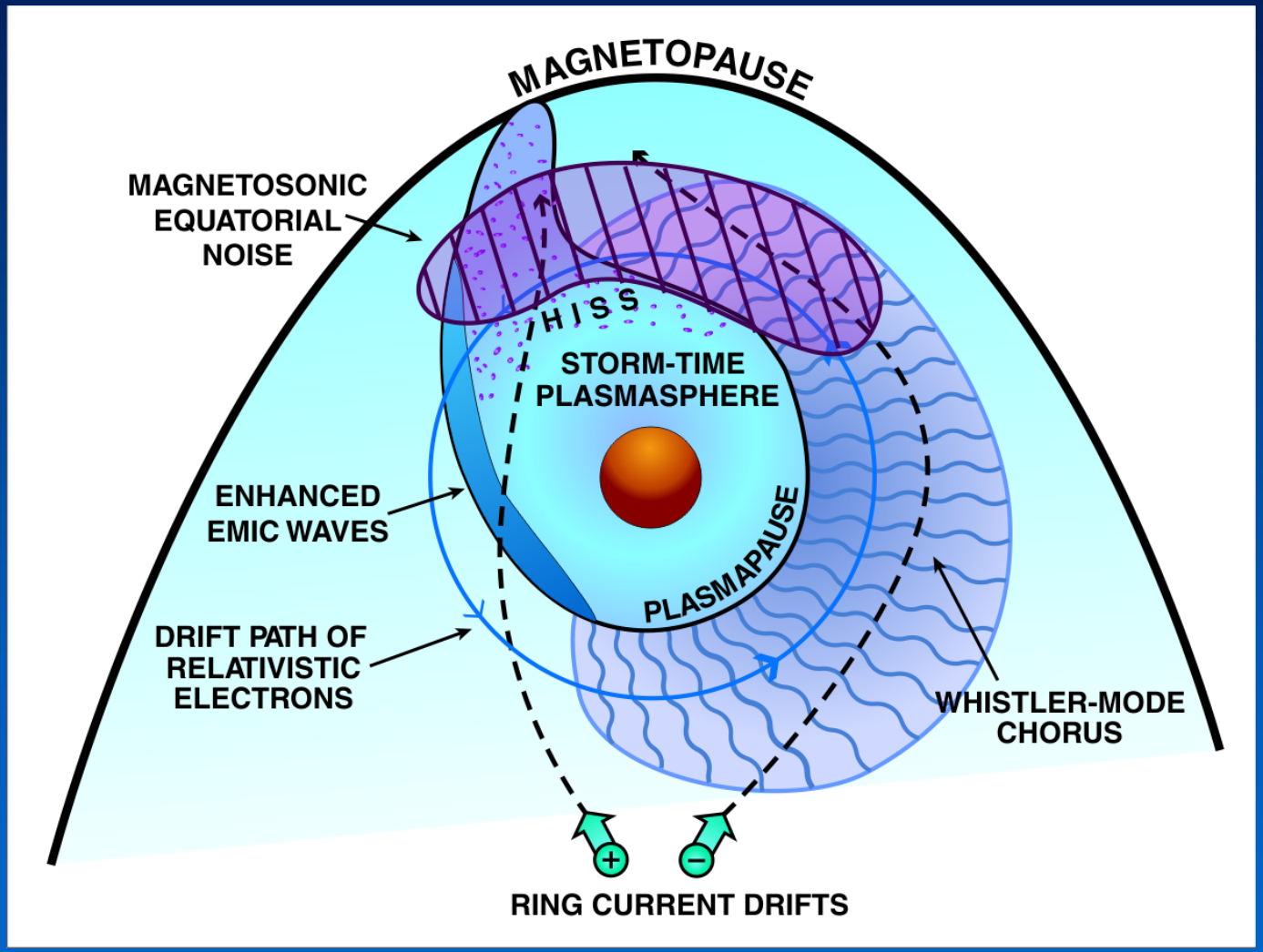


Radiation Belt Waves

Key waves important for wave-particle interactions



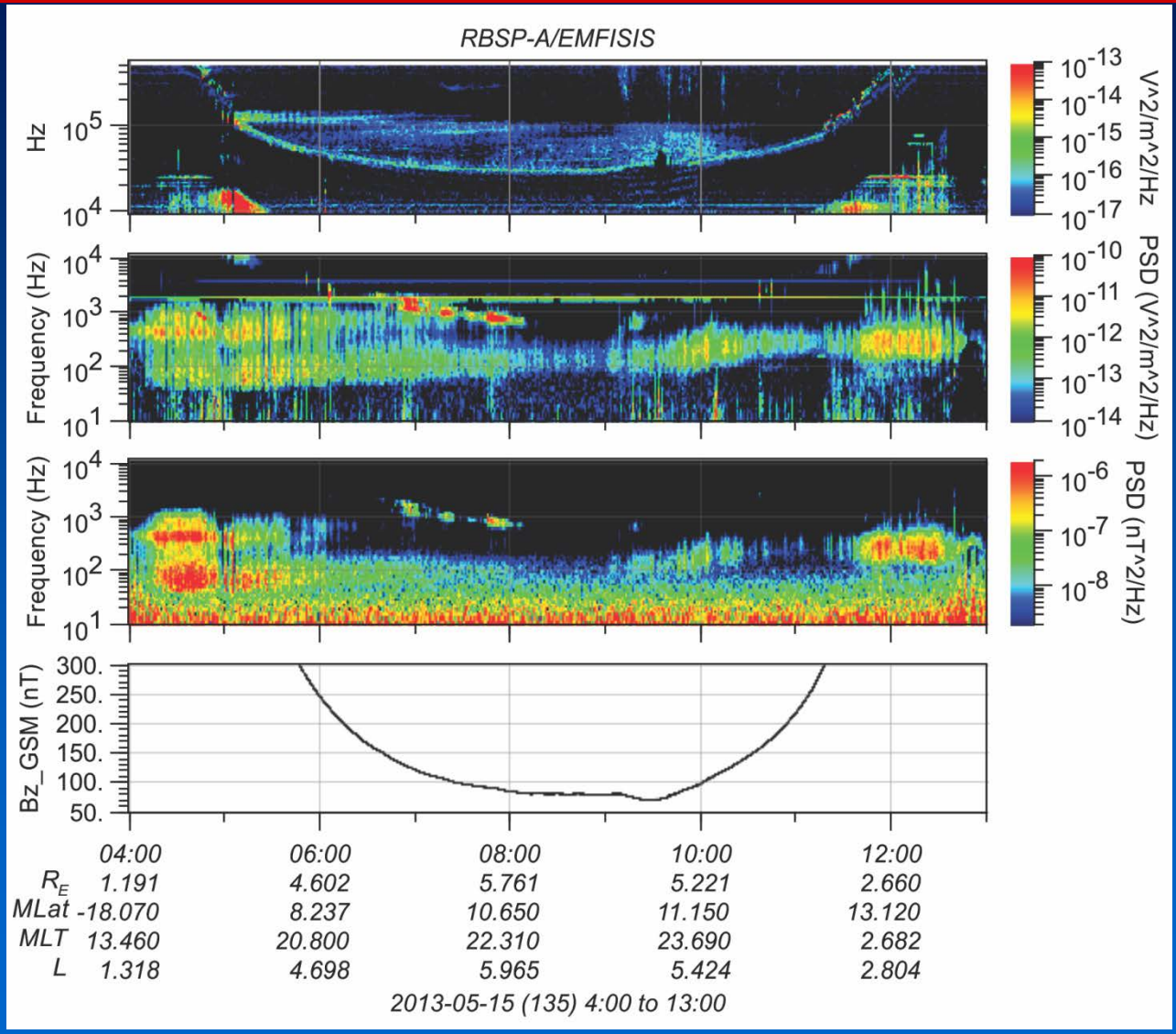
EMFISIS Data Example
(5-15-2013)

E-HFR

WFR E

WFR B

DC MAG



HFR (single channel): 10 kHz-400 kHz

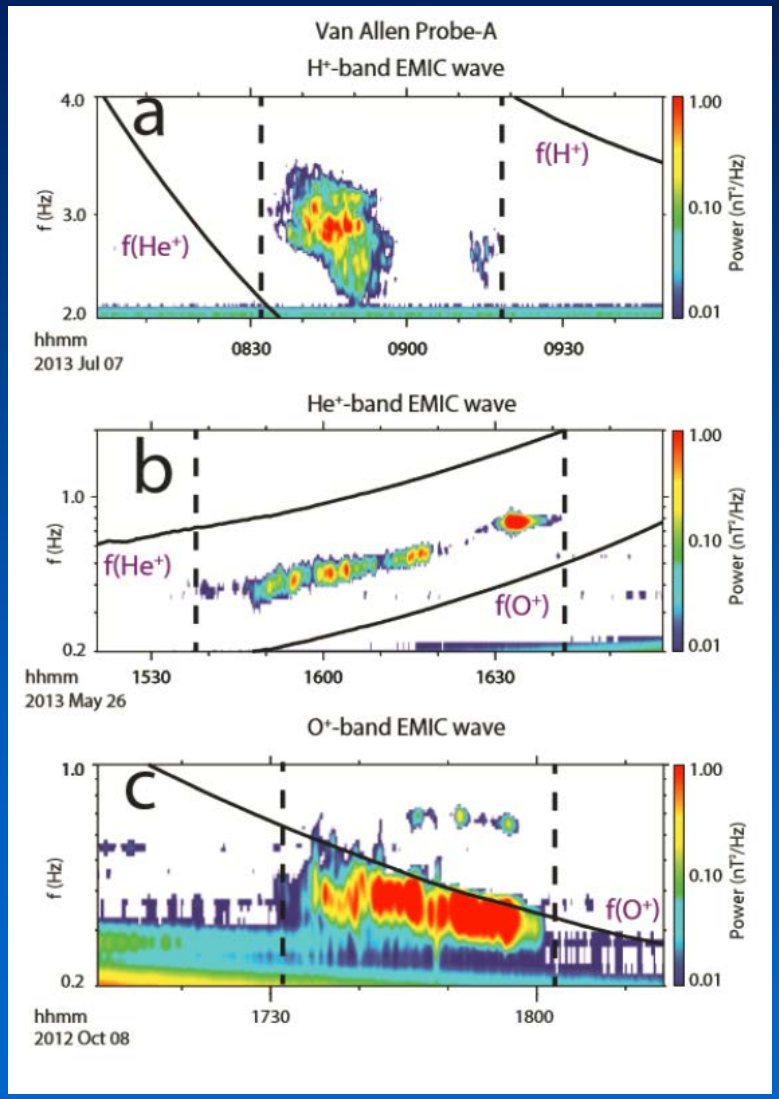
Vector E: 10 Hz-12 kHz

Vector B: 10 Hz-12 kHz

Vector B: 0-30 Hz

EMIC Waves

Three bands split by cyclotron frequncies



H+

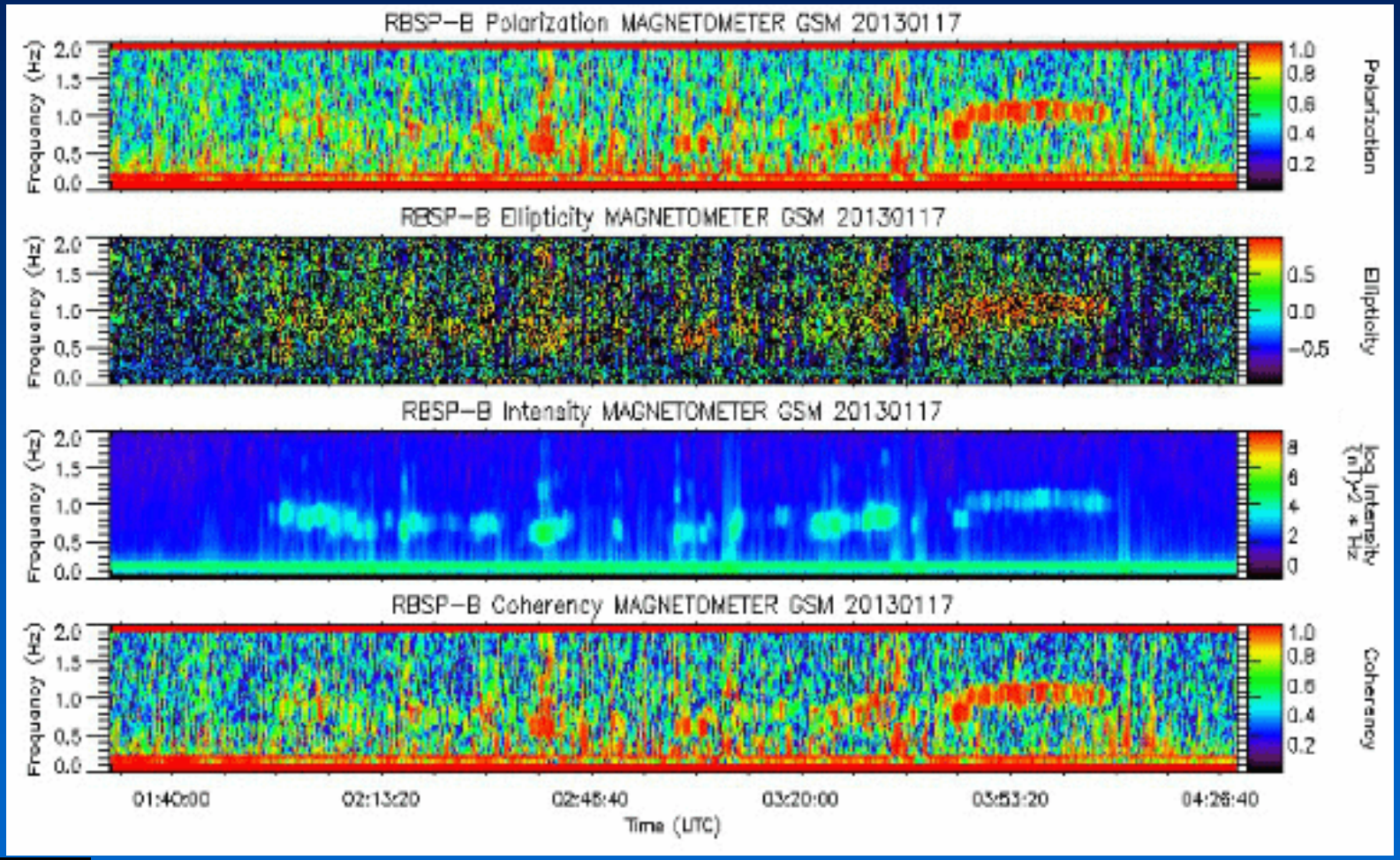
He+

O{

From A. Saiken, UNH

EMIC Wave Properties

Hydrogen band seen in both E and B



Polarization

Ellipticity

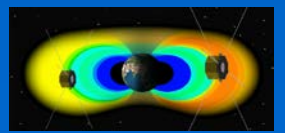
|B|

Coherence

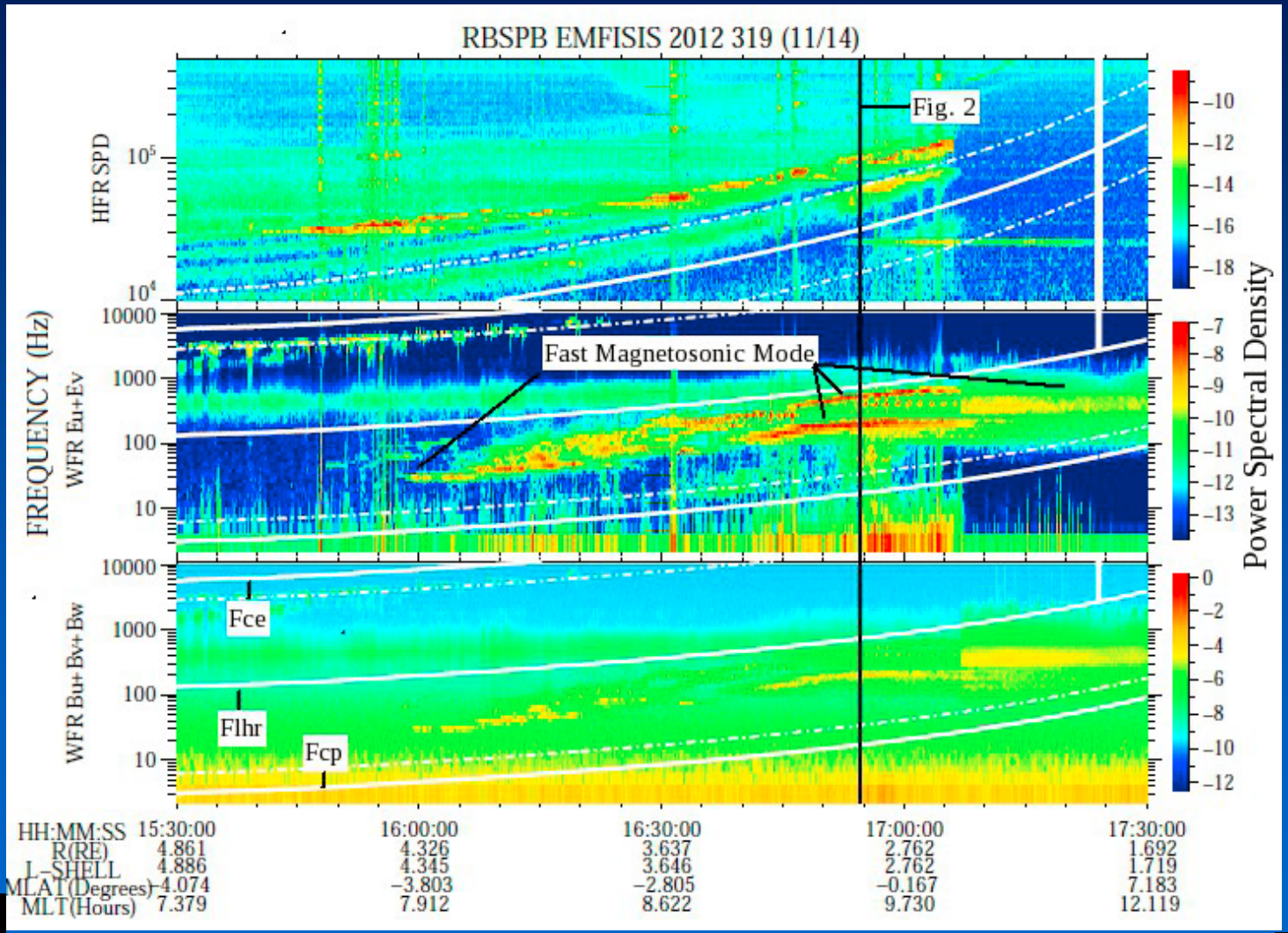
From M. Argall, UNH

EMIC Waves

- Driven by ring current ions – when drift exceeds Alfven speed.
- Interact with relativistic electrons via electron cyclotron resonance; primarily left-hand polarization.
- This interaction results in pitch angle scattering and loss to the atmosphere.
- Scattering rates depend on ion composition.
- For the lab:
  - Can pitch angle scattering be measured?
  - Can effects of ion composition be measured?
  - What conditions make electrostatic harmonics?



Magnetosonic Waves



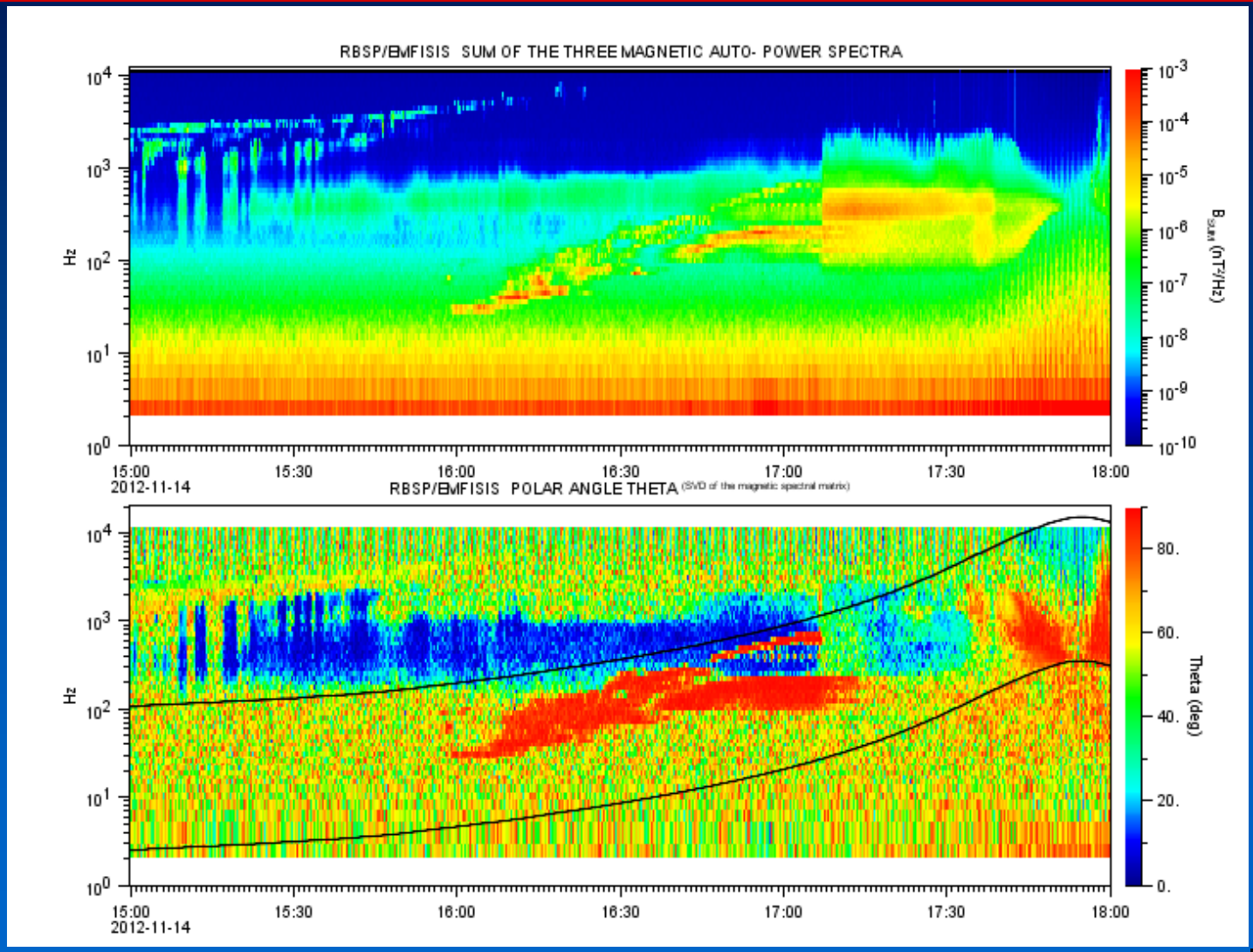
HFR

E PSD

B PSD

From S.Boardsen, GSFC and G. Hospodaarsky, UI

Magnetosonic Wave Vector

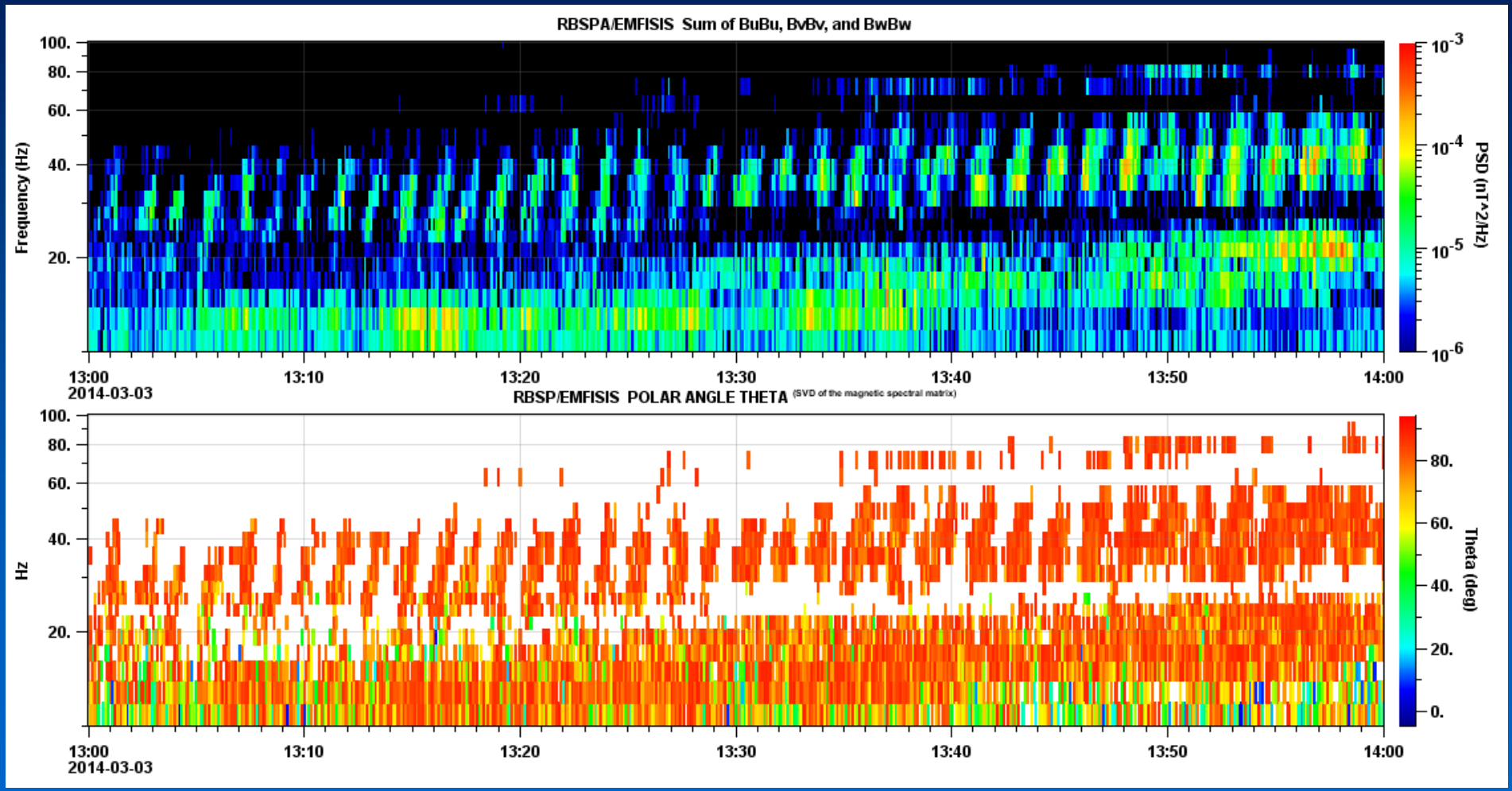


B PSD

Wave Normal θ

Rising Tone Magnetosonic Waves

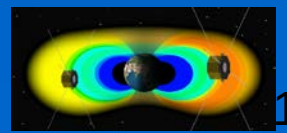
From March 3, 2014.



From S.Boardsen, GSFC and G. Hospodaarsky, UI

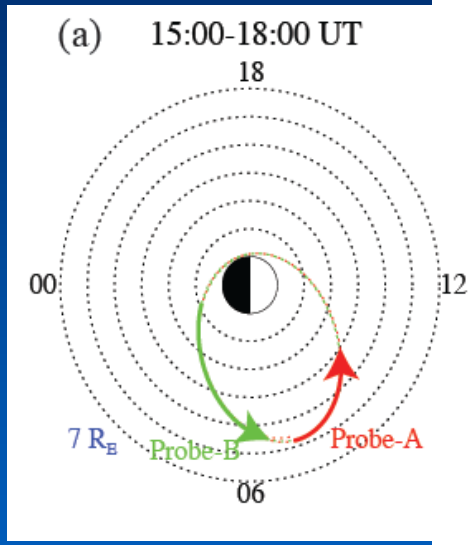
Magnetosonic‘Equatorial Noise’

- Intense, very linearly polarized, planar, and propagating almost exactly perpendicular to B.
- Generated by proton ring distributions.
- Found almost exclusively at the magnetic equator
- Acceleration of electrons to relativistic energies via electron Landau resonance rather than the Doppler shifted electron cyclotron resonance.
- For the lab?
  - Can these be generated by proton ring distributions?
  - Can energization of electrons be seen in the lab?
  - Can the rising tone phenomenon be reproduced?

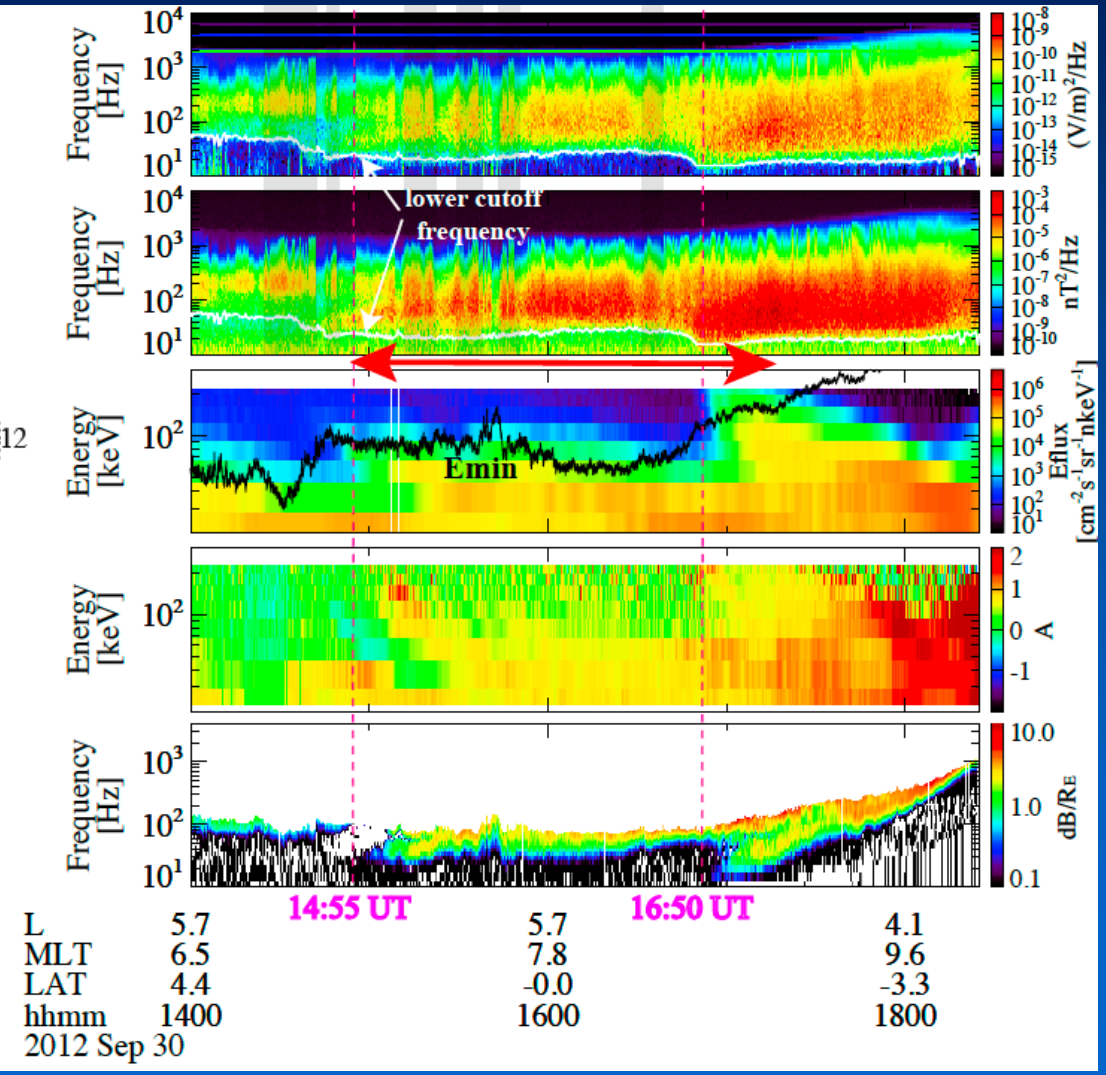


Hiss Growth

RBSP-A shows growth at very low frequencies



From Li, et al. 2013



E

B

MagEIS Electrons

Anisotropy

Growth rate

Plasmaspheric Hiss

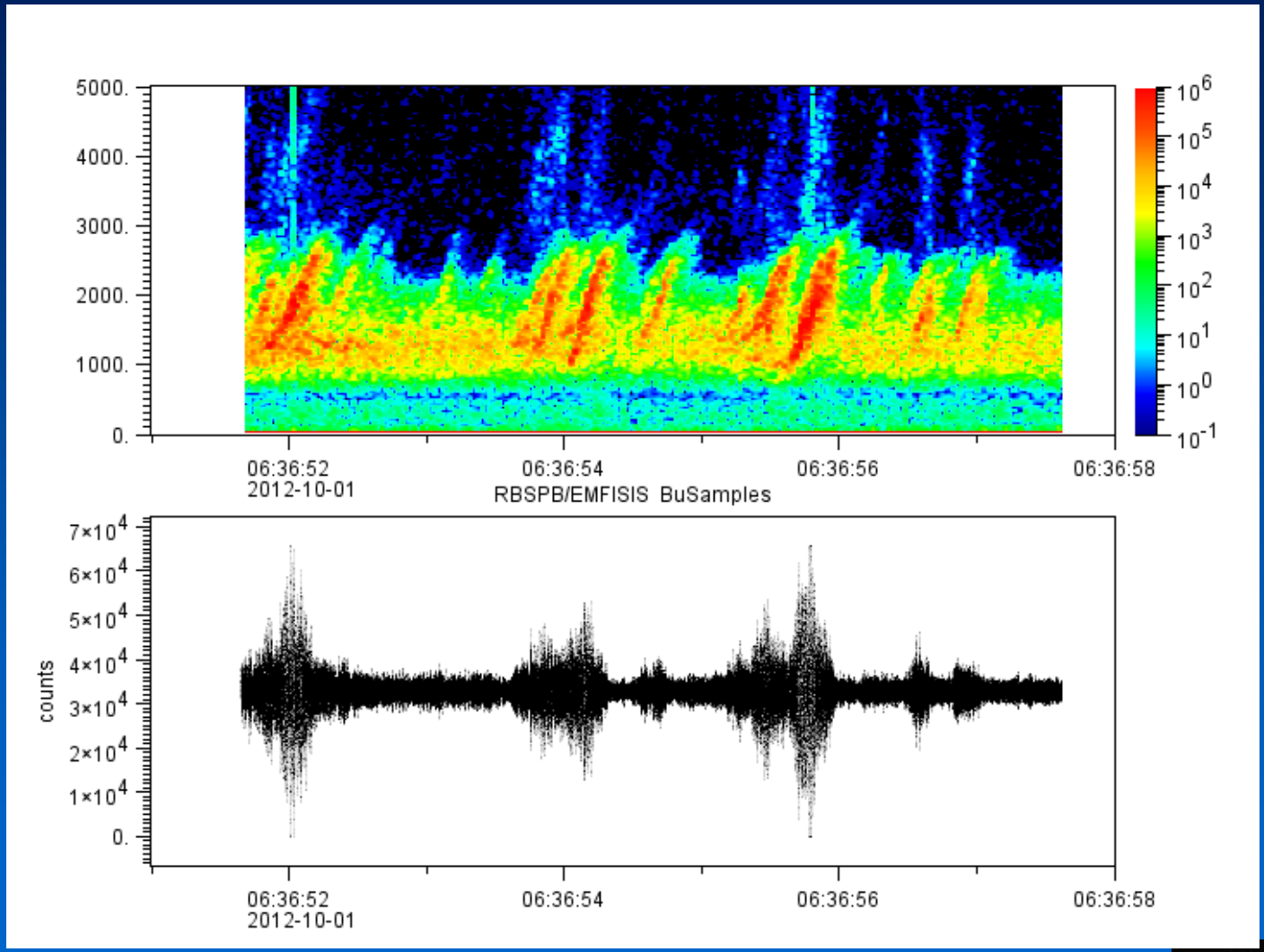
- Several theories for generation mechanism.
- Broadband whistler mode waves between lower hybrid frequency and ~0.1-0.2 f_{ce}
- Interact with relativistic electrons via electron cyclotron resonance:

$$\omega - k_{\|} v_{\|} = \pm \frac{|\Omega_e|}{\gamma}$$

- As for EMIC waves interaction results in pitch angle scattering and loss to the atmosphere.
- For the lab:
  - Can the scattering process be measured?
  - Can we identify growth conditions?

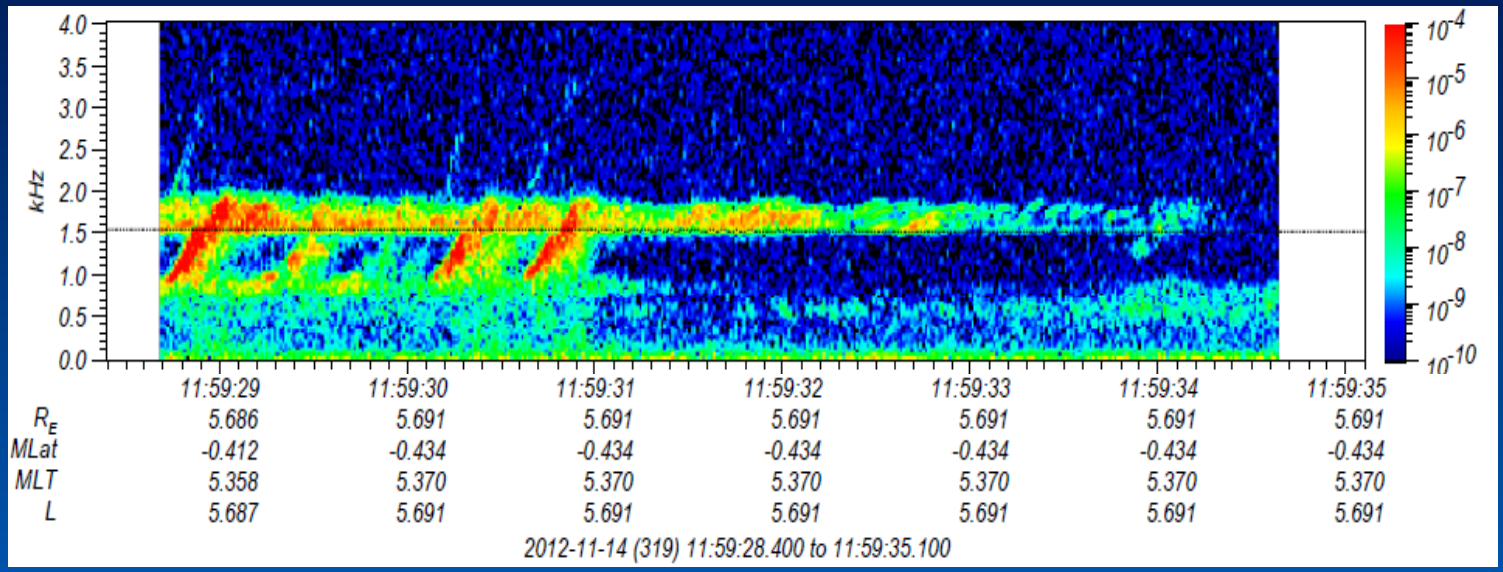
Chorus Waveforms

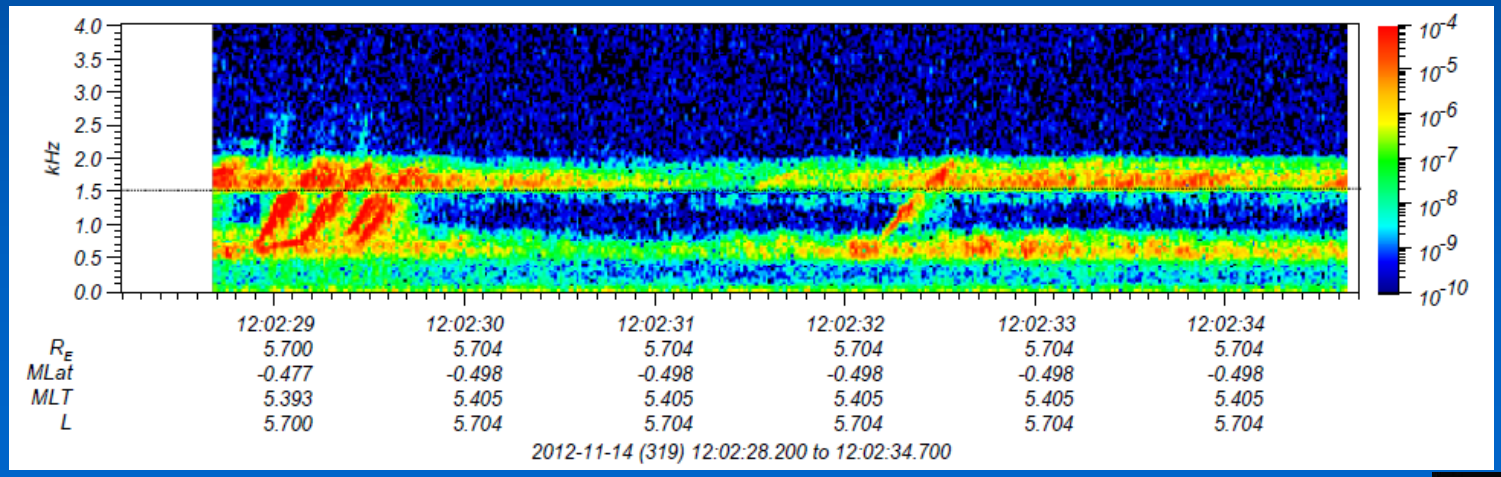
Power level triggered waveform burst captures are working well!



Chorus and the “Gap”

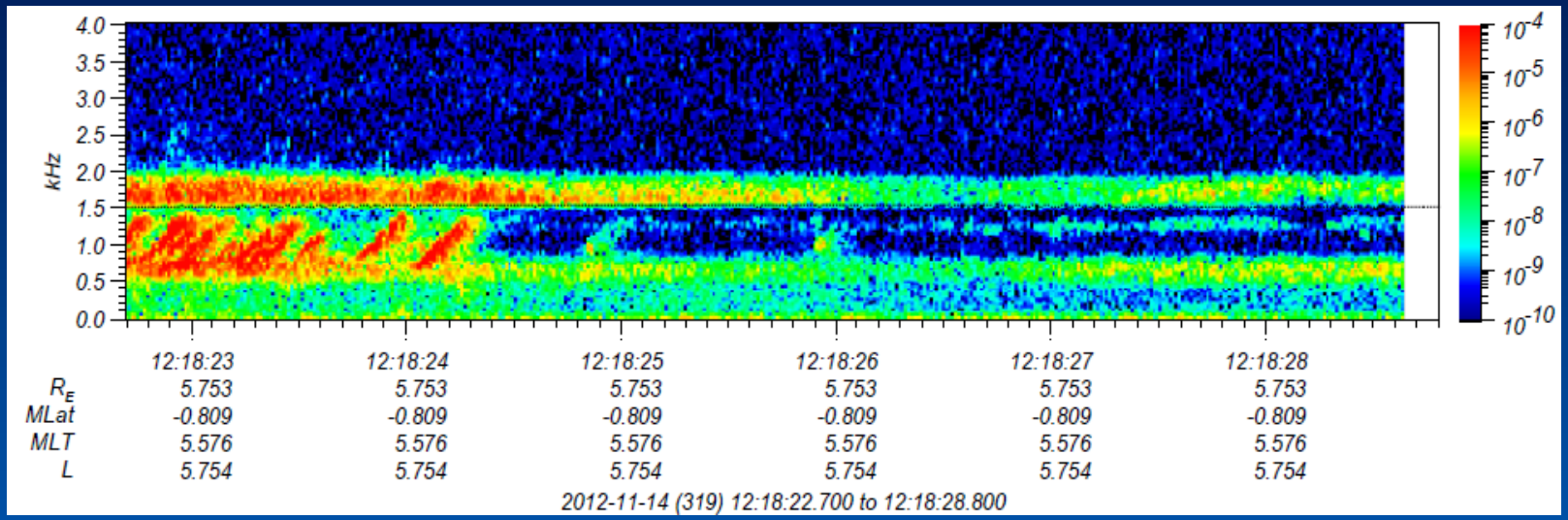
At or very near the generation region

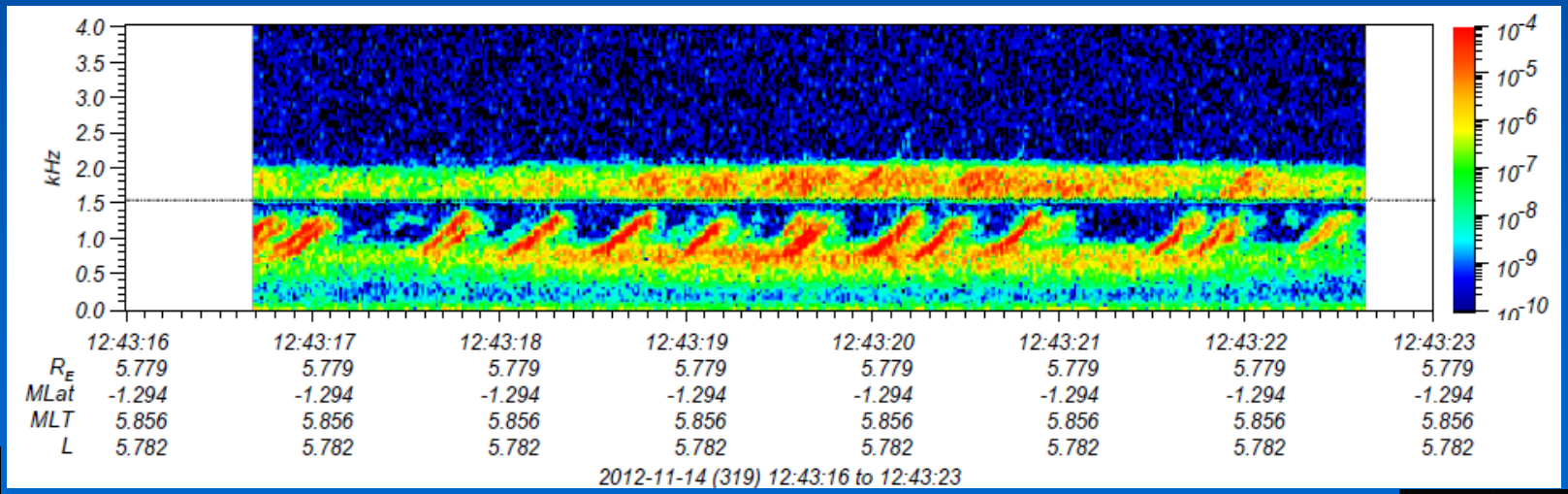




The “Gap” Appears!

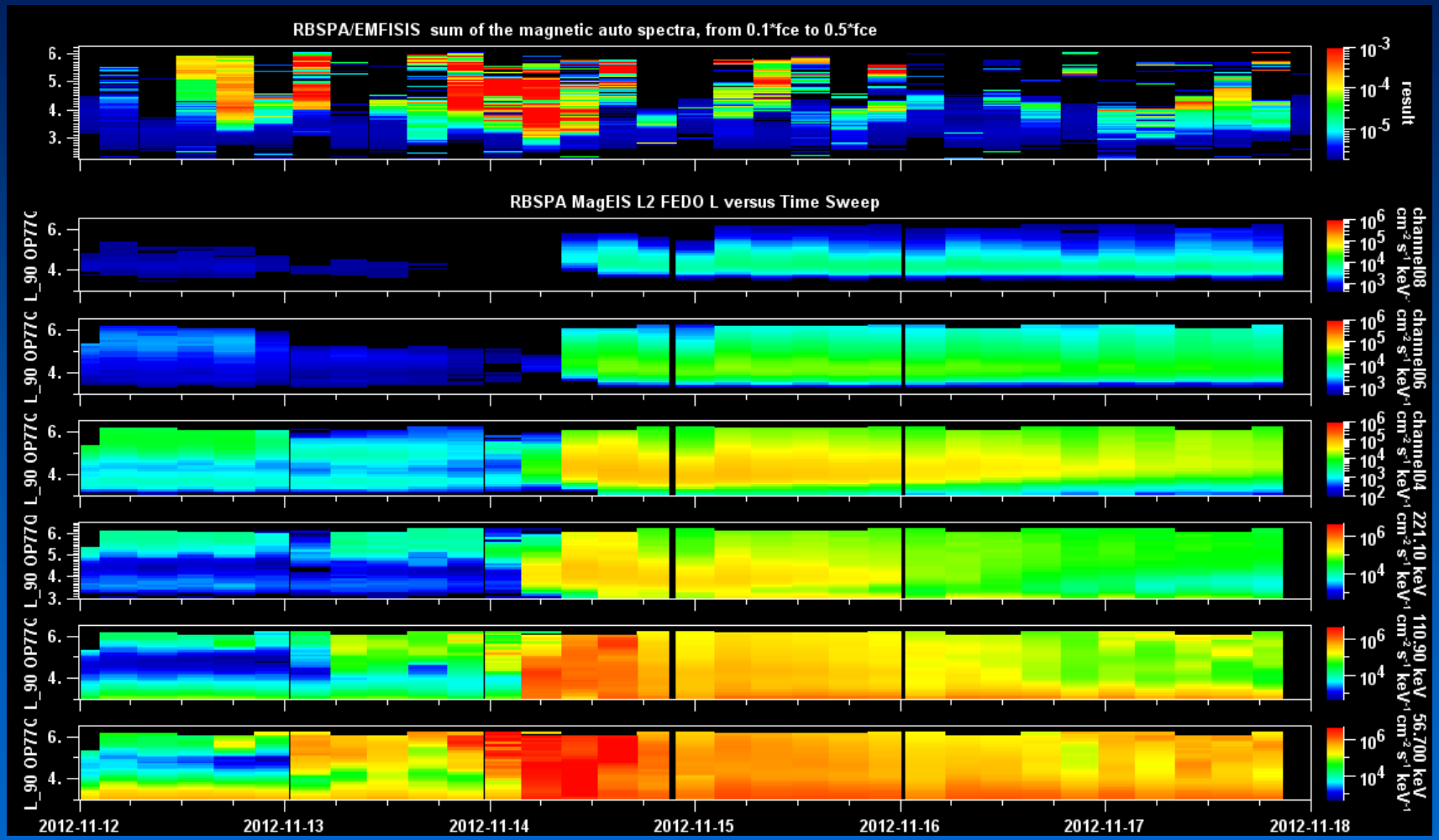
Above the generation region





Chorus Energy Transfer

Lower energy electrons drive chorus which energizes electrons.



1.1 MeV

730 keV

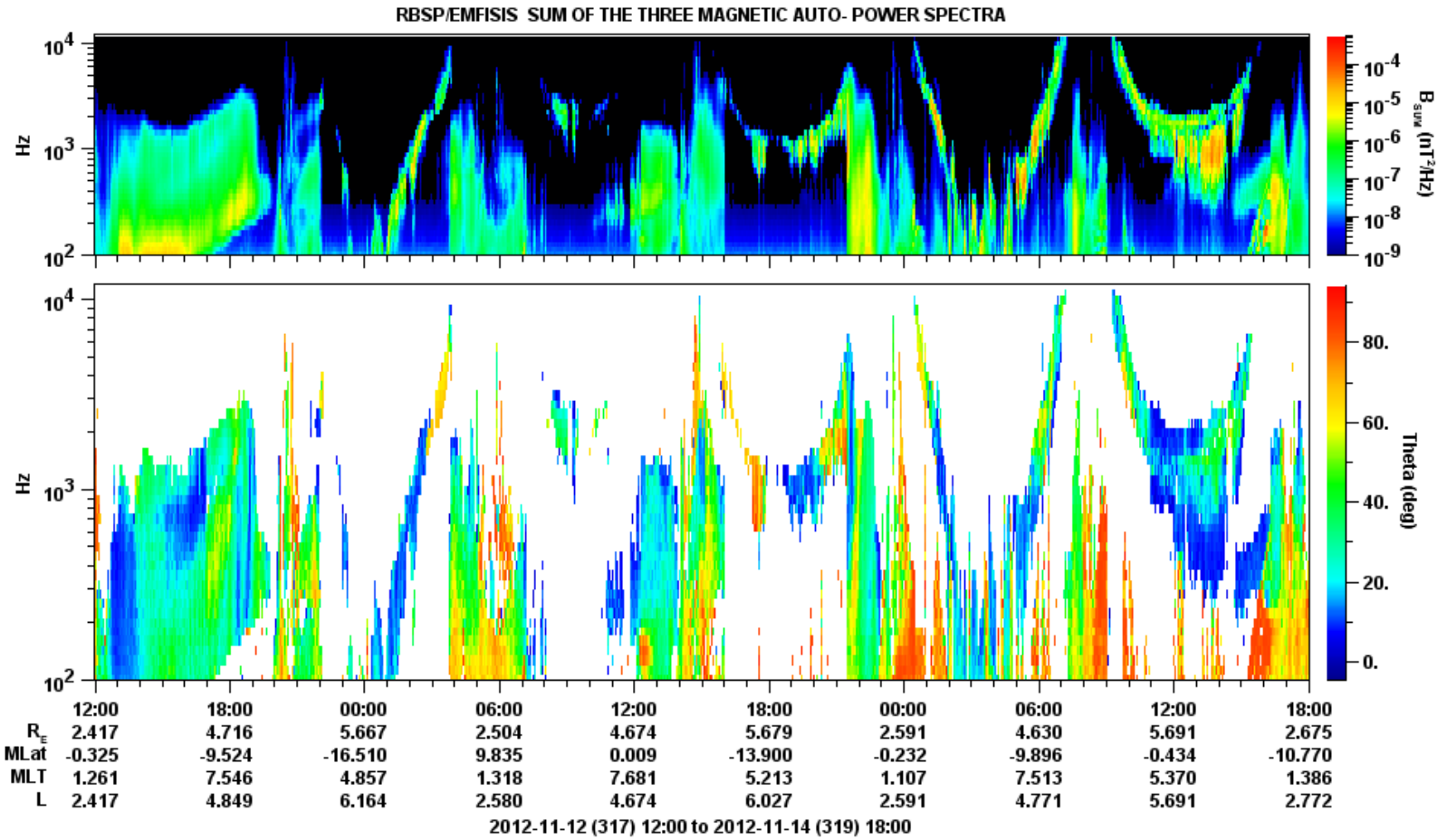
456 keV

221 keV

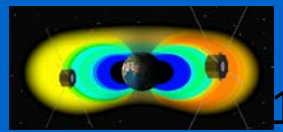
111 keV

57 keV

Wave Normal Direction



Wave normal can be quite oblique



Wave-particle interaction

Parallel propagation, non-relativistic

Whistler mode Dispersion relation:

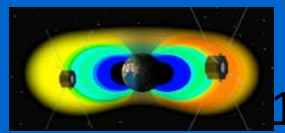
$$\frac{k^2c^2}{\omega^2} = 1 + \frac{{\omega_{pe}}^2}{\omega(\omega_{ce}\cos\theta - \omega)}$$

Resonance Condition:

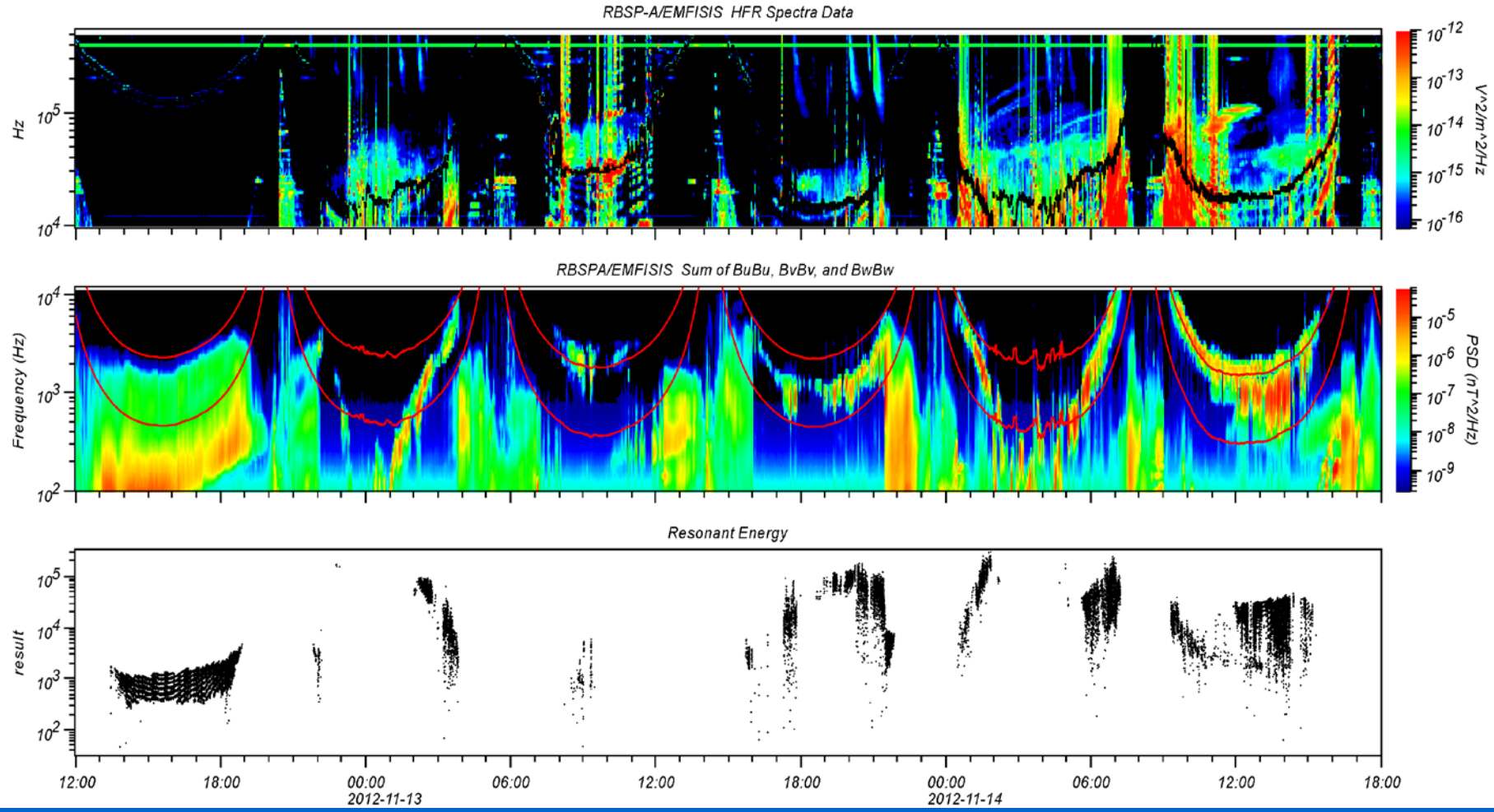
$$\omega - k_{||}v_{||} = \omega_{ce}$$

Resonant Energy:

$$\frac{2E}{mc^2} = \frac{(\omega_{ce} - \omega)^2(\omega_{ce}\cos\theta - \omega)}{\omega\cos^2\theta\,(\omega\omega_{pe}\cos^2\theta - \omega^2 + {\omega_{pe}}^2)}$$

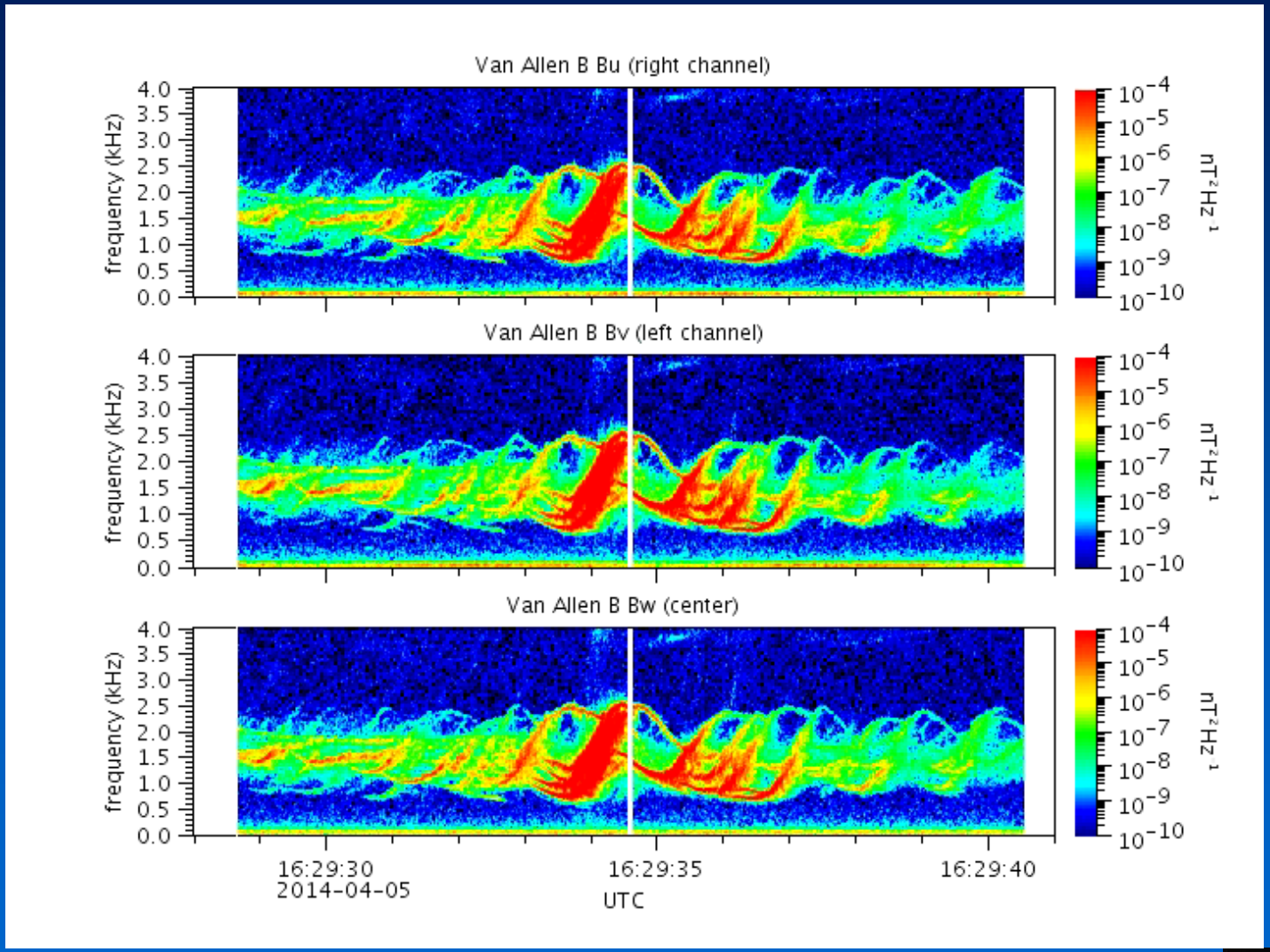


Electron Resonant Energy



Twisted Chours

A fun example to keep the theorists busy!



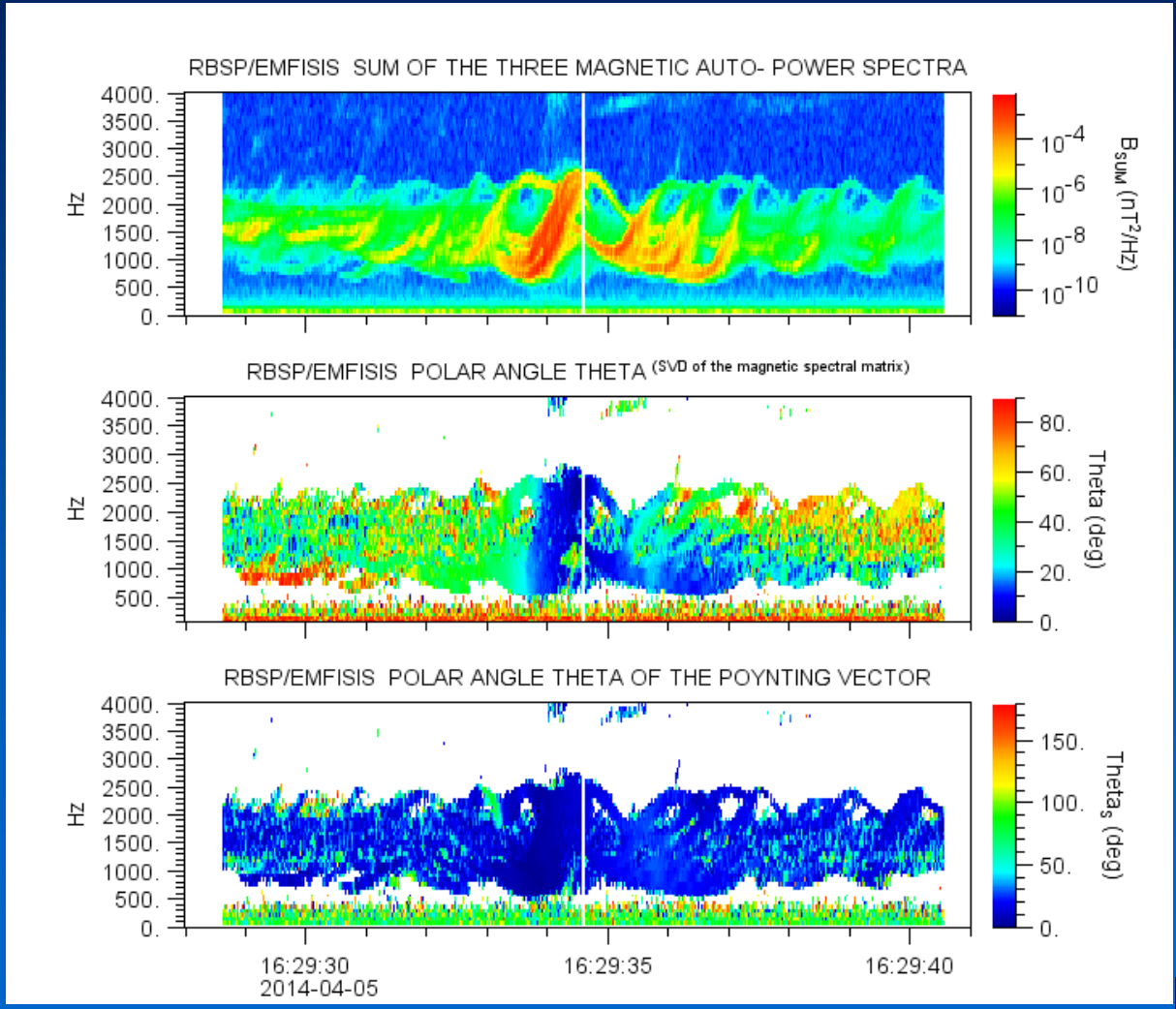
Twisted Chorus: WNA

A mix of oblique and parallel wave normal directions

B

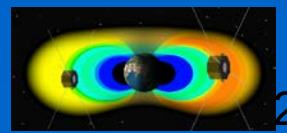
Wave Normal θ

Poynting Flux θ



Whistler Mode Chorus

- Generation mechanism is only generally understood.
- Two frequency ranges. Lower band is 0.1 f_{ce}–0.5 f_{ce}, upper band is 0.5 f_{ce}–0.8 f_{ce}
- Interact with electrons via electron cyclotron resonance to both scatter and accelerate electrons.
- Scattering of lower energy electrons few to 100 keV.
- Acceleration of seed in electrons with 100's of keV energy up to MeV energies is possible.
- For the lab:
  - Recent LAPD & NRL experiments yield chorus-like waves
  - What conditions make simpler rising or falling tones?
  - Can we see electron energization?



Conclusions

- Van Allen Probes continue to return outstanding wave data that allow some of the best wave property measurements ever made.
- There are many phenomena that may be amenable to lab experiments:
  - Generations of EMIC and scattering properties.
  - Generation of magnetosonic waves and acceleration of electrons.
  - Scattering of energetic electrons by hiss
  - Better understanding of the parameters for generating chorus and measuring acceleration of electrons.

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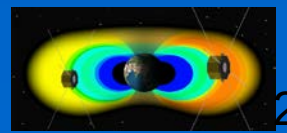

That’s all folks!