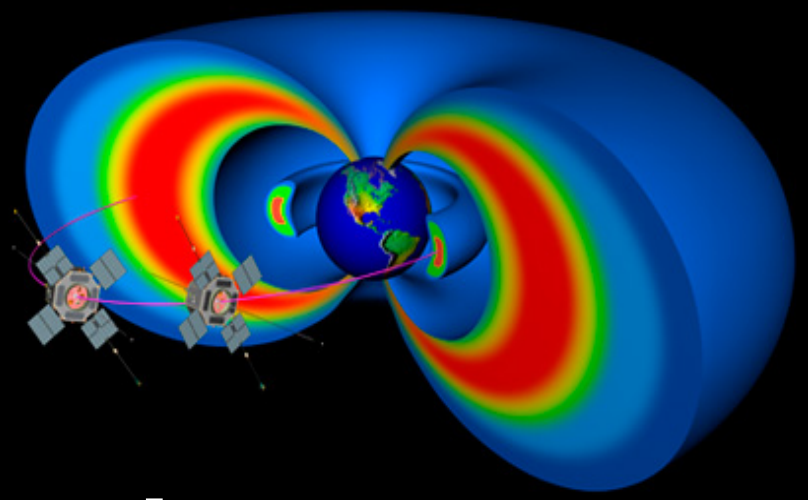
Waves in the Radiation Belts: Overview and Initial Results from the Van Allen Probes

C. A. Kletzing, W. S. Kurth, R. MacDowall, R. B. Torbert, G. B. Hospodarsky, S. R. Bounds, C. W. Smith, J. Connerney, O. Santolik, R. Thorne, V. Jordanova, M. Agnell, J. Wygant, J. W. Bonnell, H. Spence, D. N. Baker, J. Fennel,G. Reeves, B. Blake, J. Goldstein, and W. LI



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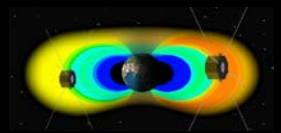
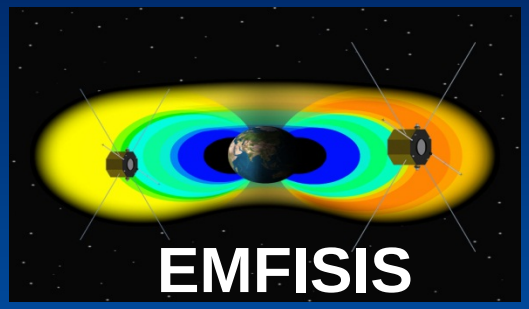


Acknowledgements

We would like to thank the Van Allen Probes instrument teams contributing to this talk:



C. A. Kletzing, W. S. Kurth, M. Acuna, R. J. MacDowall, R. B. Torbert, T. Averkamp, D. Bodet, S. R. Bounds, M. Chutter, J. Connerney, D. Crawford, J. Dolan, R. Dvorsky, G. Hospodarsky, J. Howard, V. Jordanova, R. Johnson, D. Kirchner, B. Mokrzycki, G. Needell, J. Odom, D. Mark, J. Phillips. C. Piker, S. Remington, O. Santolik, R. Schnurr, D. Sheppard, C. W. Smith, R. M. Thorne, J. Tyler, and the extended Van Allen Probes EMFISIS team

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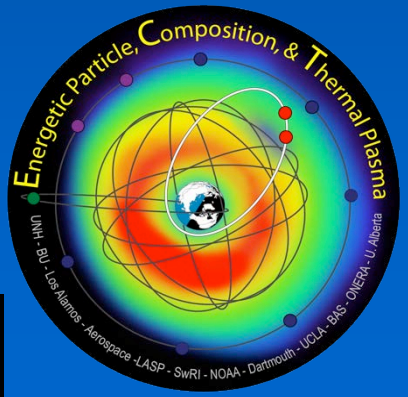
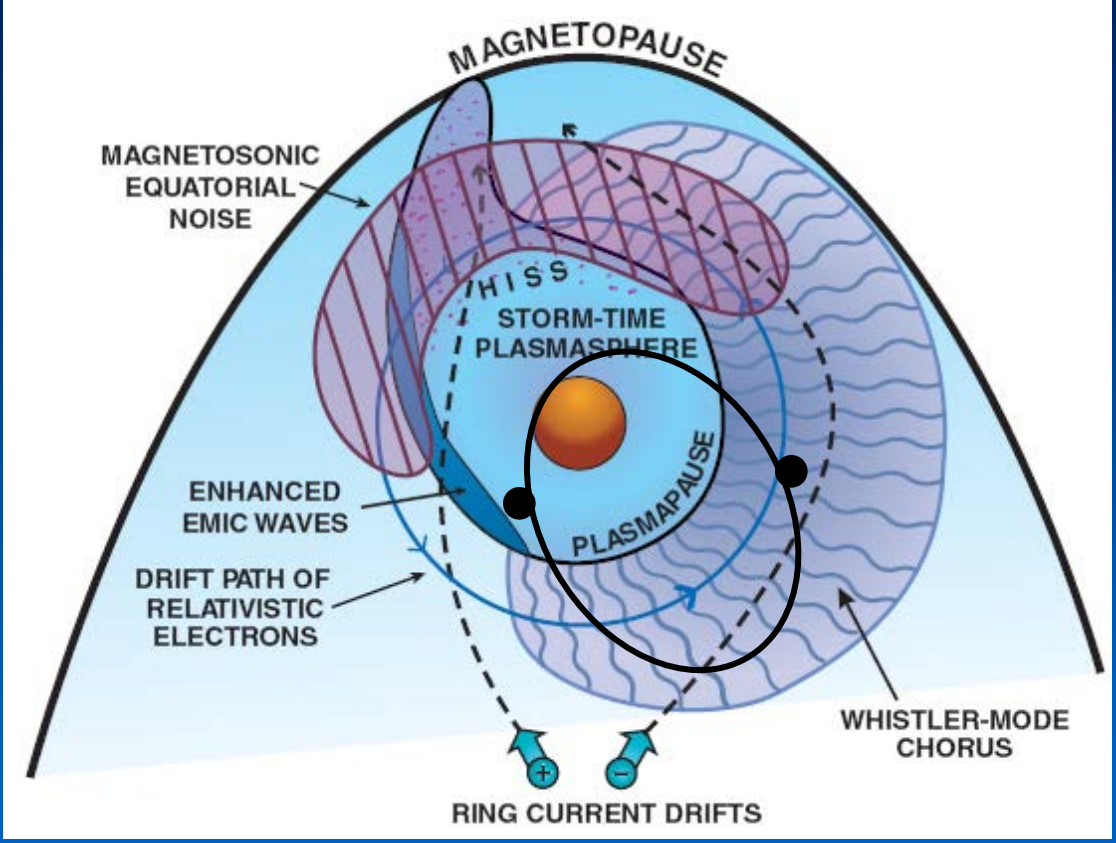


Harlan Spence, Geoff Reeves, Herb Funsten, Bern Blake, Dan Baker, Richard Thorne, Anthony Chan, Jim Clemmons, Scot Elkington, Joe Fennell, Reiner Friedel, Jerry Goldstein, Mike Henderson, Mary Hudson, Jörg-Micha Jahn, Vania Jordanova, Shri Kanekal, Brian Larsen, Xinlin Li, Liz MacDonald, Paul O'Brien, Ruth Skoug, Michelle Thomsen, and the extended RBSP-ECT Science Team

Van Allen Probes

Launched on August 30, 2012



Two identically instrumented satellites is a first!
Continuously in the radiation blets.

EMIC Waves

- Driven by ring current ions
- Interact with relativistic electrons via electron cyclotron resonance for either L or R polarization:

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

- This interaction results in pitch angle scattering and loss to the atmosphere.
- Frequencies in bands below ωcifor H+, He+, and O+ Amplitudes of 1-10 nT.
- A key question is: When is this effective for electrons below 2 MeV?

Plasmaspheric Hiss

- Several theories for generation mechanism.
- Frequency range is 0.1 < *f*< 2 kHz.
- Amplitudes up to ~100 pT, average ~40 pT.
- Interact with relativistic electrons via electron cyclotron resonance:

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

- As for EMIC waves interaction results in pitch angle scattering and loss to the atmosphere.
- Can scatter electrons from ~50 keV up to ~1 MeV in energy.

Magnetosonic‘Equatorial Noise’

- Intense, very linearly polarized, planar, and propagating almost exactly perpendicular to B.
- Frequency range is a few Hz up to fLH(<300 Hz)
- Amplitudes of 10-6–10-2nT2/Hz.
- Generated by proton ring distributions.
- Acceleration of electrons to relativistic energies via electron Landau resonance rather than the Doppler shifted electron cyclotron resonance.
- Thorne et al., 2007 show that bounce-averaged energy and pitch angle diffusion are quite significant.
- Can give acceleration comparable to chorus.

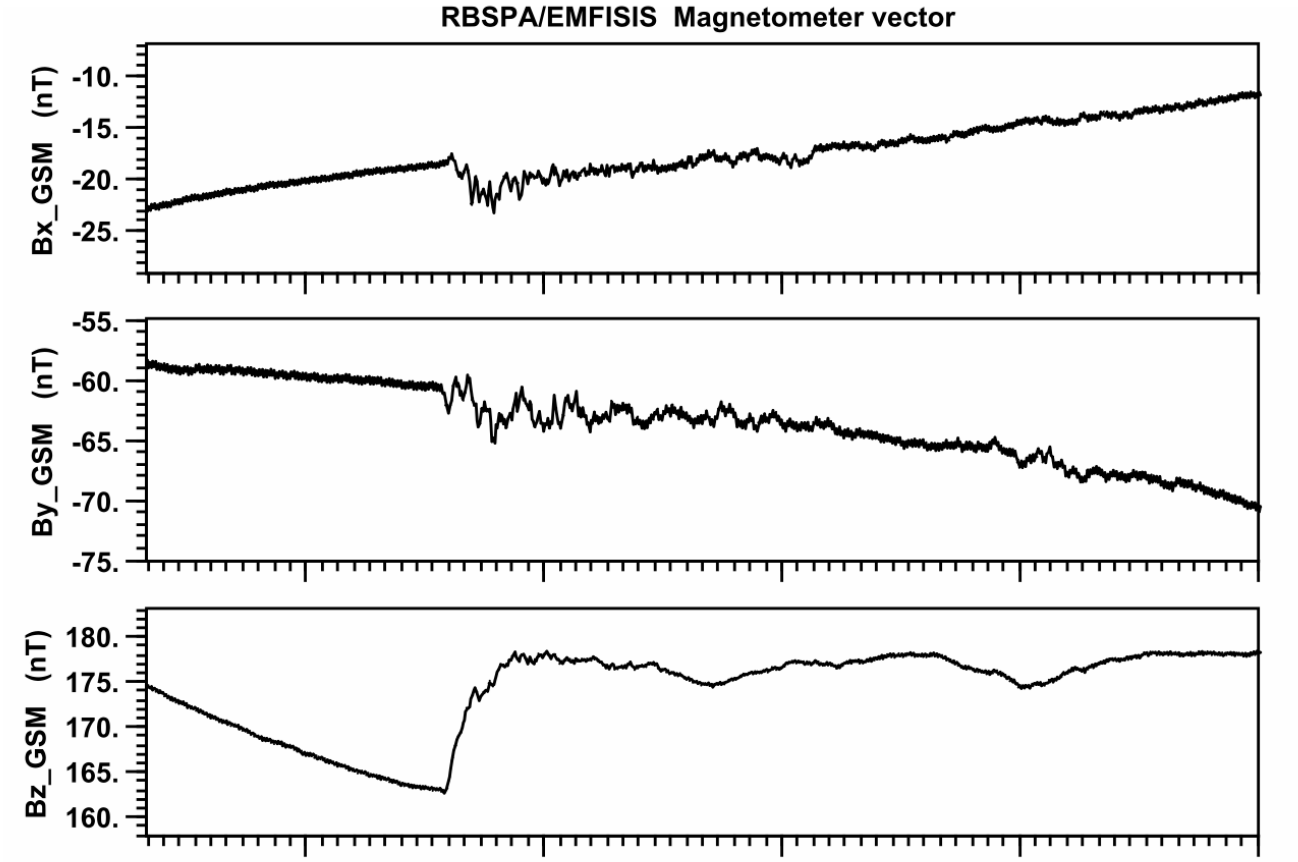
Whistler Mode Chorus

- Generation mechanism is only generally understood.
- Two frequency ranges. Lower band is 0.1 fce–0.5 fce, upper band is 0.5 fce–0.8 fce
- Amplitudes up to 10-2nT2/Hz, average during active times of ~10-3nT2/Hz.
- Interact with electrons via electron cyclotron resonance to both scatter and accelerate electrons.
- Scattering is of lower energy electrons few keVto 100 keV.
- Acceleration of seed in electrons with 100's of keVenergy up to MeVenergies is possible.

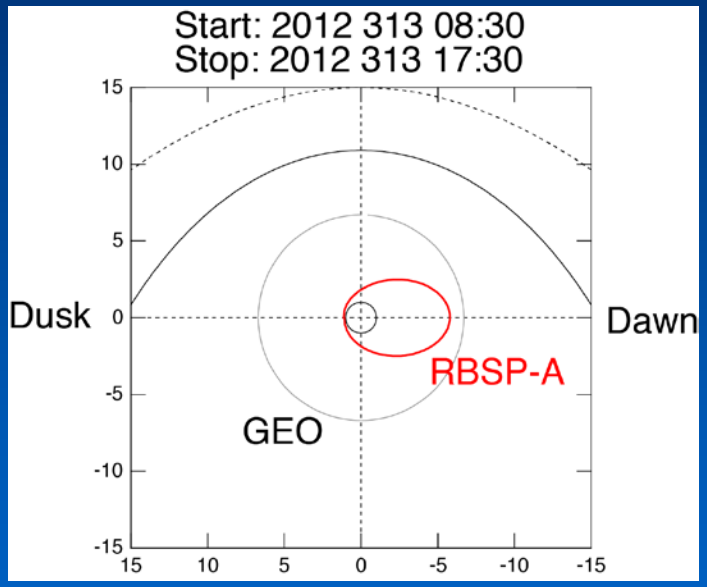
EMFISIS Components and Performance

- **Triaxial Magnetometer** (MAG):
  - vector B, DC-30 Hz;
  - 3 ranges: ± 256 nT, ± 4,096 nT and ± 65,536 nT with corresponding resolutions: ±0.008 nT, ±0.125 nT ±2nT
- **Waves:**
  - *Magnetic field:*
    - vector B.
    - 10 Hz-12 kHz and sensitivity: $3x10^{-11}$ nT^2Hz^{-1} @1 kHz.
  - *Electric field*:
    - vector E from double probe experiment.
    - 10 Hz-12 kHz (vector),\10-400 kHz (single channel)
    - sensitivity: $3x10^{-17}$ $V^2m^{-2}Hz^{-1}$ @ 1 kHz,
- **EMFISIS data rate: 31.6 kbits/s.**

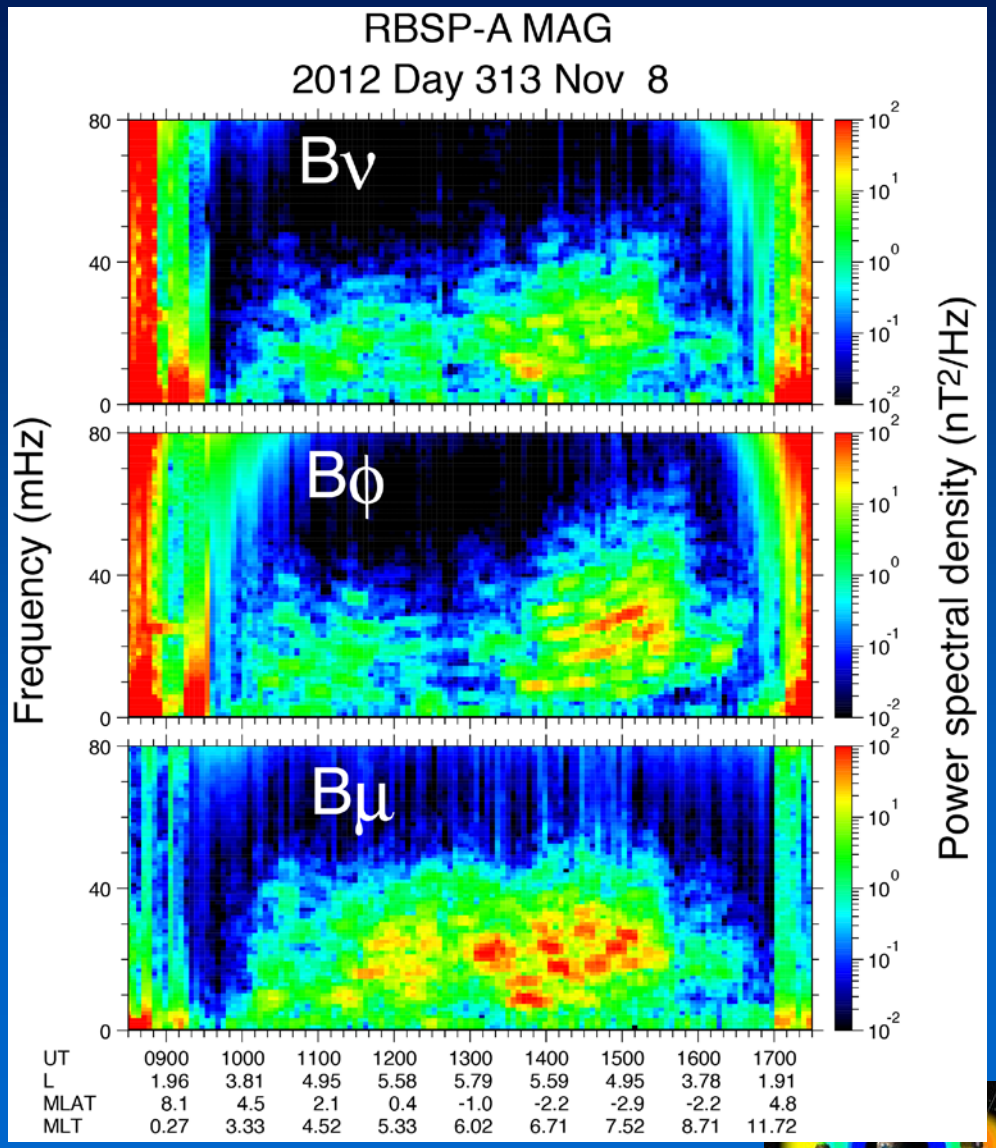
EMFISIS DC Magnetic Field



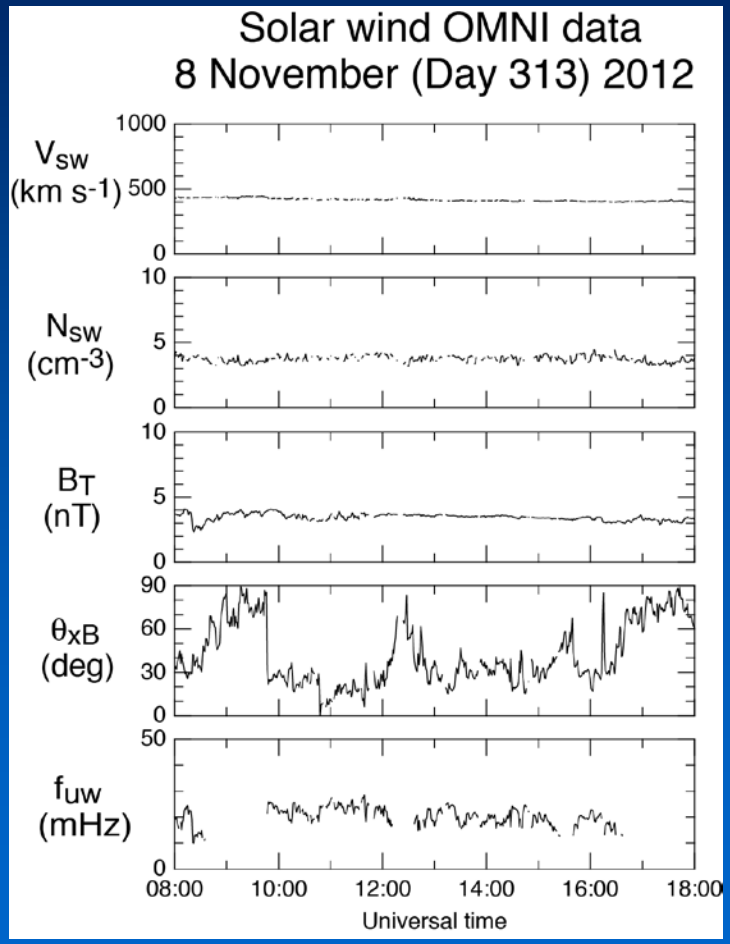
Magnetic field dynamic spectra

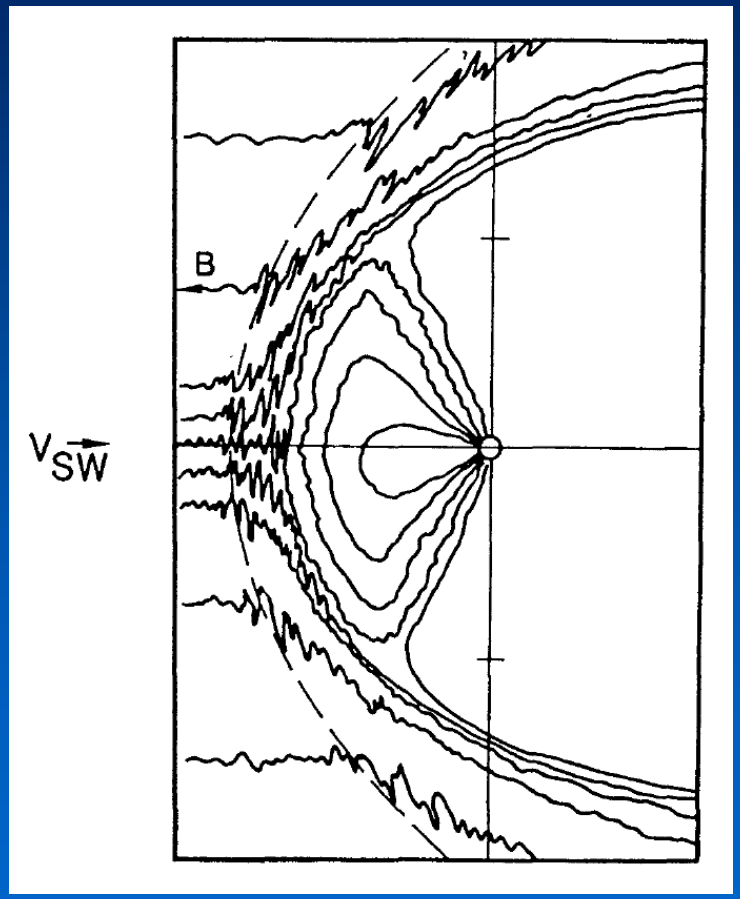


From K. Takahashi, APL



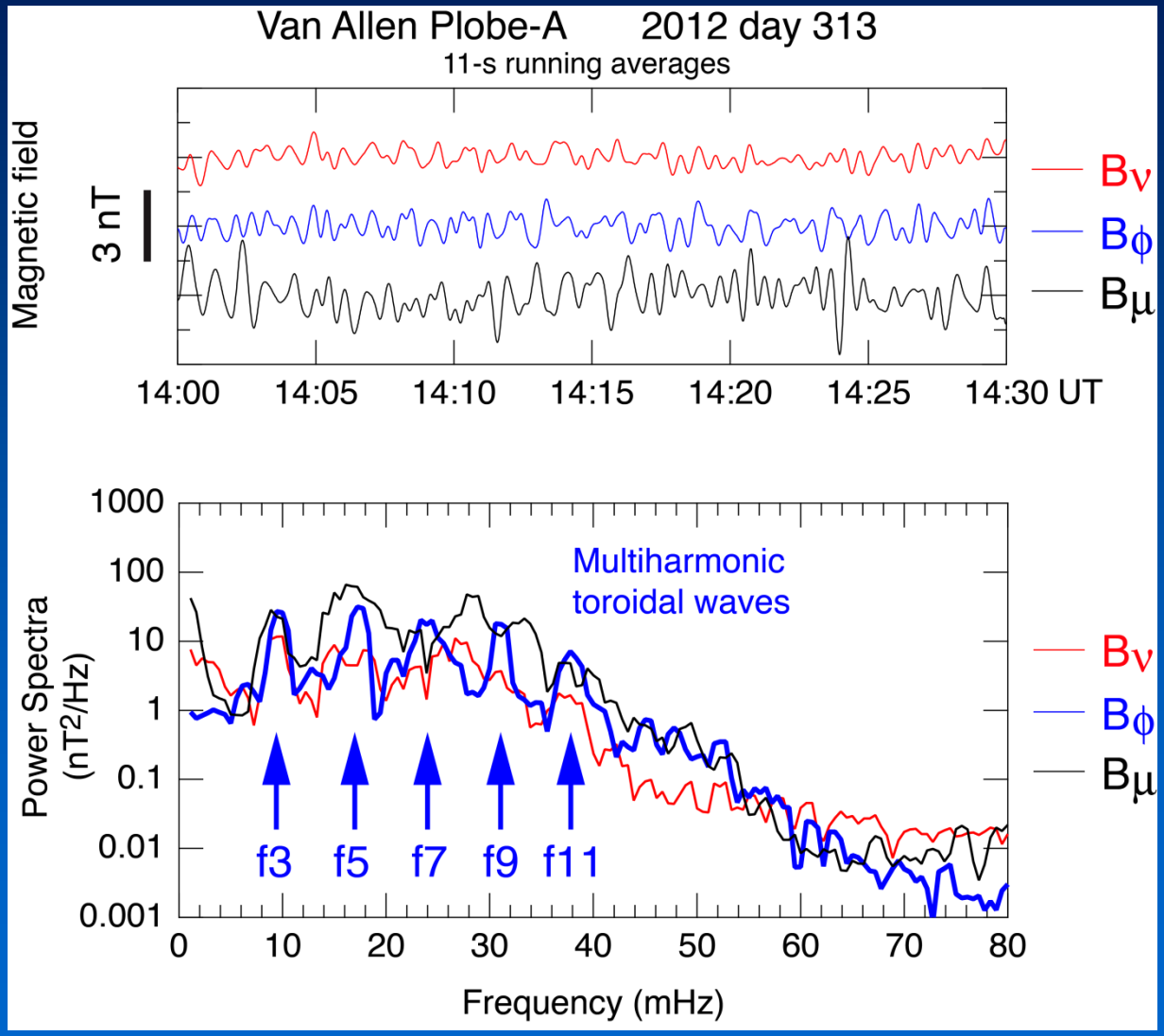
ULF Wave generation at quasiparallel shock



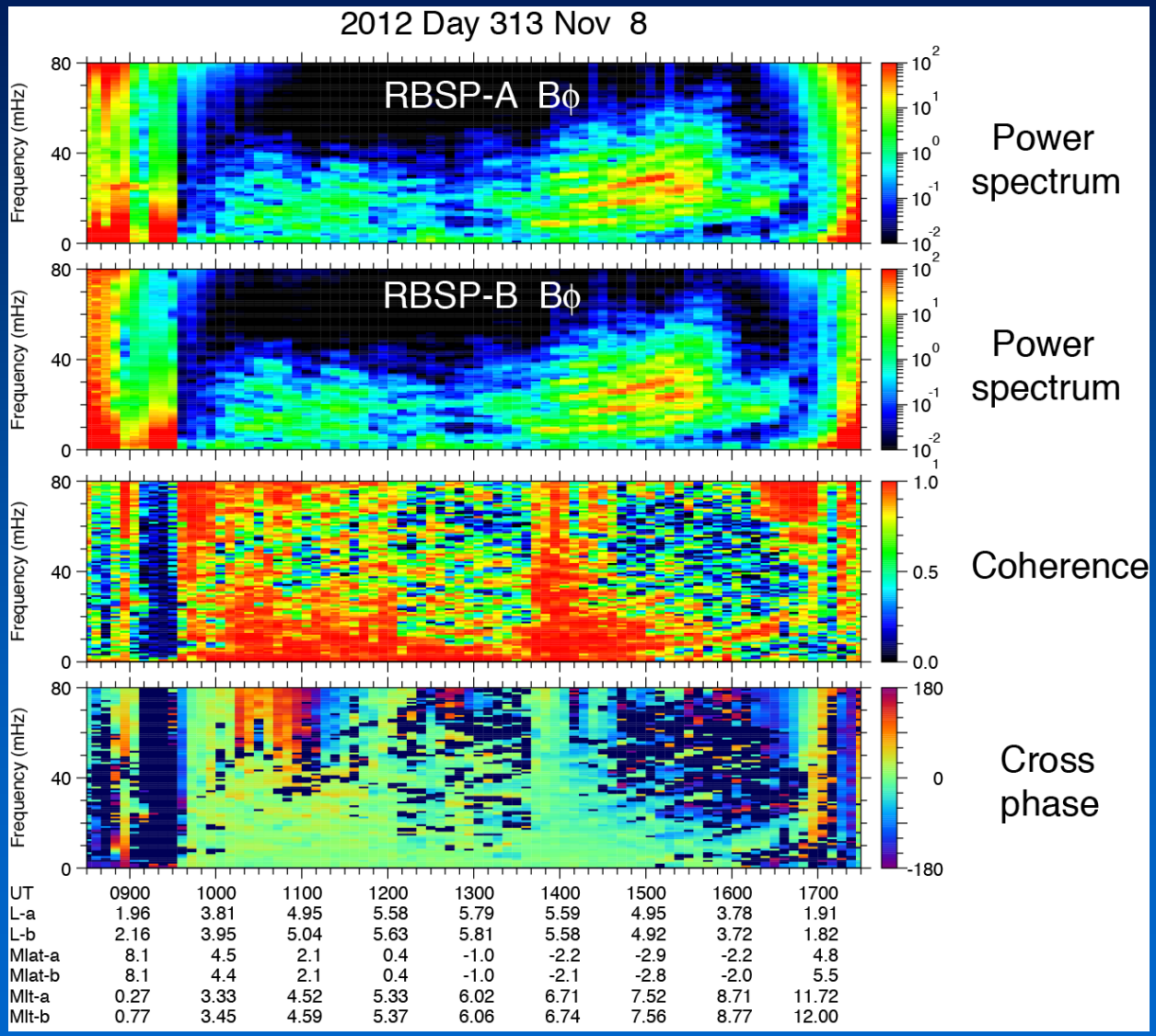


Greenstadt et al. [1980]

Magnetic field time series and spectra

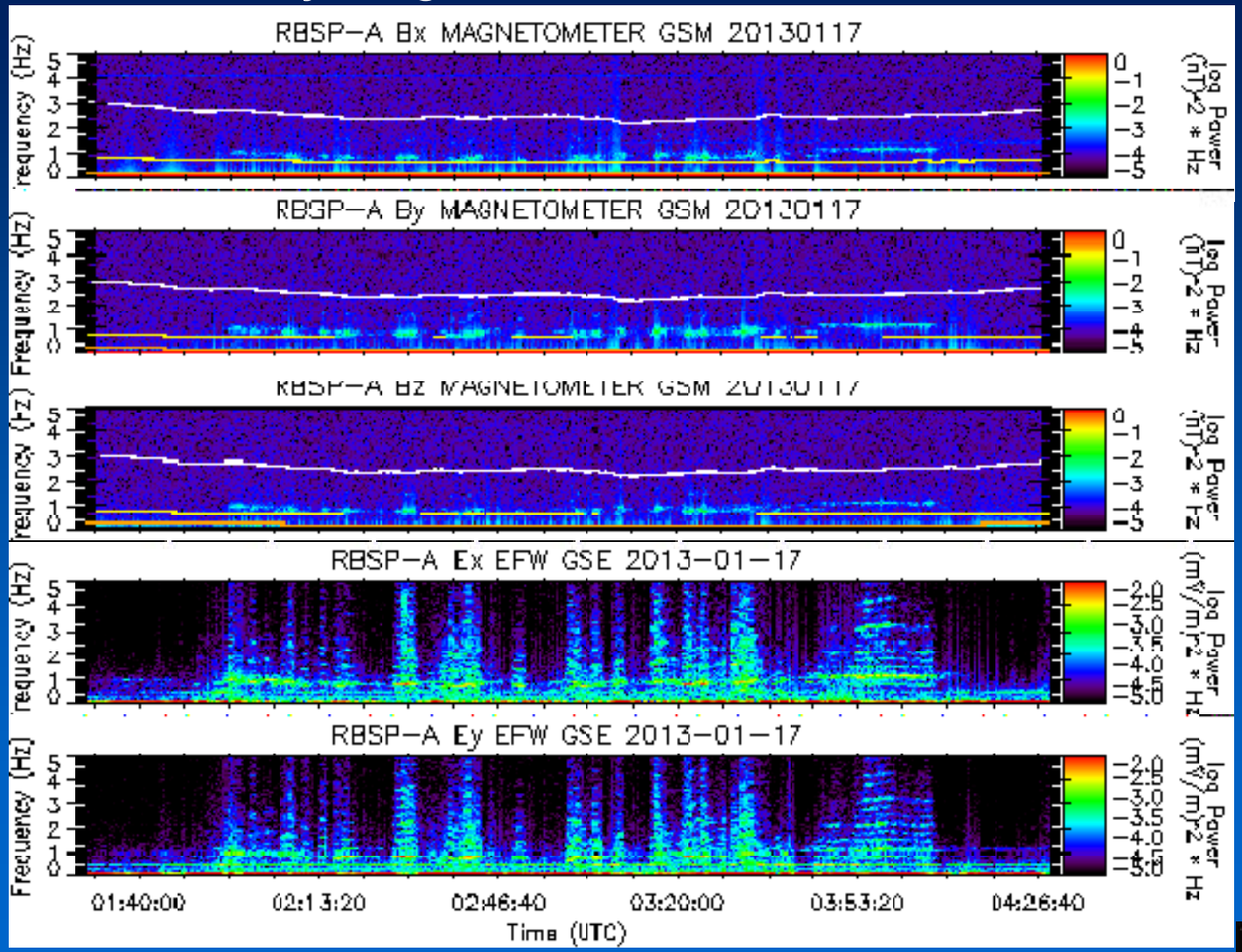


Cross spectral analysis



EMIC Waves

Hydrogen band seen in both E nd B



Bx

By

Bz

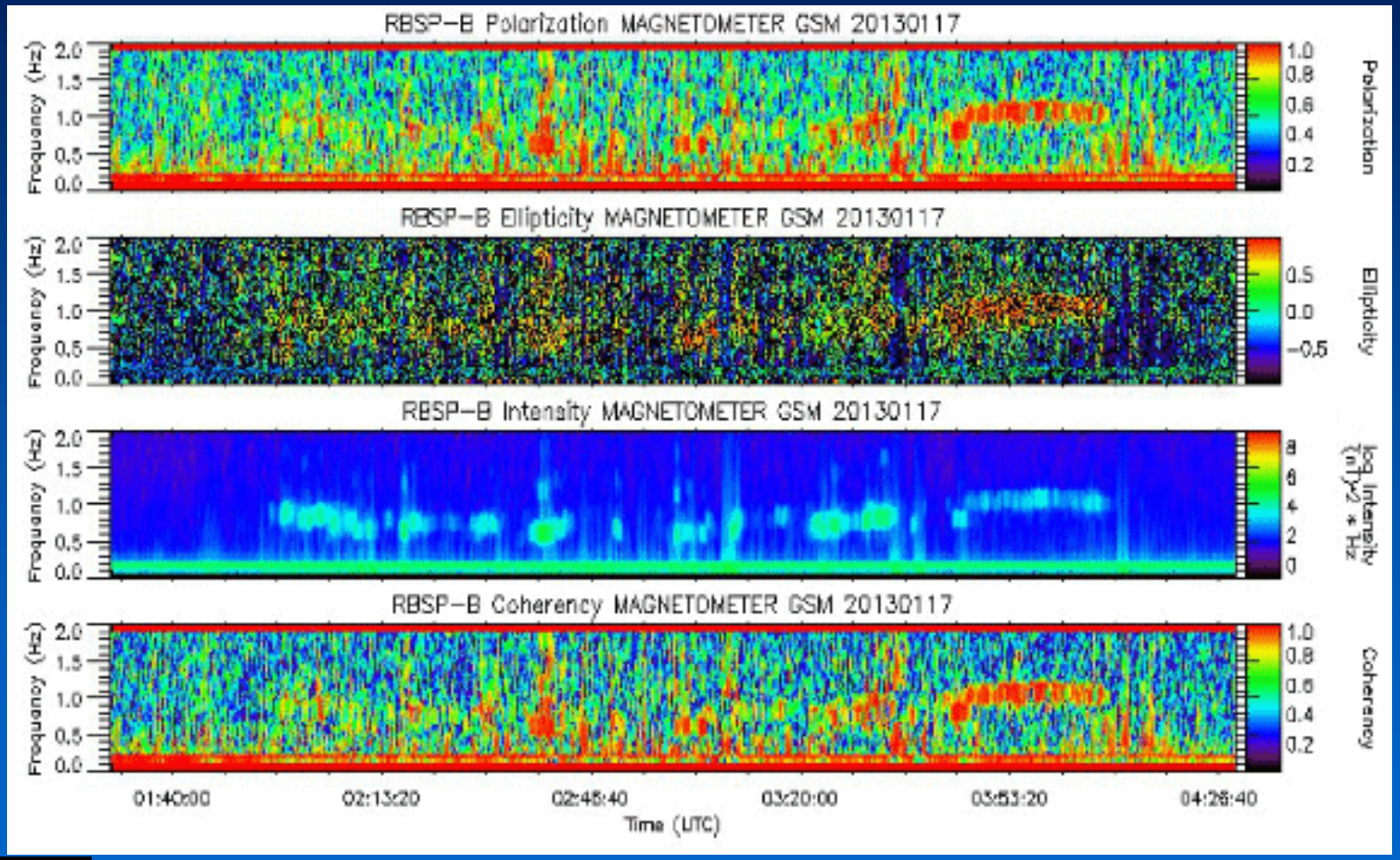
Ex

Ey

From M. Argall, uNH

EMIC Wave Properties

Hydrogen band seen in both E nd B



Polarization

Ellipticity

|B|

Coher.ence

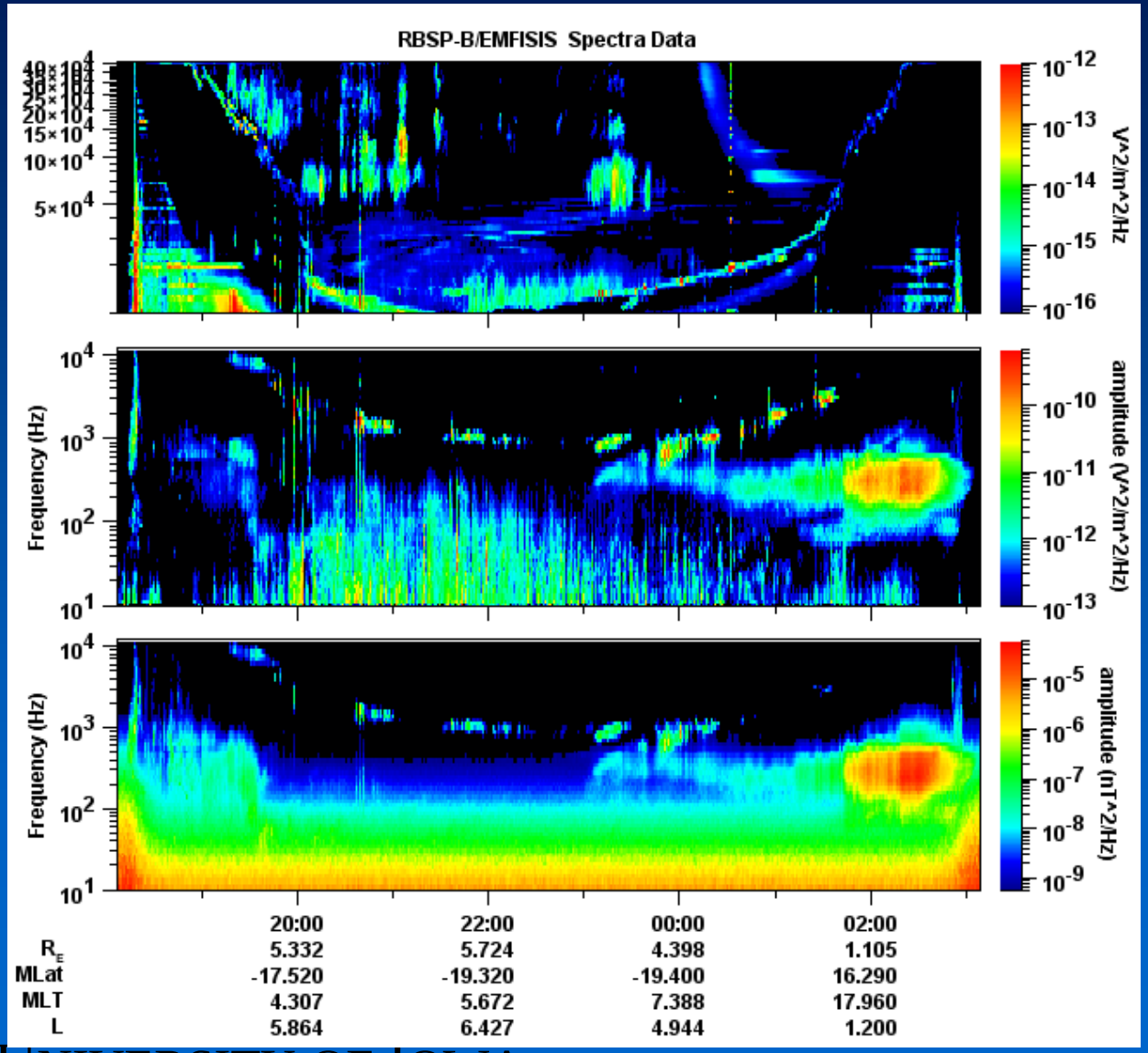
EMFISIS Wave Spectra Data Example

(11-17-2012)

E-HFR

E spec sum

B spec sum

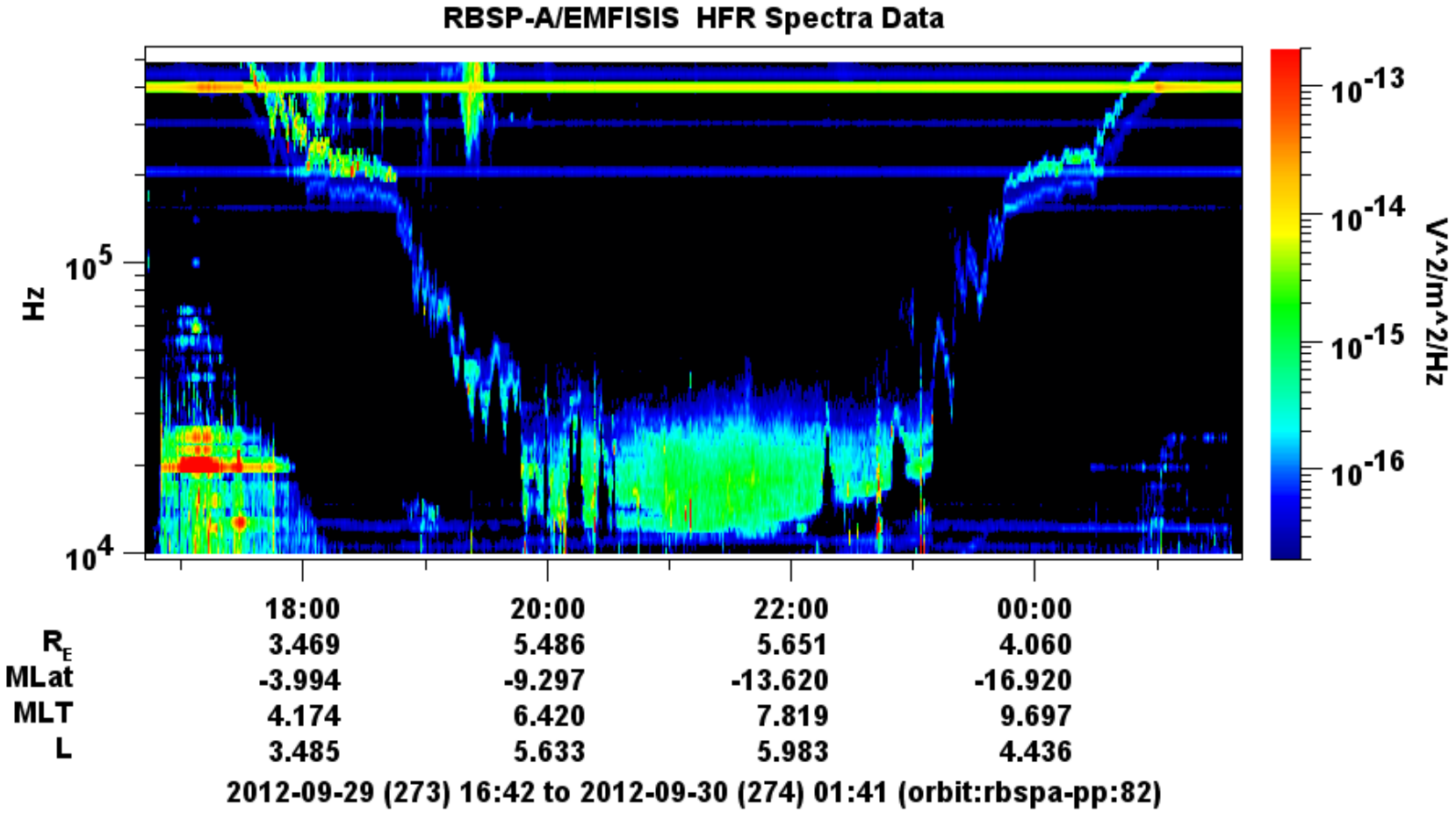


HFR (single channel): 10 kHz-400 kHz

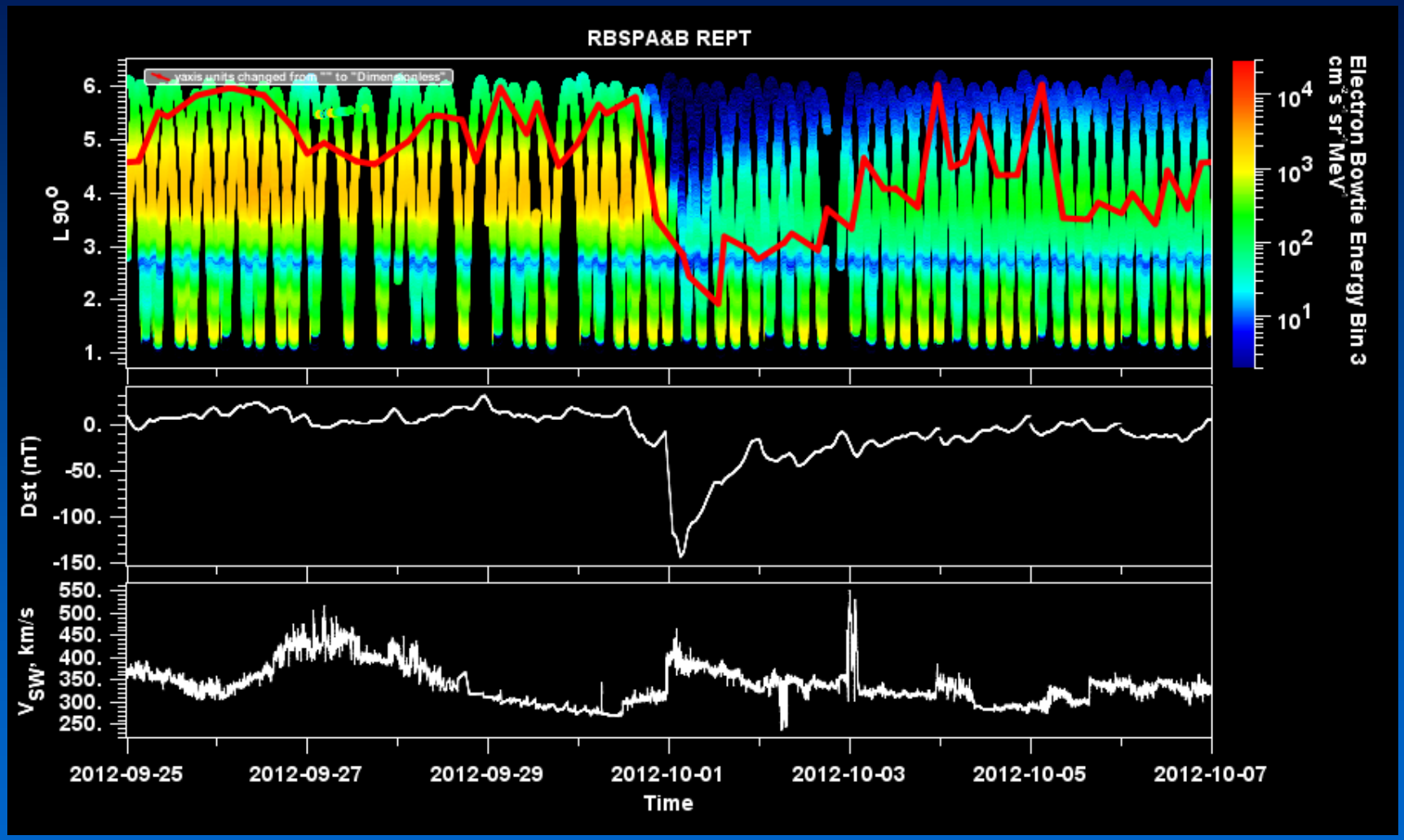
Vector E: 10 Hz-12 kHz

Vector B: 10 Hz-12 kHz

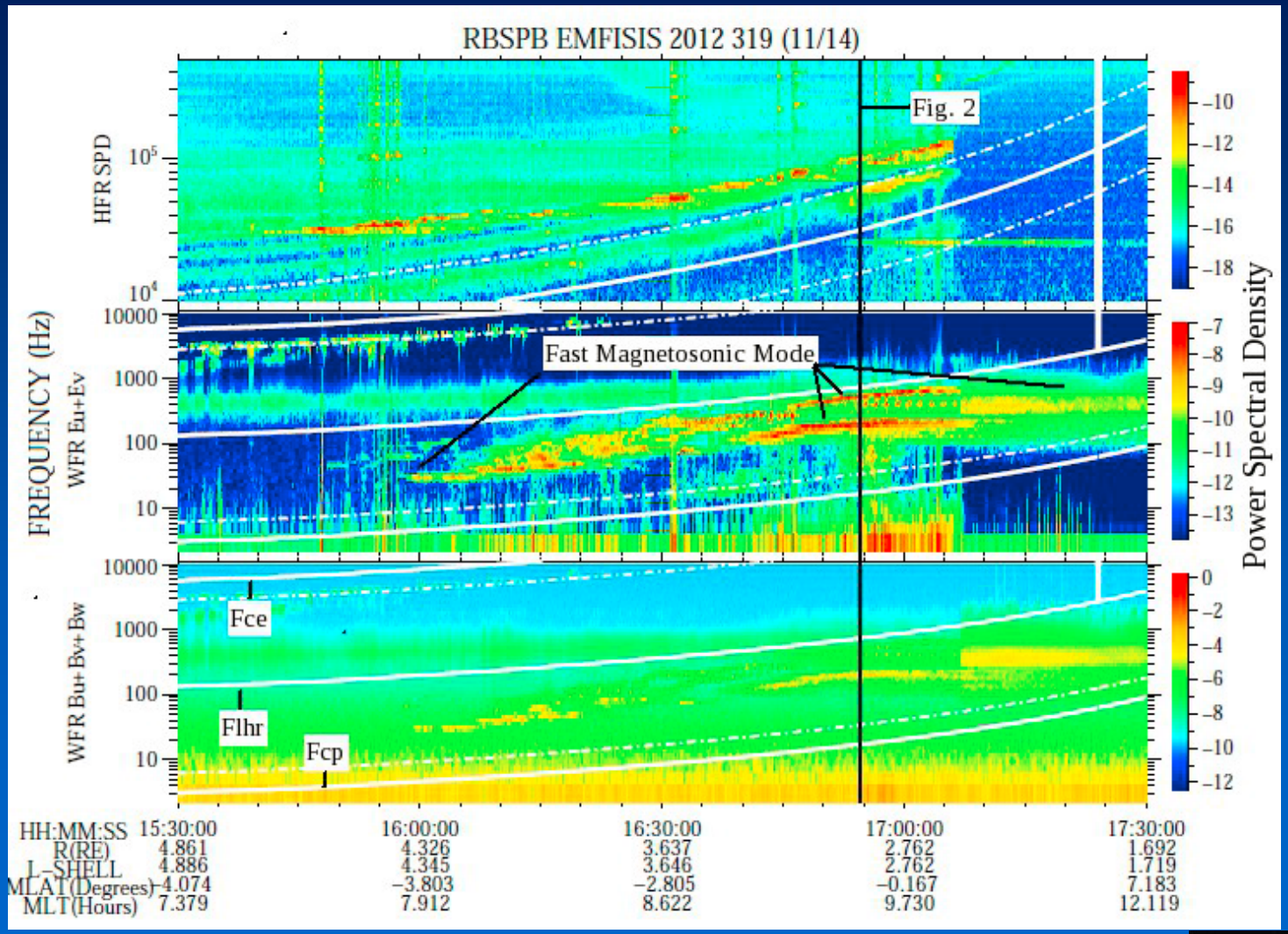
Plasmapause from UHR



Plasmapause and Outer Belt

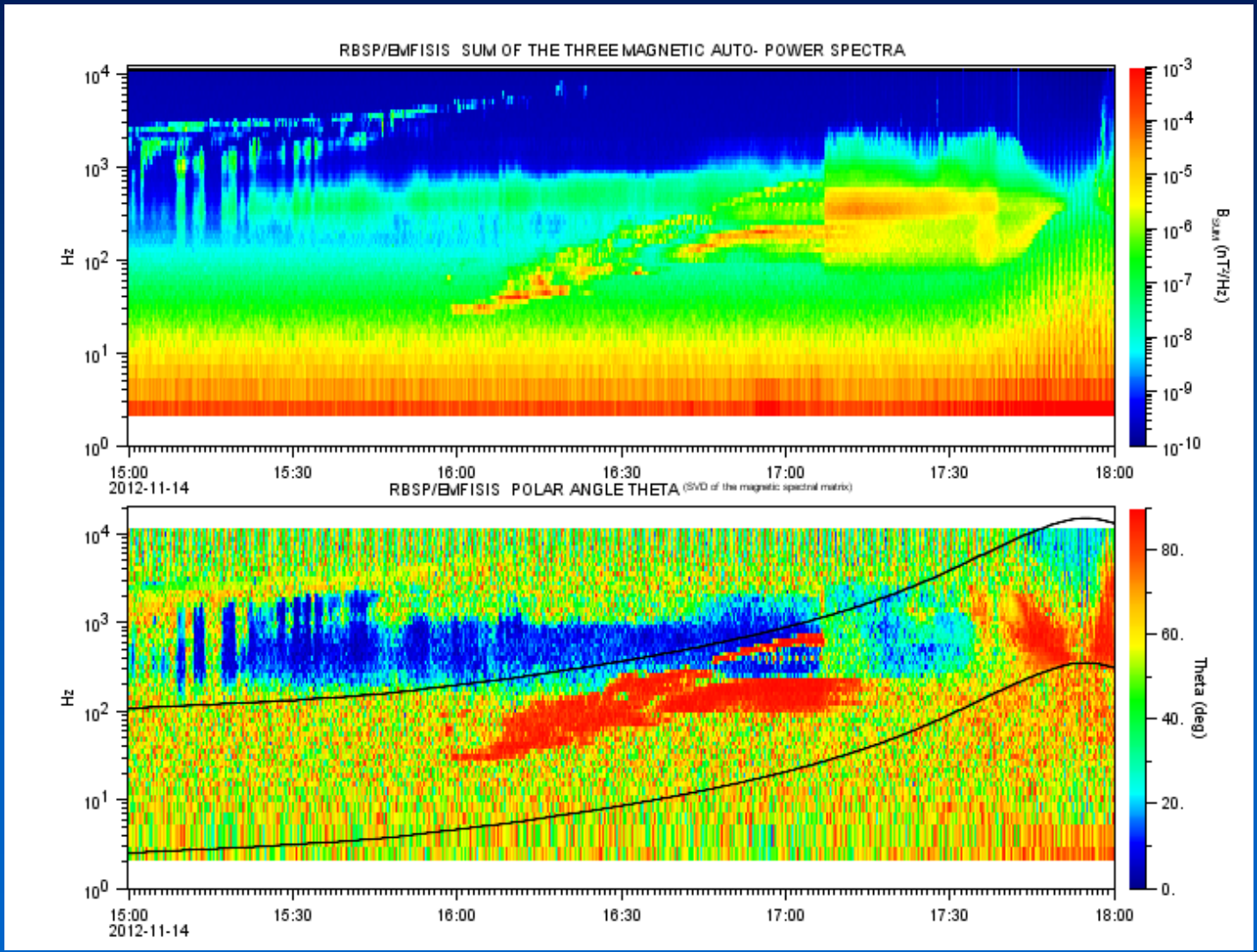


Magnetosonic Waves



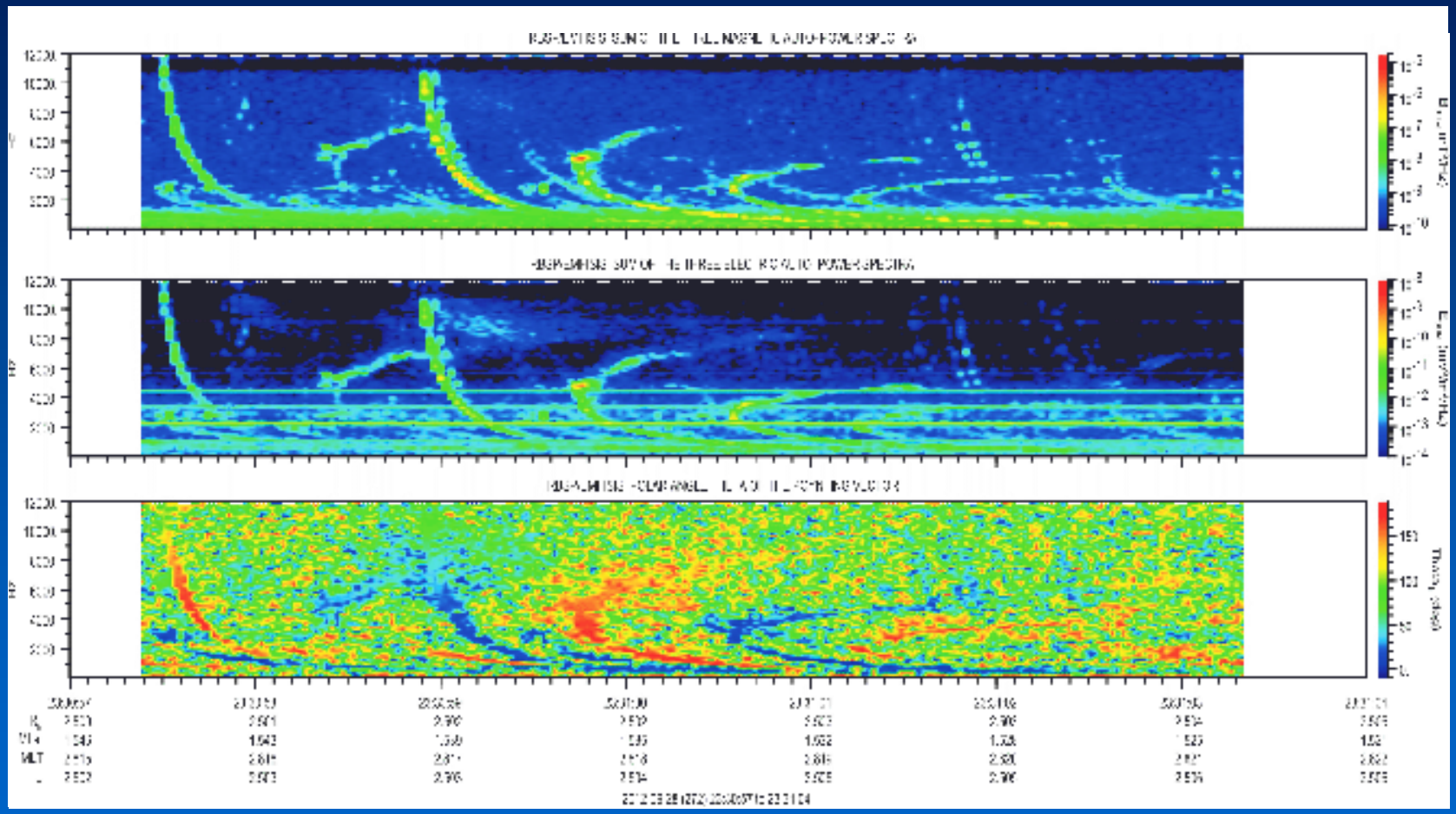
From S.Boardsen, GSFC and G. Hospodaarsky, UI

Magnetosonic Wave Vector



Waveform Wave Normal Analysis

Bouncing Whistlers

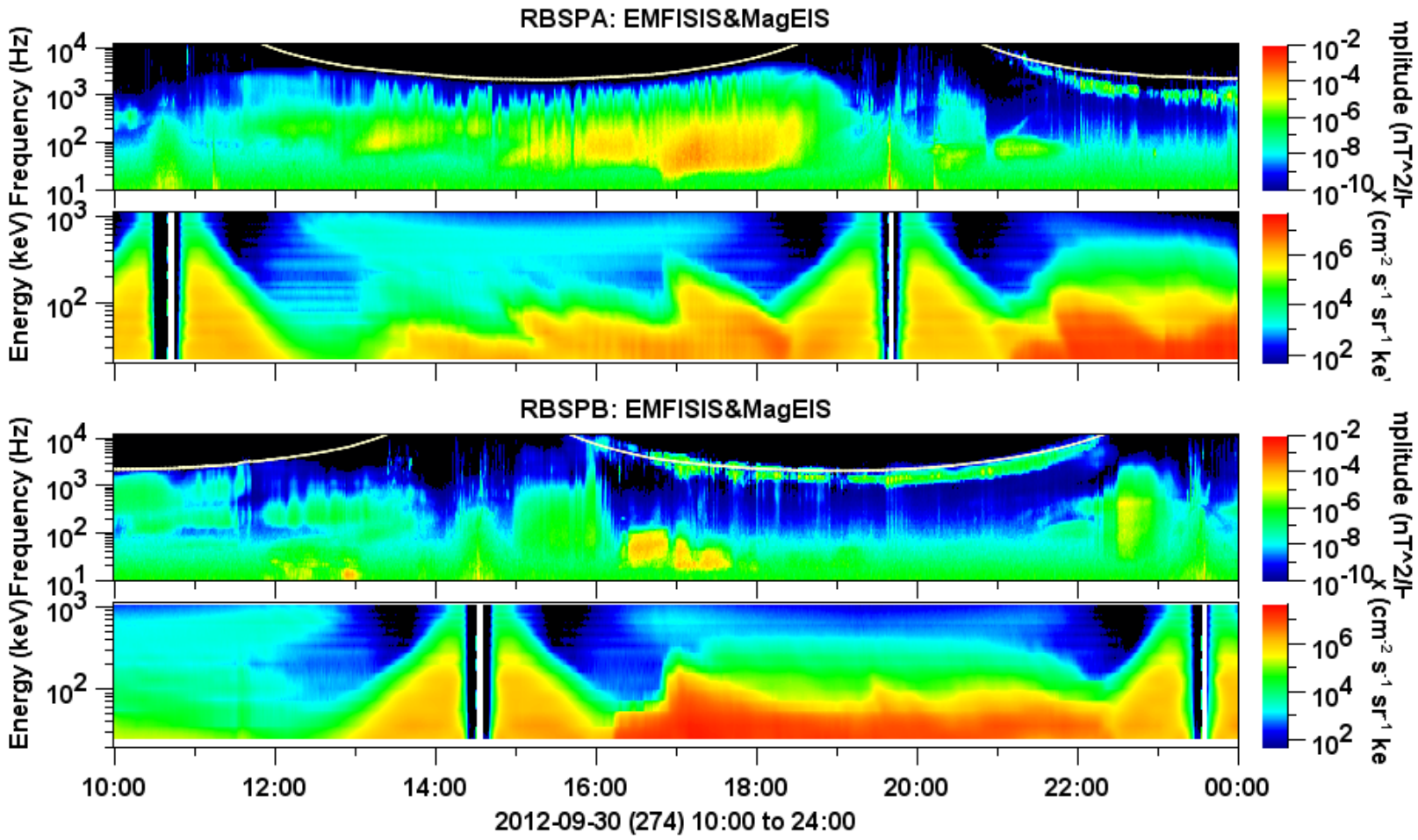


B

E

θ

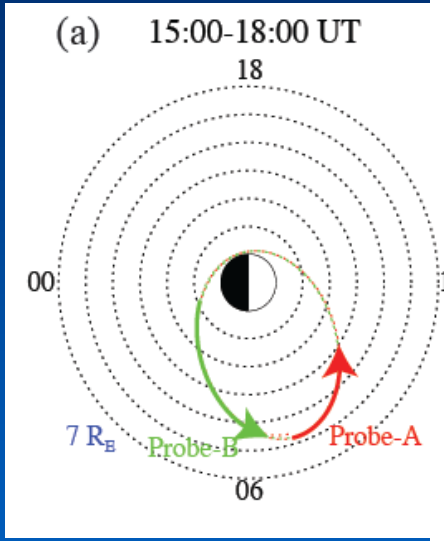
Plasmashperic Hiss and Electrons

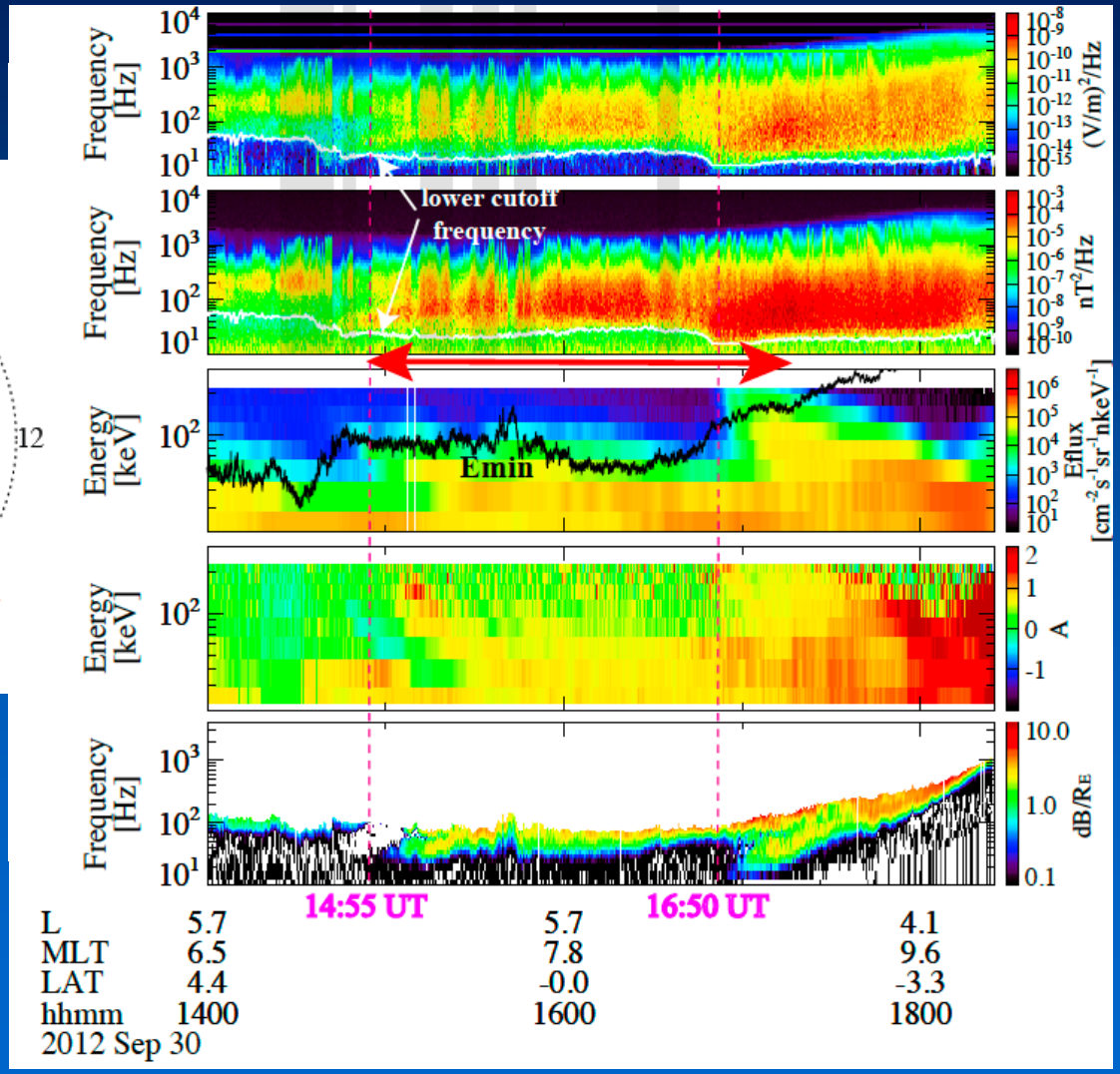


With help from G. Reeves, LANL

Hiss Growth

RBSP-A shows growth at very low frequencies





E

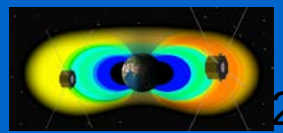
B

MagEIS Electrons

Anisotropy

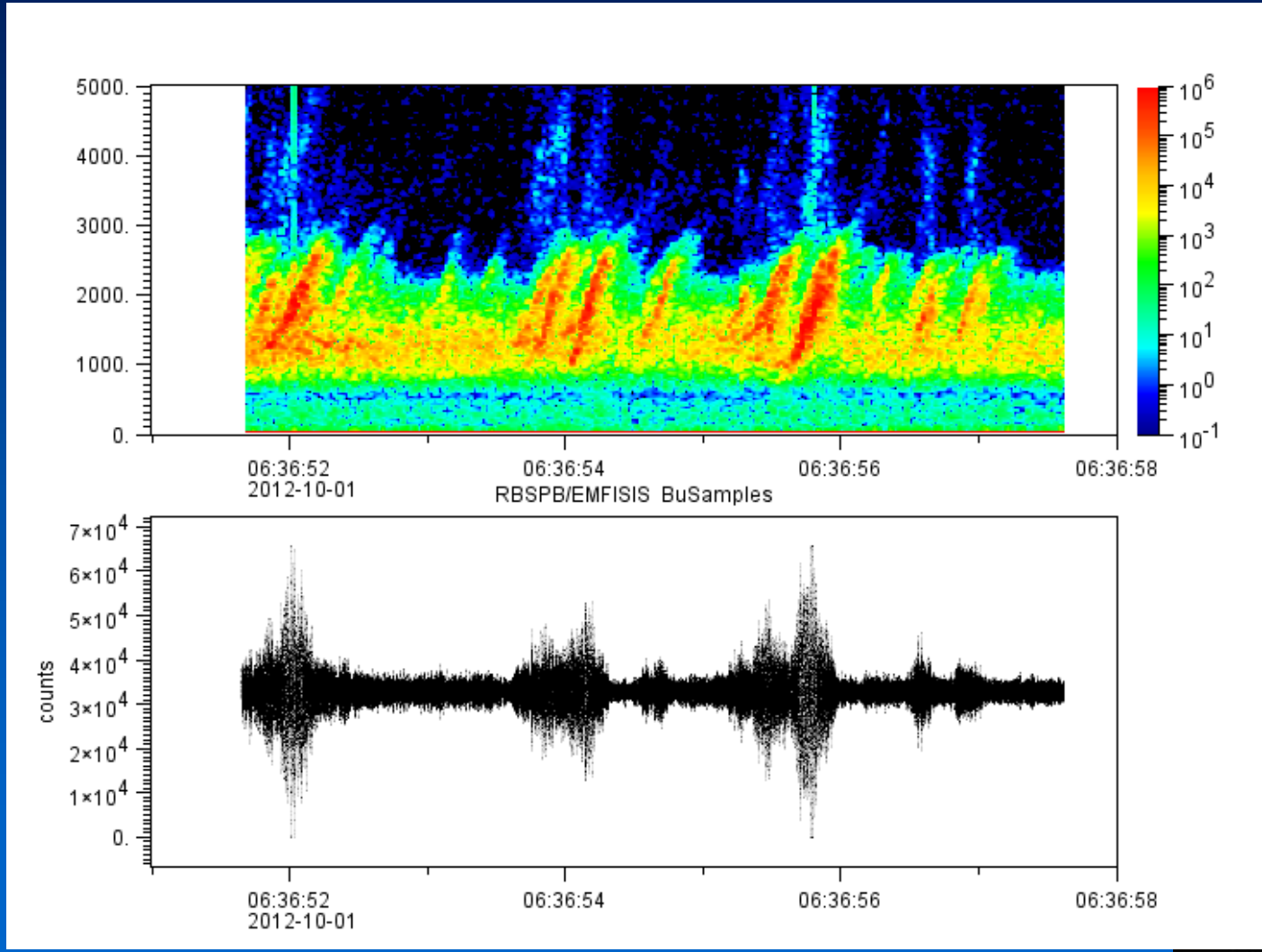
Growth rate

From Li, et al. 2013



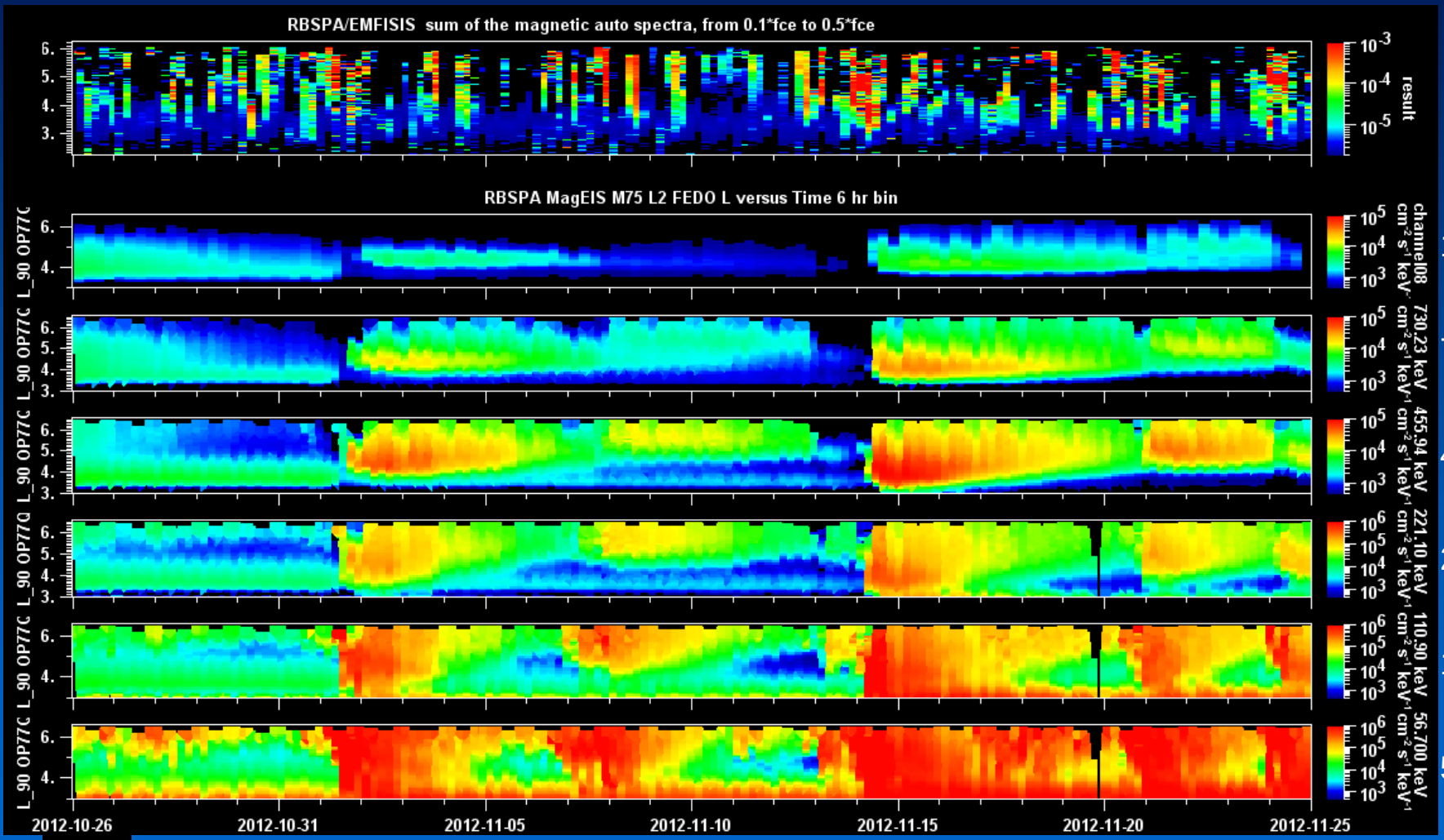
Chorus Waveforms

Power level triggered waveform burst captures are working well!



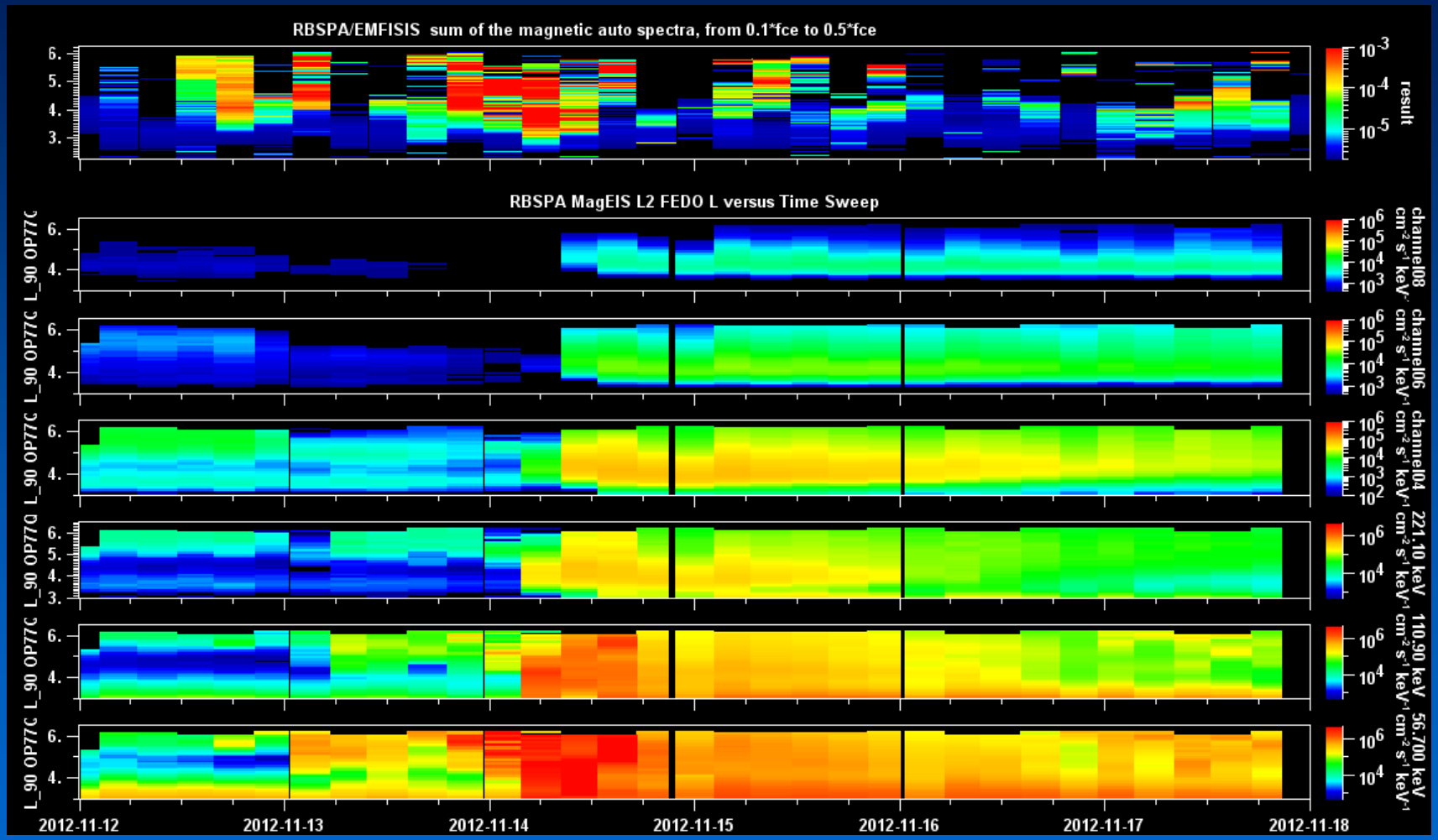
Chorus and Electrons in November

Particle fluxes and wave activity show clear macroscale correlation



Chorus Energy Transfer

Lower energy electrons drive chorus which energizes electrons.



1.1 MeV

730 keV

456 keV

221 keV

111 keV

57 keV

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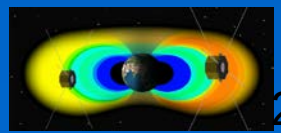
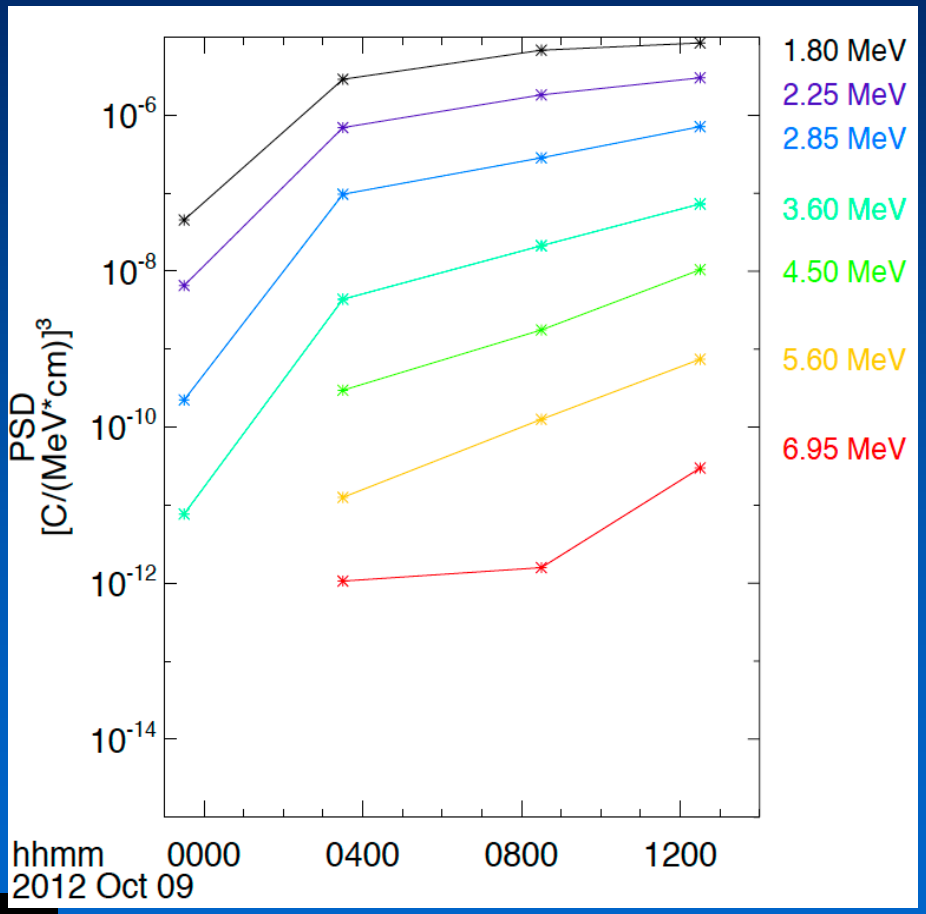
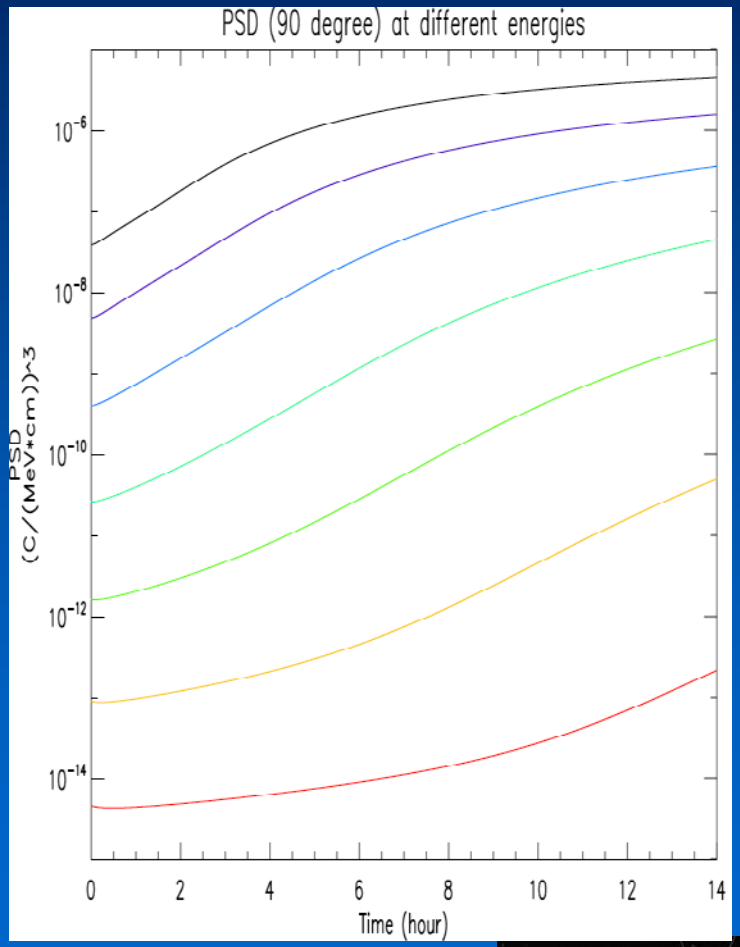


Evolution of Electron PSD over 14 hrs during the second dip of the Oct 8-9 storm using EMFISIS chorus observations.

Observation



Simulation

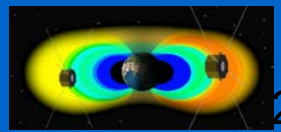


From R. Thorne

Conclusions

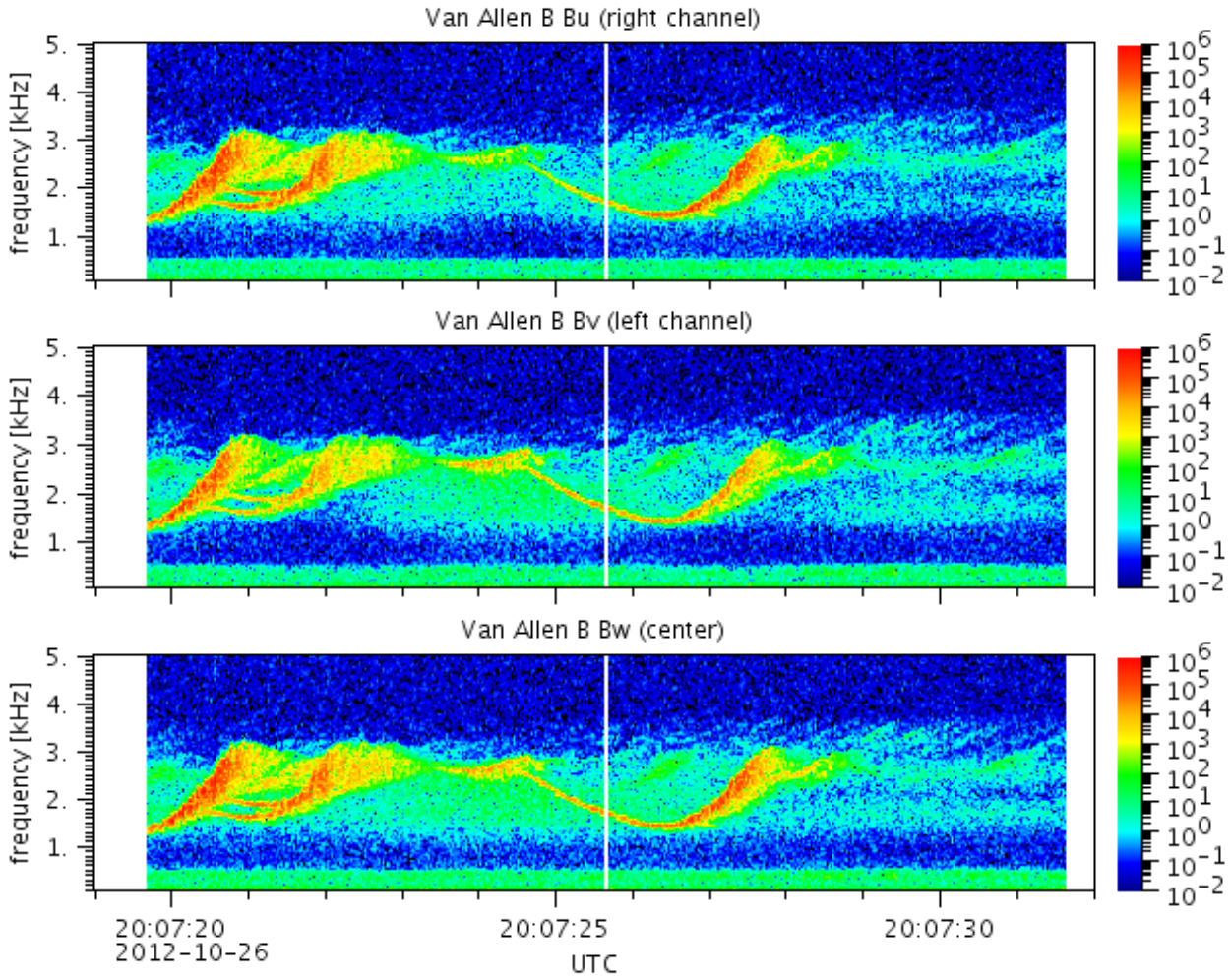
- Van Allen Probes are returning outstanding data
- Wave-based plasmapause identification similar to model and bounds *outer* edge of outer belt electrons
- EMIC observations are clear with good wave parameters.
- Wave normal analysis shows clear magnetosonic waves.
- Plasmaspheric hiss can be locally generated
- Waveform captures provide full detail of burst events.
- Chorus power correlates with higher energy electrons.
- We have the Tools to resolve the Schism between radial and local acceleration – “I know the pieces fit”!

emfisis.physics.uiowa.edu



Some 'Good Vibrations'

A fun example to keep the theorists busy!



That’s all folks!