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

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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 frequencies

From A. Saiken, UNH
EMIC Wave Properties

Hydrogen band seen in both E and B

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

From S. Boardsen, GSFC and G. Hospodaarsky, UI
Magnetosonic Wave Vector

RBSP/EmFISIS SUM OF THE THREE MAGNETIC AUTO-POWER SPECTRA

RBSP/EmFISIS POLAR ANGLE THETA (ID/OF THE MAGNETIC SPECTRAL MATRIX)

B PSD

Wave Normal $\theta$
Rising Tone Magnetosonic Waves


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
Plasmaspheric Hiss

- Several theories for generation mechanism.
- Broadband whistler mode waves between lower hybrid frequency and ~0.1-0.2 \( f_{\text{ce}} \)
- 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.
- 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.

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Wave normal can be quite oblique
Wave-particle interaction

Parallel propagation, non-relativistic

Whistler mode

Dispersion relation:

\[
\frac{k^2 c^2}{\omega^2} = 1 + \frac{\omega_p^2}{\omega(\omega_c \cos \theta - \omega)}
\]

Resonance
Condition:

\[
\omega - k || v || = \omega_c
\]

Resonant Energy:

\[
\frac{2E}{mc^2} = \frac{(\omega_c - \omega)^2(\omega_c \cos \theta - \omega)}{\omega \cos^2 \theta (\omega \omega_p \cos^2 \theta - \omega^2 + \omega_p^2)}
\]
Electron Resonant Energy

RBSP-A/EMFISIS HFR Spectra Data

RBSPA/EMFISIS Sum of BuBu, BvBv, and BvBw

Resonant Energy

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Twisted Chours

A fun example to keep the theorists busy!
Twisted Chorus: WNA

A mix of oblique and parallel wave normal directions

![Wave Normal θ](image1)

![Poynting Flux θ](image2)
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.

emfisis.physics.uiowa.edu
That’s all folks!