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

Acknowledgements

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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:

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

- This interaction results in pitch angle scattering and loss to the atmosphere.
- Frequencies in bands below \(\omega_c\) for 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 $\sim 100$ pT, average $\sim 40$ 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 $\sim 50$ keV up to $\sim 1$ 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^{-2} nT^2/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^-2nT^2/Hz, average during active times of ~10^-3nT^2/Hz.
- Interact with electrons via electron cyclotron resonance to both scatter and accelerate electrons.
- Scattering is of lower energy electrons few keV to 100 keV.
- Acceleration of seed in electrons with 100’s of keV energy up to MeV energies 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 ±2 nT

- **Waves:**
  - **Magnetic field:**
    - Vector B.
    - 10 Hz-12 kHz and sensitivity: $3 \times 10^{-11} \text{ nT}^2 \text{Hz}^{-1}$ @1 kHz.
  - **Electric field:**
    - Vector E from double probe experiment.
    - 10 Hz-12 kHz (vector), 10-400 kHz (single channel)
    - Sensitivity: $3 \times 10^{-17} \text{ V}^2 \text{m}^{-2} \text{Hz}^{-1}$ @ 1 kHz,

- **EMFISIS data rate:** 31.6 kbits/s.
Magnetic field dynamic spectra

From K. Takahashi, APL
ULF Wave generation at quasiparallel shock

Solar wind OMNI data
8 November (Day 313) 2012

Greenstadt et al. [1980]
Magnetic field time series and spectra

Van Allen Probe-A 2012 day 313
11-s running averages

Magnetic field

\[ 3 \text{ nT} \]

\( B_R \)
\( B_\phi \)
\( B_\mu \)

14:00 14:05 14:10 14:15 14:20 14:25 14:30 UT

Power Spectra (nT²/Hz)

Multiharmonic toroidal waves

\( f_3 \)
\( f_5 \)
\( f_7 \)
\( f_9 \)
\( f_{11} \)

Frequency (mHz)
Cross spectral analysis

2012 Day 313 Nov 8

RBSP-A $B \Phi$

RBSP-B $B \Phi$

Power spectrum

Coherence

Cross phase

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EMIC Waves

Hydrogen band seen in both End B

From M. Argall, uNH
EMIC Wave Properties

Hydrogen band seen in both E and B
EMFISIS Wave Spectra Data Example
(11-17-2012)

HFR (single channel): 10 kHz-400 kHz

Vector E: 10 Hz-12 kHz

Vector B: 10 Hz-12 kHz
Plasmapause from UHR

RBSP-A/EMFISIS HFR Spectra Data

\begin{align*}
\text{Hz} & \\
10^4 & 10^5 & 10^6 & 10^7 & 10^8 & 10^9 & 10^{10} & 10^{11} & 10^{12} & 10^{13} \\
\end{align*}

\begin{align*}
\text{R_E} & \\
3.469 & 5.486 & 5.651 & 4.060 \\
\text{MLat} & \\
\text{MLT} & \\
L & \\
3.485 & 5.633 & 5.983 & 4.436 \\
\end{align*}

2012-09-29 (273) 16:42 to 2012-09-30 (274) 01:41 (orbit:rbspa-pp:82)
Plasmapause and Outer Belt

![Graph showing Plasmapause and Outer Belt activities over time]
Magnetosonic Waves

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

THE UNIVERSITY OF IOWA

GEM Tutorial June 2013
Magnetosonic Wave Vector
Waveform Wave Normal Analysis

Bouncing Whistlers
Plasmashperic Hiss and Electrons

With help from G. Reeves, LANL
Hiss Growth

RBSP-A shows growth at very low frequencies

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

RBSPA/EMI/SIS sum of the magnetic auto spectra, from 0.1°ice to 0.5°ice

RBSPA MagEIS M75 L2 FEDO L versus Time 6 hr bin

1.1 MeV
730 keV
456 keV
221 keV
111 keV
57 keV
Chorus Energy Transfer

Lower energy electrons drive chorus which energizes electrons.
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!

Van Allen B Bu (right channel)

Van Allen B Bv (left channel)

Van Allen B Bw (center)

20:07:20
2012-10-26

20:07:25
UTC

20:07:30
That’s all folks!