VAN ALLEN PROBES
OBSERVATIONS OF EMIC WAVE RISING TONES: STATISTICAL STUDY UPDATE

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EMIC WAVE RISING TONES / TRIGGERED EMISSIONS

- EMIC waves have been observed in space for many years by satellites such as AMPTE/CCE, CRRES, and GOES, but rising tone triggered emissions were not reported until recently.

- H+ band triggered emissions were first reported in space using Cluster data [Pickett et al., 2010] near the plasmapause in association with >300 eV ring current ions. Rising tones were only observed by Cluster on 3 different days in 8 years, but the events included He+ band rising tones [Grison et al., 2013] and multi-spacecraft observations at separations of 300-1500 km [Grison et al., 2016].

- THEMIS studies [Nakamura et al., 2015; 2016] have reported both rising and falling tones and have examined ion hole formation associated with rising tones [Shoji et al., 2017].

- Theoretical work to explain EMIC rising tones has been based upon models developed for whistler-mode chorus elements [Omura et al., 2010; Omura and Summers, 2006]. Other studies have examined scattering by rising tones [Kubota and Omura, 2017].

- Van Allen Probes data have been used to study overall EMIC wave statistics and spatial extents [Saikin et al., 2015, 2016; Blum et al., 2016; Tetrick et al., 2017], Pc1 pearls [Paulson et al., 2017], and ion distributions for one EMIC event [Min et al., 2015]. Only one Van Allen Probes paper showing EMIC rising tones: 8-hour UT/12-hour LT event on February 23, 2014 [Engebretson et al., 2015].
PROTON BAND RISING TONES

Rising tone durations between 30-80 seconds and frequency changes between 0.5 and 1.5 Hz
PROTON BAND RISING TONES
EMIC waves are usually produced by temperature anisotropy $T_\perp/T_{\parallel}$ [Kozyra et al., 1984]. Ring distributions near the Alfvén speed can also produce EMIC waves [Mithaiwala et al., 2013; Fok et al., 2016].

Proton anisotropy = difference between the parallel and perpendicular flux divided by the total flux.

-1 = perp. ions
+1 = para. ions

$E_A =$ energy of protons at the Alfvén speed from EMFISIS density and magnetic field.
IDENTIFYING EMIC WAVE RISING TONES

• Generated an Autoplot pngwalk by orbit with a 1024 point FFT of BX and BY in SM coordinates for RBSP-A and RBSP-B from 2012-2016.

• Sorted each orbit using the Autoplot QC tool. Completed for both RBSP-A and RBSP-B.

• Used a custom Autoplot tool to digitize EMIC wave bursts for orbits marked OK.

• Adjusted FFT size and used PRASSADCO wave normal analysis used to verify EMIC wave identification when needed.


• We now have digitized EMIC wave bursts from RBSP-A from Nov. 1 2012 – June 5 2016 (41,025.7 minutes) and RBSP-B from Sept. 9 2012 – Oct. 2014 (14,356.6 minutes).
Saikin et al. [2015] EMIC wave study found 34% H+, 57% He+, and 9% O+ using Van Allen Probes data from September 2012 through June 2014.
MINUTES OF ORDINARY AND RISING TONE PROTON (H+) BAND EMIC WAVES
RBSP-A ORBITS 204-3677 (NOV. 1, 2012 TO JUNE 5, 2016)
RBSP-B ORBITS 29-2027 (SEPT. 9, 2012 TO OCT. 1, 2014)

Percentage of Minutes

<table>
<thead>
<tr>
<th></th>
<th>Ordinary</th>
<th>Rising Tone</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBSP-A</td>
<td>n=18688.6</td>
<td>129.0</td>
<td>89±0.9%</td>
</tr>
<tr>
<td></td>
<td>Ordinary</td>
<td>16649.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rising</td>
<td>2038.7</td>
<td>11±0.3%</td>
</tr>
<tr>
<td>RBSP-B</td>
<td>n=4902.5</td>
<td>66.9</td>
<td>91±1.9%</td>
</tr>
<tr>
<td></td>
<td>Ordinary</td>
<td>4481.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rising</td>
<td>420.7</td>
<td>9±0.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20.5</td>
<td></td>
</tr>
</tbody>
</table>

σ = √n
MINUTES OF ORDINARY AND RISING TONE HELIUM (He+) BAND EMIC WAVES
RBSP-A ORBITS 204-3677 (NOV. 1, 2012 TO JUNE 5, 2016)
RBSP-B ORBITS 29-2027 (SEPT. 9, 2012 TO OCT. 1, 2014)

<table>
<thead>
<tr>
<th></th>
<th>RBSP-A He+</th>
<th></th>
<th>RBSP-B He+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary</td>
<td>n=20596.7</td>
<td>σ = $\sqrt{n}$</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>n=19478.3</td>
<td>139.6</td>
<td>95±0.9%</td>
</tr>
<tr>
<td>Rising</td>
<td>n=1118.3</td>
<td>33.4</td>
<td>5±0.2%</td>
</tr>
</tbody>
</table>
RBSP-A EMIC Wave Observations
2012-11-01 to 2016-06-05
2012-11-01 to 2016-06-05
RBSP-A O+ EMIC Wave Observations

All O+ EMIC Waves

O+ band rising tones were not observed.
SUMMARY

- H+ band rising tones are generally triggered emission type events, while He+ band rising tones have chorus-like elements.
- Rising tones are often more left-hand polarized than the main band of EMIC waves.
- Previous studies have associated rising tones with proton holes. We found that they may be associated with proton ring distributions.
- Only about 10% of H+ EMIC wave events have rising tones. RBSP-B has a higher percentage of He+ band rising tones than RBSP-A, but this is probably due to differences in coverage.
- Ongoing work: Digitizing RBSP-B EMIC waves through 2016, wave normal analysis.
- Future work: Study ion distributions, rise/sweep times, relation to plasmapause.
- Abstracts submitted to Fall AGU 2018
  - Session SM023: The Role of Small-Scale Mechanisms in the Driving of Particle Energization and Loss in the Inner Magnetosphere and Radiation Belts.
    - Van Allen Probes Observations of Electromagnetic Ion Cyclotron (EMIC) Rising Tones: Occurrence Statistics
  - Session ED055: The Up-Goer Five Challenge: Tell us about the hard things you do in ten hundred words. Inspired by the XKCD Up-Goer Five comic (https://xkcd.com/1133/).
  - The US Space Team Man From Iowa Flying Space Computers Found Waves in the Outer Space Fields Around Our World
RBSP-A EMIC Wave Observations
2012-11-01 to 2016-01-31
2012-11-01 to 2016-01-31
RBSP-A O+ EMIC Wave Observations

All O+ EMIC Waves

0 MLT

12 MLT

6 L Shell

18 MLT

O+ band rising tones were not observed.