EMIC waves and their occurrence conditions in the inner magnetosphere: A statistical study

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Abstract

In the Earth's magnetosphere, electromagnetic ion cyclotron (EMIC) waves are normally excited by an anisotropic distribution of energetic (a few tens of keV) H^+ in the ring current or plasma sheet. The generation and propagation of EMIC waves are also profoundly controlled by other plasma parameters such as ion composition, cold heavy plasma, and energetic H^+ density. During the time period of 1 February 2001 – 31 December 2009, 149 time intervals of EMIC wave activity are identified from the wavelet spectrograms of high-resolution (22.4 vectors/second) magnetic field data from the Fluxgate Magnetometer (FGM) on board Cluster in the inner magnetosphere during 8 hours around each perigee pass. Those EMIC wave intervals, lasting for a few to tens of minutes, predominantly occurred on the dayside (L = 4–13) and at low/middle magnetic latitudes (MLAT = -46°–43°). In this study, using *in situ* plasma and magnetic field measurements on Cluster, upstream solar wind data, and geomagnetic indices (i.e., *Dst*), we perform a statistical study of the wave periods to investigate the occurrence conditions for the waves, including the local plasma conditions, the solar wind plasma/interplanetary magnetic field (IMF) conditions, and geomagnetic activity.

Motivation

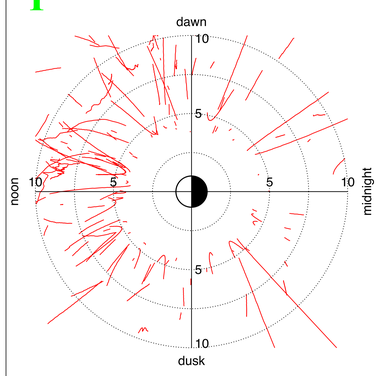
1. To investigate the spatial distribution and occurrence conditions of EMIC wave events observed by Cluster in the inner magnetosphere, which could cause pitch-angle scattering and loss of relativistic e^-.

2. To follow up the case and statistical studies of EMIC wave-associated He^+ heating events in the outer magnetosphere [*Zhang et al.,* 2010; 2011].

EMIC Wave Events @ Cluster

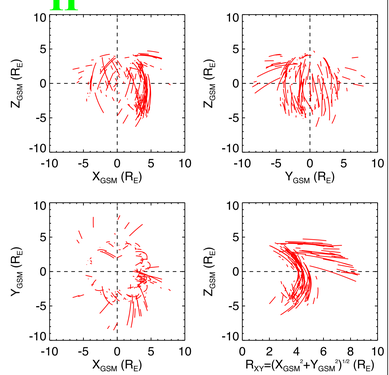
❖ **Mission Period:** 1 Feb. 2001 – 31 Dec. 2009
❖ **Selection:** Visually inspecting significant (P_{Tot} > 0.1 nT^2/Hz) EMIC wave activity in the frequency-time wave power spectra, obtained through the wavelet analysis of high-resolution (22.4 vectors/s) magnetic field measurements, which were made on Cluster/FGM in the inner magnetosphere, that is, for a perigee-centered time period of 8 hours.
❖ **Total:** 149
❖ **Magnetic Latitudes:** -46.4° – 42.8°
❖ **Occurrences (Figs. I & II):** Dominant on the dayside with MLT = 06:00 – 15:30, L = 4 – 13, X = -6.9 – 7.8, Y = -8.5 – 8.1, Z = -6.3 – 4.8, and R_{XY} = 2.2 – 8.1 (R_E)

I



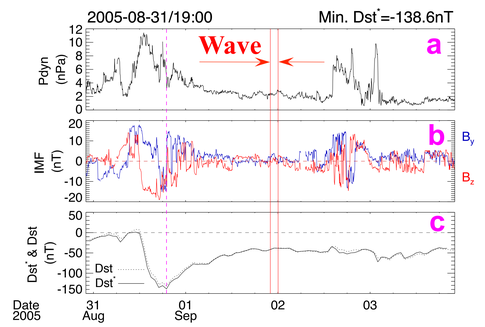
• Events (red curves) in the polar MLT-L coordinates

II

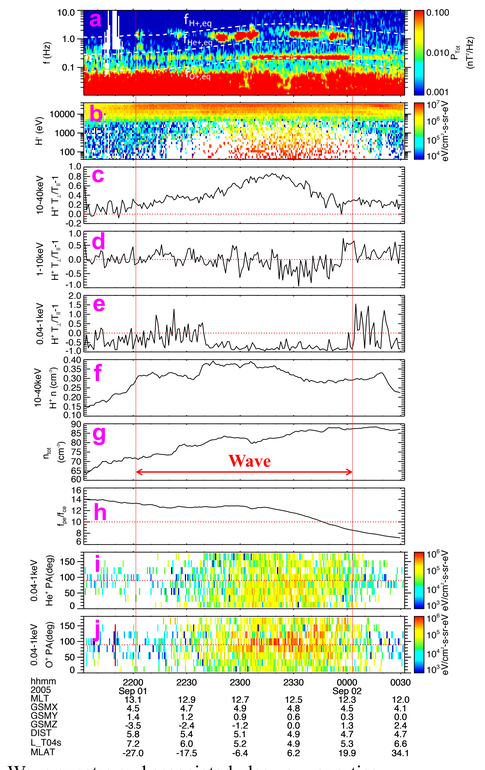


• Events (red curves) in the GSM coordinates
• Orbital changes cause 2 types in R_{XY} vs. Z

1 Sept. 2005 Event



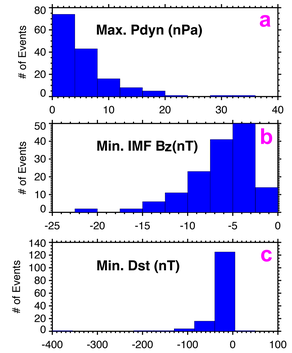
• Propagated OMNI solar wind dynamic pressure (*Pdyn*), interplanetary magnetic field (IMF) Y and Z components (B_y and B_z), and *Dst* and pressure-corrected *Dst* (*Dst**)
• Wave detected in the late recovery phase of an intense storm; limited data coverage in the storm due to the 57-hr S/C period



• Wave spectra and associated plasma properties
• Hot anisotropic H^+, increased hot H^+ density, and enhanced n_{tot} present; f_{pe}/f_{ce} above the wave excitation threshold (> 10)

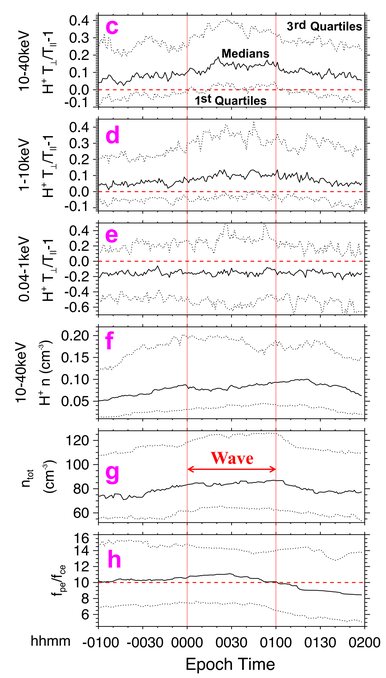
Solar Wind/Geomagnetic Conditions

All Events: Statistics



• Histograms of peak values between 24 hrs before the start time and the end time of each event
• Most events associated with solar wind disturbed times and active geomagnetic activity

Plasma Conditions



• Superposed epoch analysis of plasma data before, during, and after the events. Plotted statistics include medians (solid) and the first and third quartiles (dotted)
• Most events associated with enhancements in hot H^+ anisotropies, hot H^+ density, n_{tot} and f_{pe}/f_{ce}

Summary & Discussion

❖ **Compared to EMIC wave-associated He^+ heating events** observed by Cluster in the outer magnetosphere [*Zhang et al.,* 2011]:

	EMIC Waves	He^+ Heating Events
Time Period	1 Feb. 2001 – 31 Dec. 2009	1 Mar. 2001 – 31 Mar. 2008
# of Events	149	41
Duration*	a few to tens of minutes	one to a few hours
Region	Inner Magnetosphere	Outer Magnetosphere
MLT	All MLTs but dayside dominant	Only in the afternoon sector
MLAT	-46.4° – 42.8°	-4.3° – 51.7°
Geomagnetic Condition	Mostly active	Almost always Quiet
Wave Frequency	[$f_{O+,eq}$, $f_{H+,eq}$]	Around $f_{He+,eq}$
Ion Heating	~50%	He^+ heating: 100%
Hot H^+ Anisotropy**	up to 0.2	up to 0.3
Hot H^+ Density**	up to 0.1 cm^{-3}	up to 0.1 cm^{-3}
n_{tot}**	up to 88 cm^{-3}	up to 70 cm^{-3}
f_{pe}/f_{ce}**	up to 11 (> 10)	up to 12 (> 10)
Occurrence Conditions	an overlap of 1) **hot anisotropic H^+** from the ring current or plasma sheet & 2) **cold dense plasma** from the plasmasphere or a plasmaspheric plume or plume-like region	

*: *Difference mainly due to the different crossing time in the regions*
**: *Medians from the superposed epoch analysis of all events*

❖ **Wave Generation:** the EMIC instability is satisfied and the EMIC waves are excited with characteristic frequencies between $f_{O+,eq}$ and $f_{H+,eq}$ at low magnetic latitudes, when the following are present:
1) hot (e.g., >1 keV), anisotropic H^+ – wave free-energy provider
2) cold (e.g., < 40 eV), dense plasma (e.g., He^+) – wave generation catalyst

❖ **Wave-Particle Interactions:**
1) Hot anisotropic H^+ provide energies for the EMIC waves to be generated.
2) He^+ obtain energies via resonant interactions with the waves and are energized.
3) In a similar way, O^+ can also be energized by the waves when the wave characteristic frequency is in the vicinity of $f_{O+,eq}$.

❖ **Future Work:** 1) create lists of all Cluster-observed EMIC waves & associated plasma properties; 2) understand discrepancies between observations & wave theories/modeling [e.g., *Kennel et al.*, 1966; *Gary et al.*, 1994; *Blum et al.*, 2009].

References

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