EMIC waves observed by Cluster at middle magnetic latitudes in the dayside magnetosphere

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Abstract

Electromagnetic ion cyclotron (EMIC) waves are preferably excited in the local regions of minimum magnetic field strength, which is associated with a low characteristic energy for wave-particle cyclotron interactions. The generation and propagation of EMIC waves are also profoundly controlled by plasma properties such as temperature anisotropy of energetic (a few tens of keV) H^+, ion composition, total plasma density, and energetic H^+ density.

It has been well accepted that the propagation of EMIC waves are bidirectional near their source regions but unidirectional off the regions. From 0348 to 0530 UT on 9 April 2005, Cluster observed long-lasting EMIC wave activity, identified from the spectral analysis of high-resolution (22.4 vectors/second) magnetic field data from the Fluxgate Magnetometer (FGM). The wave event occurred at middle magnetic latitudes (MLAT = 33.4–46.5 deg.) on the dayside (MLT = 10.3–10.4), where L = 10.8–11.6 and the distance from the Earth is in the range of 7.4–9.2 R_E. In this study, we perform a case study to investigate the propagation and properties of the wave activity. It is found the EMIC waves were not locally excited but they propagated bidirectionally along the ambient magnetic field.

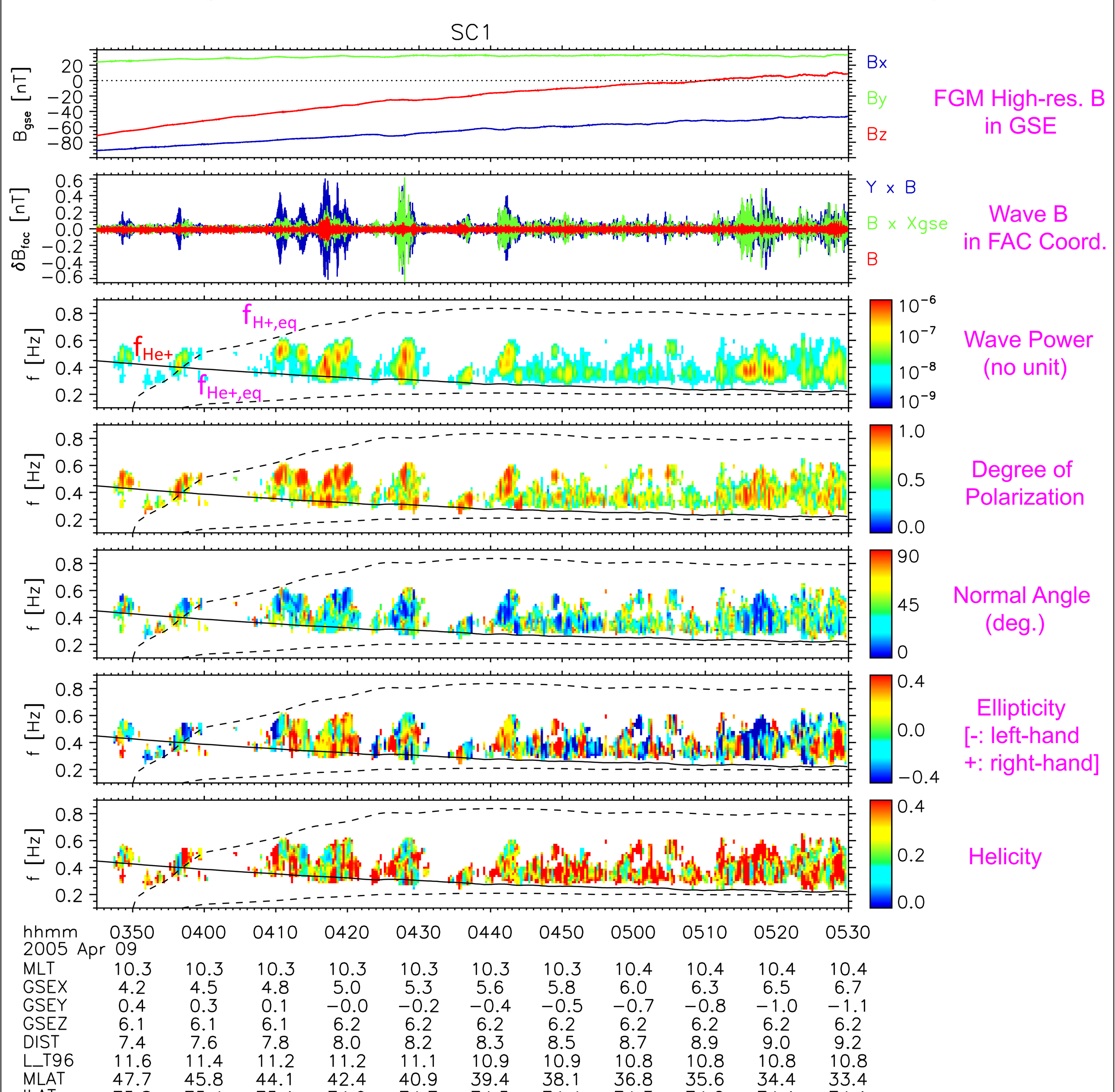
Motivation

1. To test the dependence of EMIC propagation directions on MLAT, i.e., unidirectional when MLAT> 11° [*Loto'aniu et al.*, 2005].

2. To follow up the recent theoretical and observational studies of off-equator EMIC waves on the dayside [e.g., *McCollough et al.*, 2010; *McCollough et al.*, 2012; *Liu et al.*, 2012].

3. To investigate the propagation and properties of the EMIC wave activity observed by Cluster at middle magnetic latitudes in the dayside magnetosphere on 9 April 2005.

Magnetic Field & Polarization Analysis

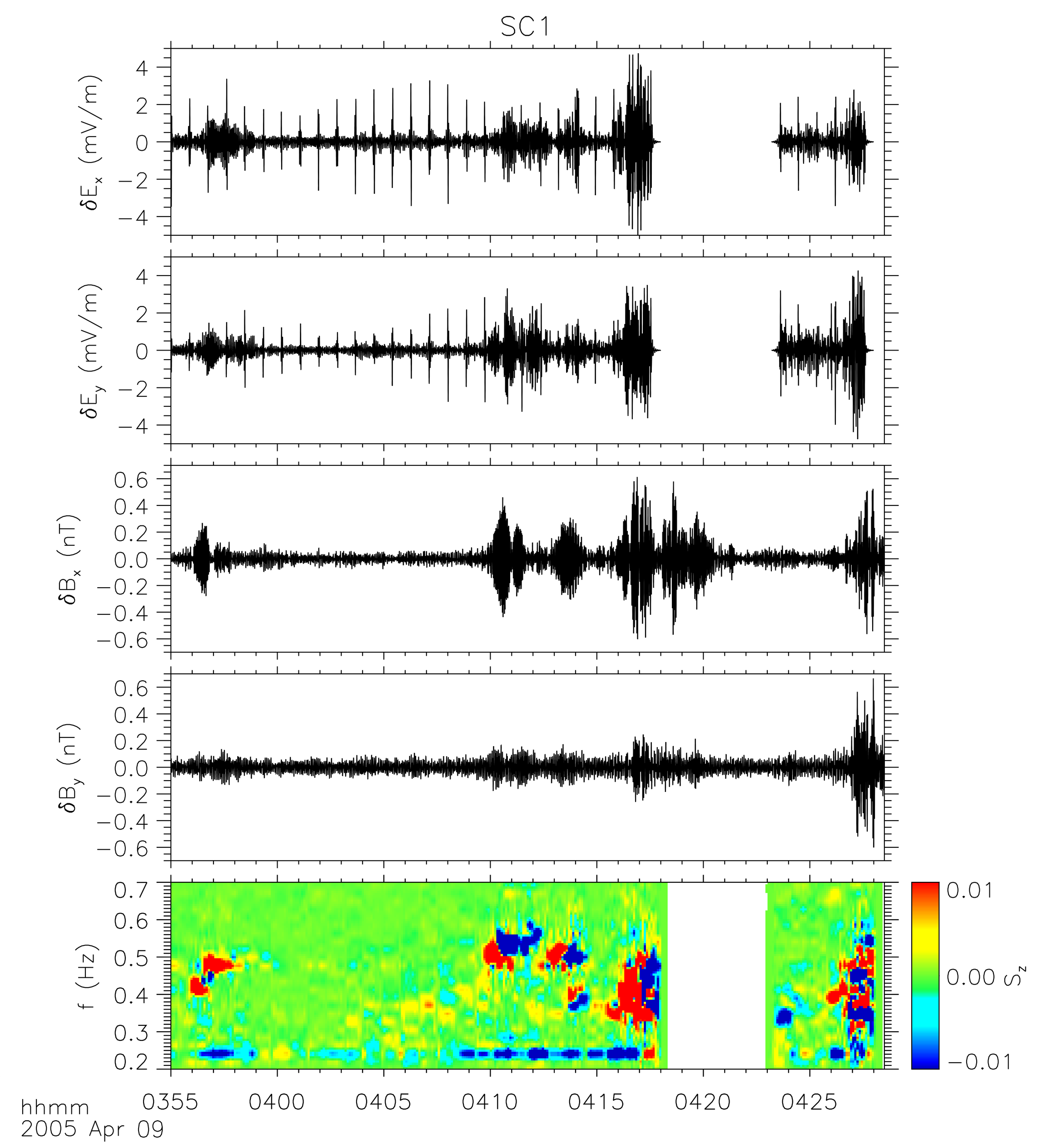


Poynting Vector Spectra

- Poynting vector in an inhomogeneous, anisotropic medium [*Loto'aniu et al.*, 2005]:
  - Formula:

$$\mathbf{S}_{av} = \frac{1}{4\mu}(\delta\mathbf{E}^* \times \delta\mathbf{B} + \delta\mathbf{E} \times \delta\mathbf{B}^*)$$

  where $\mathbf{S}_{av}$ is the time-averaged Poynting vector. $\delta\mathbf{E}$ and $\delta\mathbf{B}$ are the complex spectral matrices of the wave fields; $\delta\mathbf{E}^*$ and $\delta\mathbf{B}^*$ are their conjugate matrices.
  - Direction: the propagation direction of the wave energy, same as that of the wave group velocity **Vg**.
- The periodical spikes every ~52 s in δE_x are due to the sounding interference by another instrument onboard the same S/C: WHISPER. The enhancement at 0.25 Hz in S_z is the harmonic responses to the S/C spin.
- The ratio of the wave electric to magnetic field is larger than those in events (e.g., 30 Mar. 2002 & 22 Nov. 2003) observed by Cluster near perigee (MLAT~0 and L~4.5) by a factor of ~10.
- The sign of the Poynting vector z-component (S_z), along the ambient magnetic field, indicates the EMIC waves are mixed with opposite directions of the wave energy fluxes.



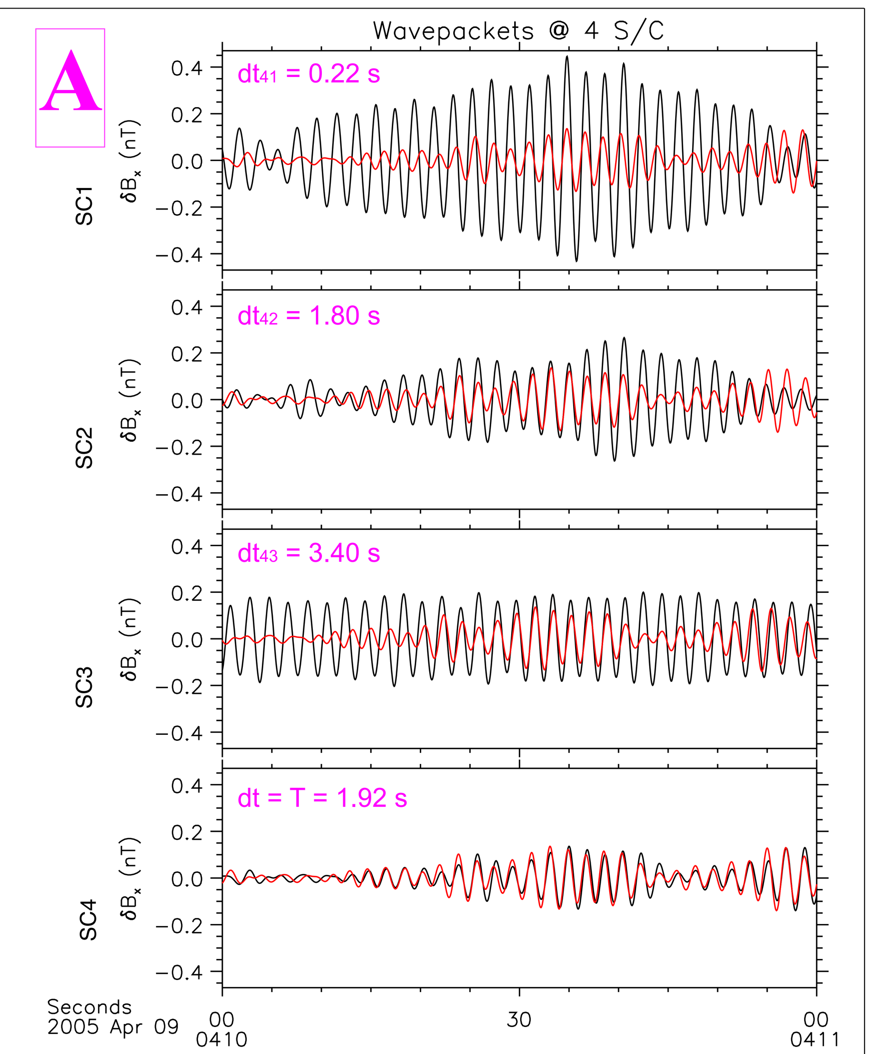
Wave Parameters

- The Phase Differencing technique [e.g., *Dudok de Wit et al.*, 1995] is used to determine wave vector **k**.
- Figures 1 & 2: Wave packet (T = 1.92 s or f = 0.52 Hz) at ~0410:30 UT first arrived at SC4 and then at SC1, SC2, and SC3 with a time delay of 0.22 s (dt_{41}), 1.80 s (dt_{42}), and 3.40 s (dt_{43}), respectively.
- Figure 3: Wave propagation velocity **Vp** can be found by solving

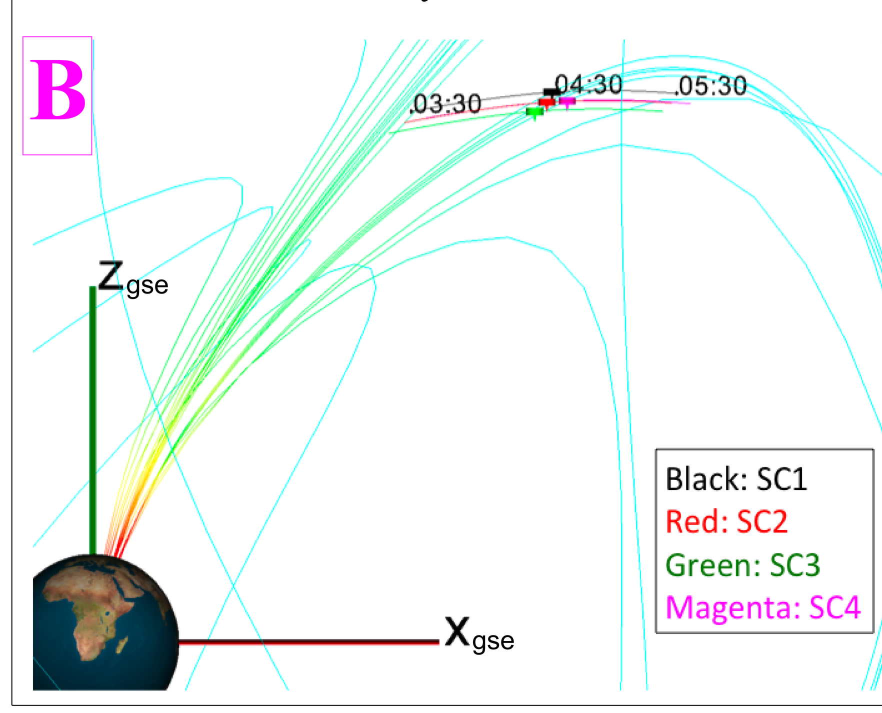
$$\mathbf{S}_{4i} \cdot \frac{\mathbf{Vp}}{Vp^2} = dt_{4i},$$

  where i = 1, 2, and 3 and $\mathbf{S}_{4i}$ is the distance vector between SC4 and the other spacecraft. Aliasing, i.e., $dt = dt + nT$, may make the results unreliable.
- Once **Vp** is determined, wave k vector as well as other wave parameters is thus obtained. The results at this time point and ~0412:30 UT are listed in the Table in the Summary and Discussion section.

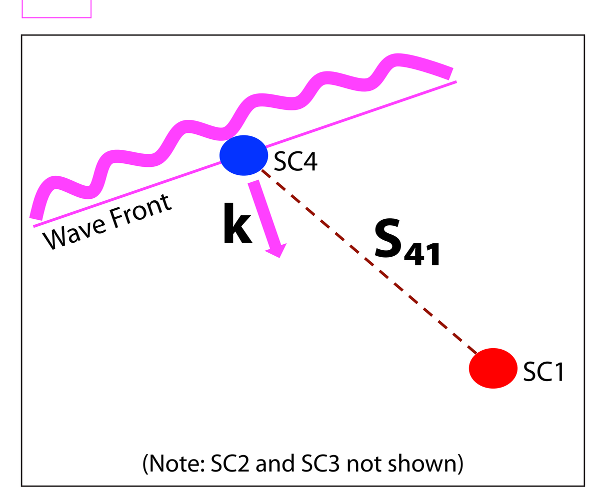
A



B



C



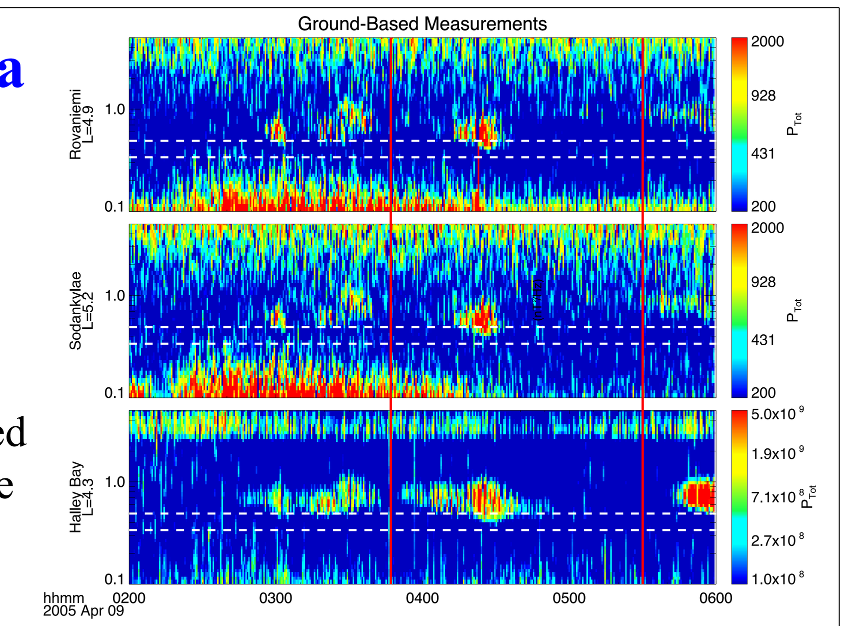
A: Waveforms on each S/C (in black) overplotted with time-shifted waveforms on SC4 (in red).

B: Trajectories of four Cluster S/C from 0330 to 0530 UT on the X-Z plane.

C: A schematic diagram of the EMIC wave packet (magenta curve) at ~0410:30 UT, which arrived first at SC4 (blue oval) and then at the other three S/C (only SC1 shown as the red oval) at later times.

Ground-based Data

- Ground-based stations:
  Rovaniemi:66.78°N 25.94°E
  Sodankylä:67.42°N 26.39°E
  Halley Bay:75.31°S 26.40°W
- The vertical red lines indicate the period of the waves observed by Cluster. The horizontal white lines show the frequency range of the Cluster waves.



Summary & Discussion

1. From 0348 to 0530 UT on 9 April 2005, Cluster observed long-lasting EMIC waves.
   - **Location**: L=10.7-11.5, MLT=10.3-10.4, MLAT=33.2-48.6°
   - **Polarization**: mixed with left-hand and right-hand
   - **Propagation**: both along and against ambient magnetic field directions
   - **Ground-based Data**: similar wave activity (w/ higher frequencies) detected in both hemispheres
   - **Local Plasma Condition** (not shown): not favorable for the wave generation, i.e., non-existing hot and anistropic protons, cold dense plasma, etc.
   - **Solar Wind and Geomagnetic Activity** (not shown): quiet

2. **Wave parameters** at two times, showing opposite propagation directions:

Time (UT)	~0410:30	~0412:30
Ambient b*	(-0.85, 0.36, -0.38)	(-0.84, 0.29, -0.47)
Arrival Sequence	4 => 1 => 2 => 3	3 => 2 => 1 => 4
Frequency (Hz)	0.52	0.54
Period (s)	1.92	1.85
k/|k|	(-0.62, -0.17, -0.76)	(0.94, 0.34, 0.01)
|k| (km⁻¹)	0.020	0.017
Vp (km/s)	(-364.03, -101.85,-445.48)	(625.43, 227.20, 8.26)
|Vp| (km/s)	584.24	665.47
Normal Angle (deg.)	40.58	133.93
Wave Length (km)	303.81	359.35

*: (*bx, by, bz*) *in the GSE coordinate system. All the vectors in the table are also in GSE.*

3. The bidirectional propagation of the waves observed at middle latitudes indicates that the equator cannot be the only source region.

4. These results are consistent with the suggestion that waves can be excited by particles executing Shabansky orbits when the minimum B region is located off the equator, as suggested by by *McCollough et al.* [2010; 2012].

5. The *Loto'aniu et al.* [2005] results from CRRES did not include local times from 8:00-14:00. This may explain why these waves were not observed, as this type of field configuration is located preferentially on the dayside.

References

Dudok de Wit, T., et al. (1995), *GRL*, 22(19).
Loto'aniu, T. M., et al. (2005), *JGR*, 110(A07214).
Liu, Y.-H., et al. (2012), *GRL*, 39(L17102).
McCollough, J. P., et al. (2010), *JGR*, 115(A10214).
McCollough, J. P., et al. (2012), *JGR*, 117(A01208).

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