



# Observations of Wave Mode Conversion from Magnetosonic to Ion Cyclotron in Earth's Magnetosphere



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## Abstract

Electromagnetic ion cyclotron (EMIC) waves have recently gained popularity in the modeling community due to their role in scattering energetic electrons, but the conditions leading to their generation are still not completely understood. In particular, the time-modulated emissions in this wavemode known as Pc1 pearl pulsations have yet to be explained. The previously observed independence of their excitation and modulation frequencies from the changing background field across L implies the generation conditions are not constrained to a small area. Instead, an external source may be triggering the marginally unstable local plasma distributions which give rise to modulated EMIC waves. One such wave mode able to propagate across field lines and so access different magnetospheric regimes is the fast magnetosonic mode. Here we present several observations of pearl pulsations coupled to the magnetosonic wavemode near the plasma-pause boundary, suggesting a relationship between the compressional fast mode wave and Pc1 pearl pulsations.

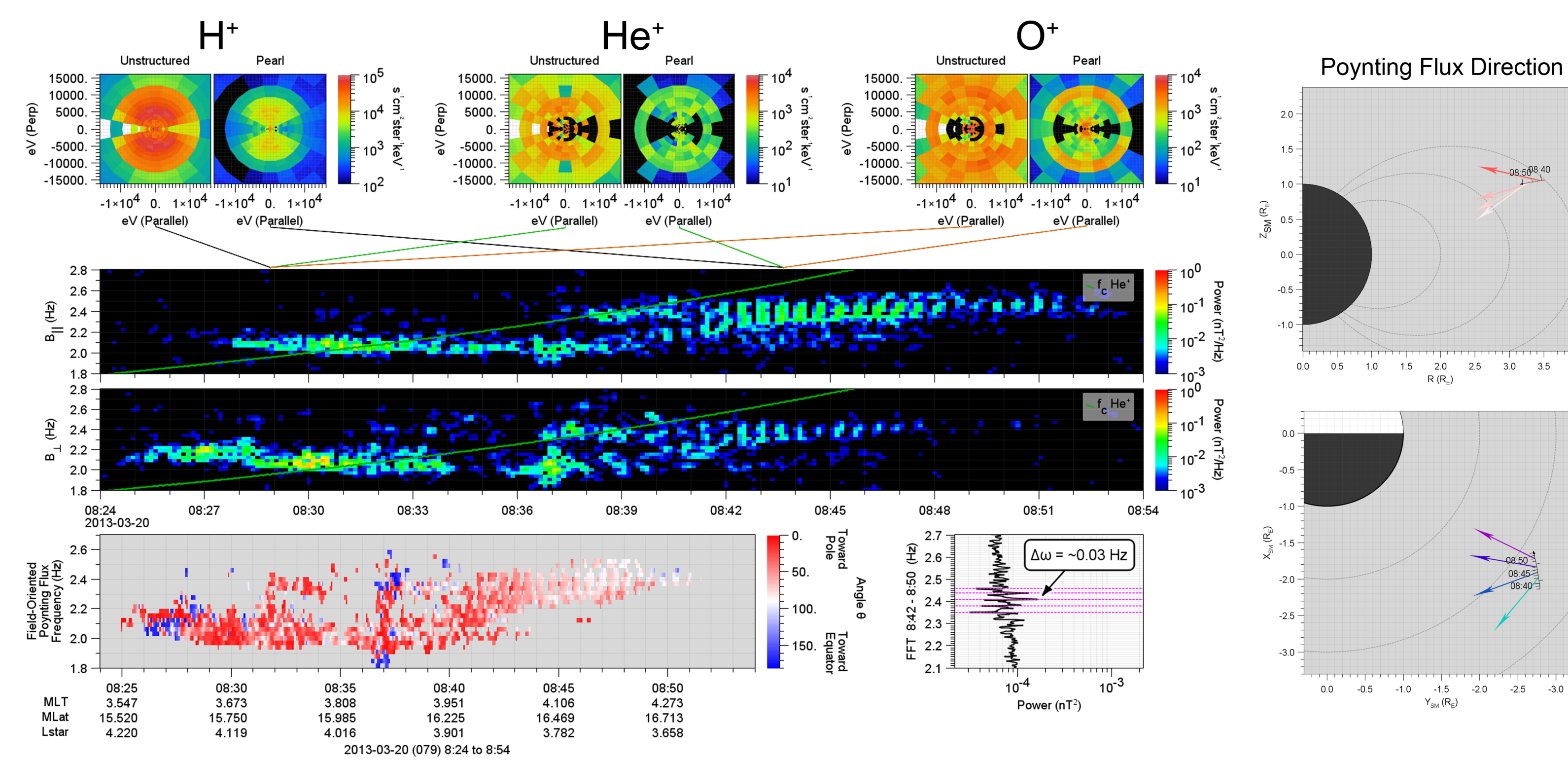
## EMIC Waves

- Left-hand circularly polarized transverse wave mode
- Generated near magnetic equator by hot ion temperature anisotropy ("pancake" distribution)
- Frequency stop bands at ion gyrofrequency lines
- Subsets of this wave category include time-modulated Pc1 pearl pulsations:
  - Modulated in time by 10s-100 seconds
  - Often consist of rising frequency tones
  - Occurrence peak during late recovery period of storms

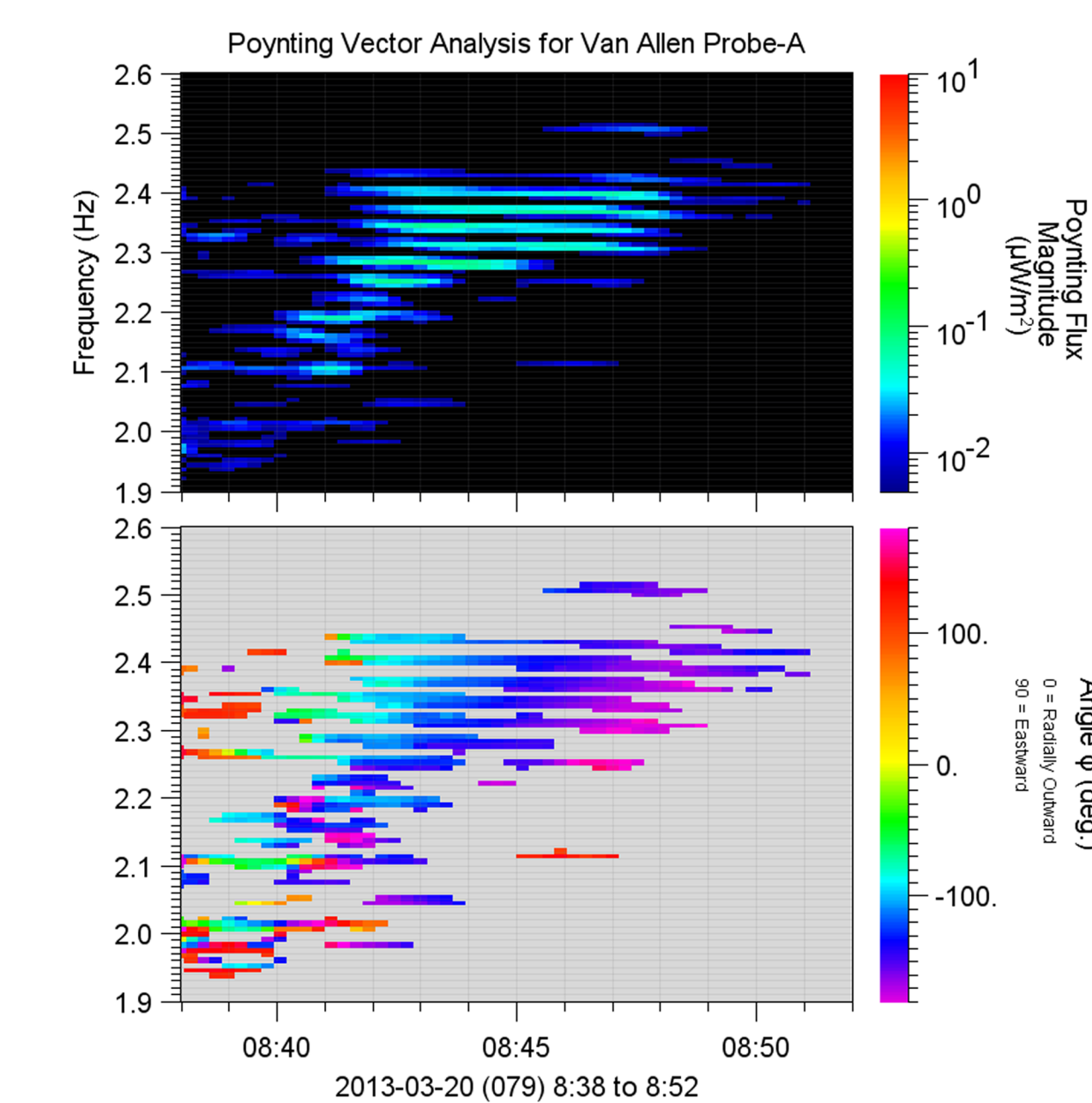
## Magnetosonic Waves

- Linearly polarized compressional wave mode propagating across the magnetic field
- Typically generated near the magnetic equator by proton ring distribution [Perraut (1982), JGR]
- Generated at multiples of the ion cyclotron frequency extending up to the Lower Hybrid resonance
- Recent observations of rising tones [Fu (2014), GRL] and time-modulated elements [Boardsen (2014), GRL] are similar to the sweep rate and modulation period associated with pearl pulsations

## 2013-03-20 Event



Van Allen Probe-A observed this event exhibiting both unstructured EMIC wave and pearl pulsation activity spanning the helium gyrofrequency just outside of the plasmapause boundary (crossing at 8:52 UT not shown). While the unstructured portion is largely transverse, the pearl elements quickly transition to a compressional dominant mode. The spacecraft recorded this event during the late recovery phase of the 2013-03-17 geomagnetic storm.

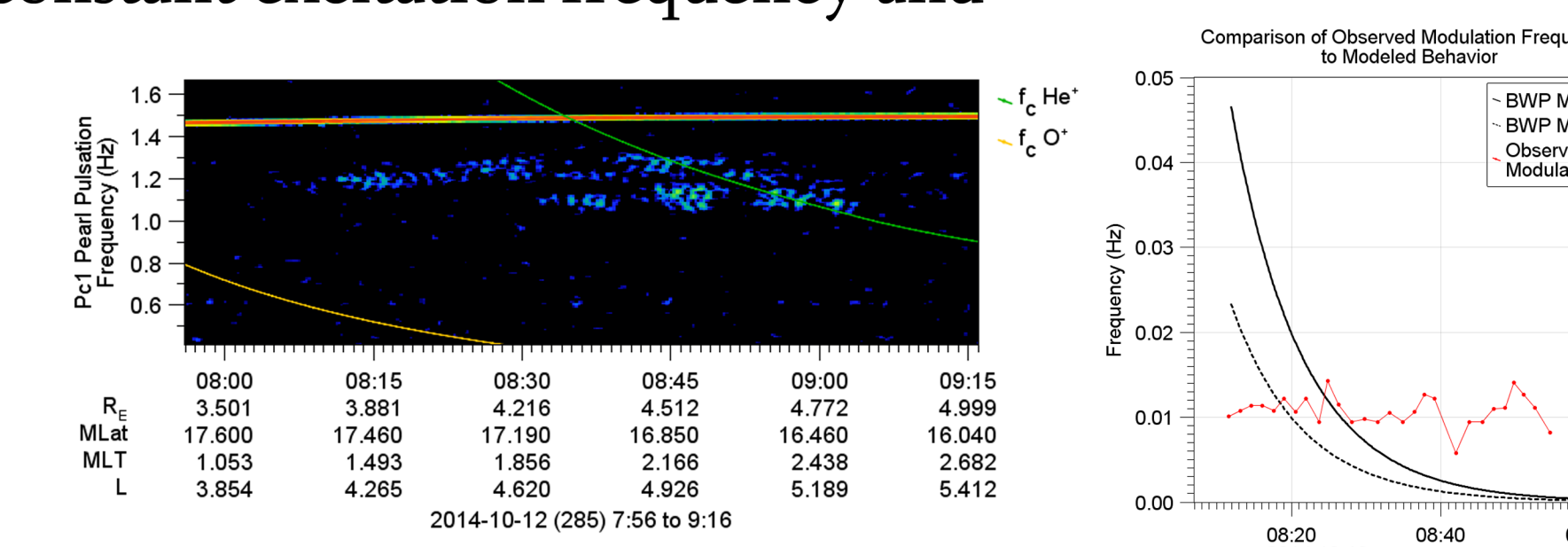


- The HOPE instrument recorded a distinct ring distribution of 10 keV O<sup>+</sup> within the compressional enhancement
- Field-aligned Poynting flux measurements demonstrate typical poleward EMIC propagation transitioning to highly oblique pearl elements
- Frequency analysis of pearl elements reveal wave power peaks at ~30 mHz spacing (O<sup>+</sup> gyrofrequency at this point ~60 mHz)
- Perpendicular Poynting flux measurements within compressional enhancement rotate from marginally oblique westward to radially Earthwards propagation.

## Constant Frequency

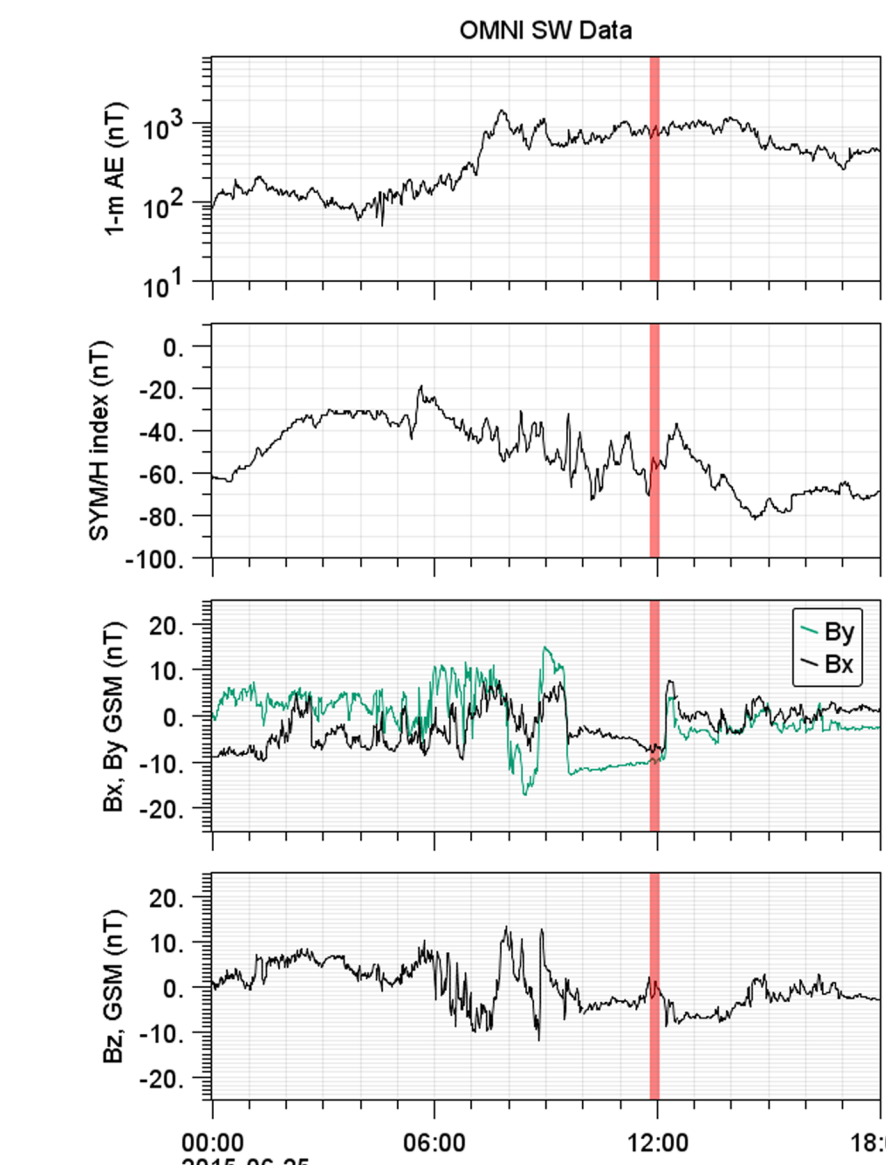
Pc1 pearl pulsations typically occur at a constant excitation frequency and modulation period across L

- Right, pearl pulsation excited at ~1.2 Hz from L=4.1-5.3
- Far right, modulation frequency at 10 mHz (red) compared to modeled wave bounce frequency (black)

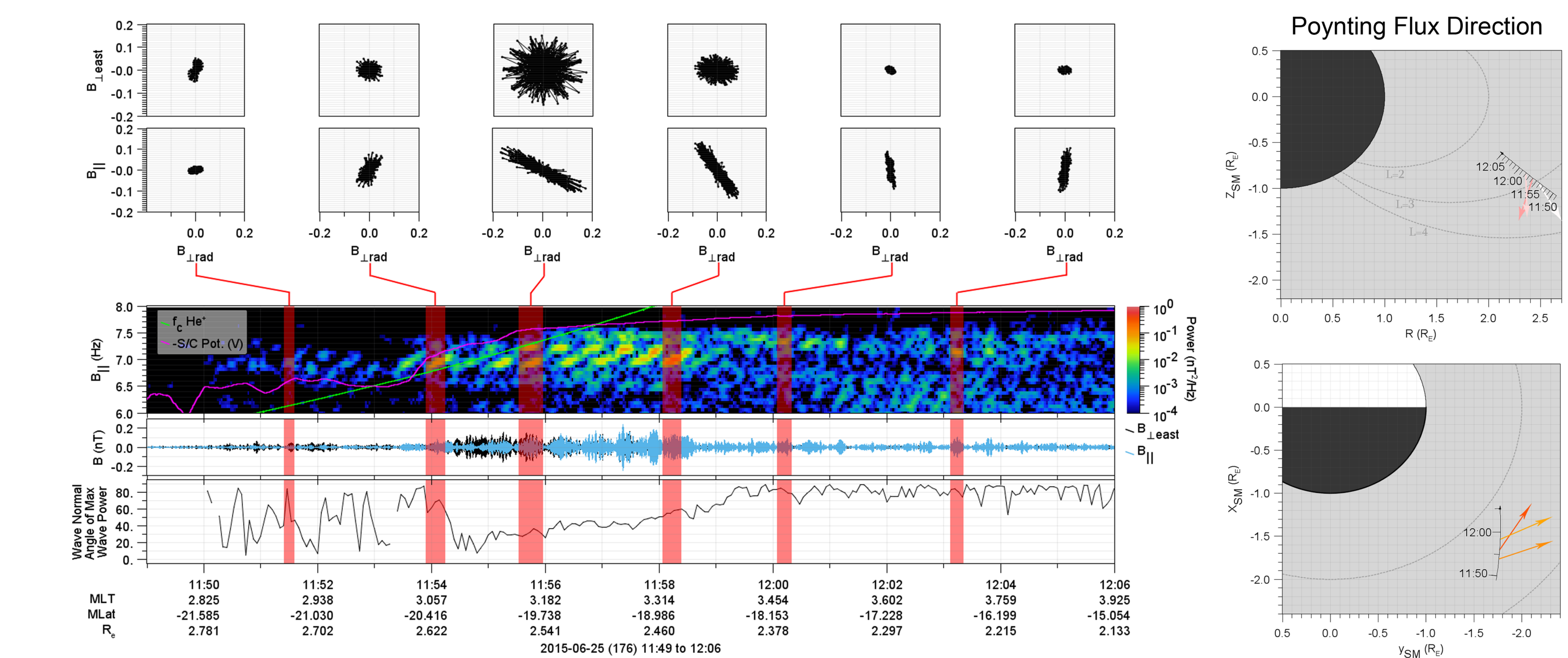


## 2015-06-25 Event

MMS observed a series of Pc1 pearl pulsations in the He<sup>+</sup> frequency band. As the spacecraft samples different regions of the wave enhancement region, the wave transforms from a slightly oblique transverse mode to an almost purely compressional mode.



- Wave event was observed during interaction of the magnetosphere with a flux rope during recovery period of significant 2015-06-22 storm
- Hodograms at various points show progression from transverse to compressional
- Excitation frequency remains constant through change in L/MLat
- Wave Normal Angle demonstrates smooth transition from ~20° to nearly 90°
- Conversion occurs off equator (~20° MLat) just inside the electron plasmaspheric boundary



## Conclusions/Discussion

In our previous work recording Pc1 pearl pulsations, we observed a tendency for the wave events to exhibit a constant excitation frequency across L, as well as a constant modulation period. This is at odds with most of the currently proposed generation mechanisms for this wavemode (such as ULF modulation bouncing wave packets) as these require the excitation frequency to depend to first order on the background field strength.

A consistent mechanism will need to incorporate a driving nonlocal source perturbation which then interacts with the localized plasma instability. Magnetosonic waves propagate across the background field, and have recently been recorded with rising tones and time modulation, similar to pearl pulsations. As these compressional modes encounter unstable ion distributions and perhaps a resonant cavity (such as the heavy ion cyclotron resonator [Guglielmi (2000), JETPL]) they may transfer energy to the transverse mode as EMIC waves, maintaining their modulated behavior. The observed events shown here demonstrate that such a mode conversion is present in Earth's magnetosphere, adding viability to the idea of magnetosonic waves as the external driver for pearl pulsations.

### Acknowledgements

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