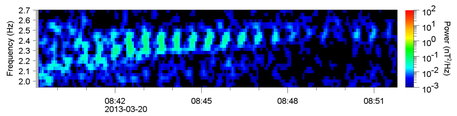
Statistical Observations of Pc1 Pearl Pulsations as Compared to Unstructured EMIC Waves Using the Van Allen Probes

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Abstract

Pc1 Pearl Pulsations are a time-modulated electromagnetic wave in the Pc1 band of the ULF spectrum. They are believed to be a subclass of electromagnetic ion cyclotron (EMIC) waves, and so are generated through the ion cyclotron instability. There have been rare isolated in situ observations of these pearl pulsations in the past, but the location and sensitivity of the Van Allen Probes spacecraft have provided us with an unprecedented number of events. Roughly one fourth of observed wave activity within the EMIC frequency range exhibits pearl structure, which is consistent with previous ground-based studies. Analysis of the central frequency dependence on the background field and their occurrence probability with respect to magnetic activity indices implies that there may exist a fundamental difference between the generation mechanisms for structured and unstructured EMIC waves. These waves often exhibit a rising frequency tone with a frequency sweep rate on the order of that observed within EMIC-triggered emissions. This frequency sweep in time has recently been proposed as exhibiting a more efficient method of wave-particle interactions with ultrarelativistic electrons. As such, we will examine conjunction events with the Polar-orbiting Operational Environmental Satellite (POES) spacecraft suggesting EMIC-driven electron precipitation. As of August of 2014, the Van Allen Probes spacecraft will have undergone one full precession around Earth, allowing for observations spanning the full range in MLT. We will therefore present here a comparative statistical analysis of EMIC waves, both pearl pulsations and unstructured, compiled over full coverage of the near-equatorial magnetosphere from L = ~2 - 6.5.



What are Pc1 Pearl Pulsations?

• Pc1 Pearl Pulsations are a subset of electromagnetic ion cyclotron (EMIC) waves found in Earth's magnetosphere. As such, they are expected to display the same wave properties, such as left-hand circular polarization and Poynting flux directed along the magnetic field. Their typical frequency range is on the order of 0.1-7 Hz, placing them in the Pc1 category of ground observations.

• Pearl pulsations separate themselves by demonstrating a wave packet structure modulated in time on the order of ~100 seconds, often with rising frequency tones as seen in the example above. This attribute gives their waveform the appearance of a string of pearls.

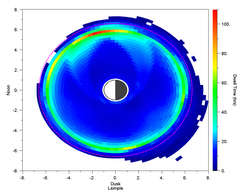
Instrumentation

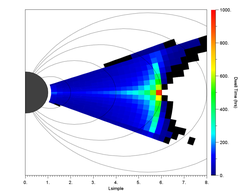
• The Van Allen Probes constitute two identical spacecraft in a highly elliptical orbit in the equatorial plane.

• During the period of this study, from 2012-09-08 through 2014-08-31, they have covered more than one full precession in MLT, with a meridional span between +/- 20 degrees magnetic latitude (coverage seen at right).

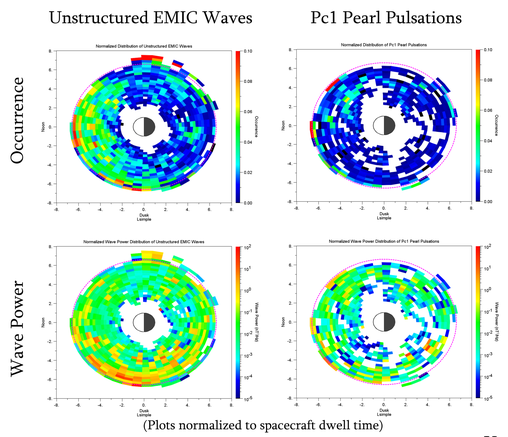
• For 760 hours of Unstructured EMIC wave activity observed by the Van Allen Probes, we have seen 225 hours of Pearl Pulsation activity.

• In order to directly observe possible precipitation due to EMIC waves, we have examined the electron contamination of omnidirectional proton channels on the POES spacecraft during magnetic conjunction.





Different Spatial Distibutions



(Plots normalized to spacecraft dwell time)

• Unstructured EMIC waves occur primarily on the day side and early dusk, with small localized sections of wave activity pre-midnight and early morning. Dayside waves are thought to be caused by magnetospheric compression

• Pearl pulsations are more uniform, with an occurrence peak in the late morning. This peak was originally attributed to storms early in mission, but the second pass of the area with precession confirms this observation.

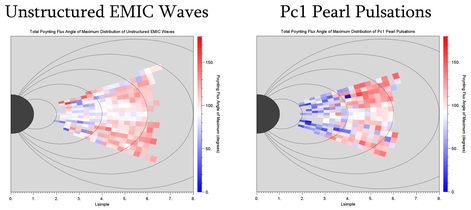
• No wave activity observed within 2 Re.

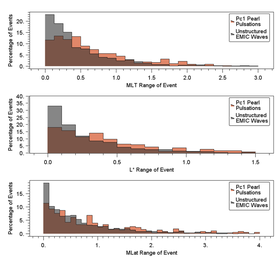
• Wave power for unstructured waves is stronger across dusk (in agreement with plasma plume generation theory) although significant wave power is still observed through all local times.

• For pearl pulsations, this wave power is again distributed relatively uniformly, though contributes less overall wave power than unstructured waves.

• Unstructured waves demonstrate unidirectional Poynting flux away from source region (red), confirming previous studies [*Loto'aniu et al. (2005), Fraser et al. (1996)*]

• Pearl pulsations show similar response for L>4, but the majority of waves within L<4 propogate equatorward (blue)





• Pearl pulsations tend to span a larger range in MLT and to a lesser extent L* compared to the unstructured waves, with a peak MLT range of 0.4 hours. Magnetic latitude ranges for the two populations are similar and small.

• The extended range in MLT for pearl pulsations could support both the ULF wave modulation [*Plyasova-Bakounina et al. (1996)*] and ion cyclotron resonance [*Guglielmi et al. (2000)*] theories of generation.

• We have observed several instances of near-equatorial mode conversion in pearl pulsations where wave activity crosses cyclotron frequencies [*Paulson et al. (2014)*], which may also be a product of the larger spatial extent of these waves.

Different Storm-Time Drivers

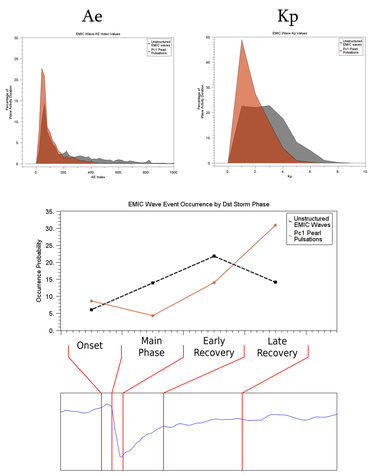
• Pearl Pulsations are observed during quiet periods, such as lower Kp and Ae activity compared to the times when unstructured waves are observed, as seen at right.

• Pearl Pulsations are least likely to occur during the main phase of a geomagnetic storm, and instead are observed more often during the late recovery period, in agreement with previous ground-based studies [*Kerttula et al. (2001)*]. This agreement verifies that the pattern of ground observations is not an ionospheric effect.

• Occurence of pearl pulsations during the recovery periods of storms could imply a preference for their generation during refilling of heavy ions in the plasmasphere.

Acknowledgements

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Reflecting Wave Packets

• Though the overall trend of unidirectional Poynting flux away from the equator dismisses the ionospheric bouncing wave packet method of generation, we have found ~20 events displaying alternating Poynting Flux directions along |B|.

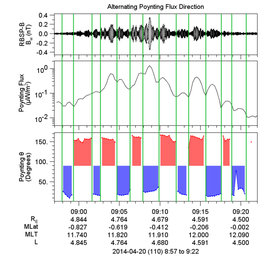
• In the example at right, successive elements display similar total Poynting Flux energy, but opposing orientations along the direction of the magnetic field, implying reflection of the wave packet.

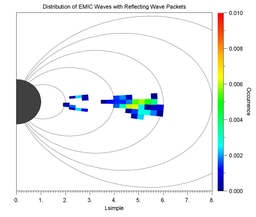
• These reflecting events are closely tied to the equatorial plane (shown in meridional plot at right), but show no obvious MLT dependence

• These events could possibly be instances of wave observations within the source region

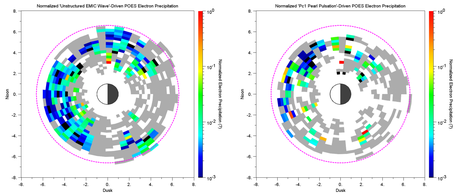
• Initial investigations into ULF modulation as a driver show no significant wave power in the Pc5 band during the observations of these events.

• Location and behavior is consistent with ion cyclotron resonator theory of generation, in which a heavy ion torus centered around the equator creates a region of standing wave modes. These standing wave modes will create bouncing wave packets as they are observed at some distance from the equator.





Electron Precipitation



• Current theoretical work suggests that EMIC waves may be responsible for the scattering of ultrarelativistic (>3MeV) electrons through a doppler shift of the polarization direction.

• In particular, some have suggested pearl pulsations have a possible association with triggered emissions, [Nakamura et al. (2014)] and that the rising tones may more effectively resonate with a scattered electron.

• In the images above, we have plotted ultrarelativistic electron contamination in the P6 (>16MeV) omnidirectional telescope of the POES satellites during magnetic conjunction with EMIC wave observations by the Van Allen Probes. Data was removed during excitations of the P7 omnidirectional telescope (immune to contamination) and when the spacecraft passed over the South Atlantic Anomaly.

• In these preliminary results, normalized to the occurrence rate of each type of EMIC wave, initial patterns of activity are swayed by data quality and availability, which will be resolved for future work.

Conclusions

The stark contrasts between the various demonstrated properties of Pc1 Pearl Pulsations and Unstructured EMIC waves lead us to believe that there exists a fundamental difference in the generation mechanism that gives rise to the modulated structure of pearl pulsations. Their uniformity in local time and the observations of reflecting wave packets implies that the ion cyclotron resonator may be at the heart of this mechanism. Previous observations of mode conversion and equatorially-directed Poynting flux for L<4 imply these waves may also be subject to different propagation and particle interaction effects than unstructured waves. Future work into the plasmaspheric cold ion composition and electron interactions will help to explore these ideas.

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