Simultaneous observation of FLR, modulated chorus and pulsating aurora on Van Allen Probes and ground

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Fundamental Unanswered Questions of Pulsating Aurora

1. What process(es) determines the size and shape of pulsating auroral patches?

2. Is the ionosphere passive or active in the formation and persistence of pulsating patches?

3. How can it be that the shape of the patches is maintained even after it seems to have ceased pulsating but then returns?

4. What controls the period of the pulsations?

5. What process generates the modulation of pulsating aurora and in what region of space does this process originate?

Pulsating Aurora, Chorus & ULF Waves

In a recent paper, Li et al., [JGR, 2011] show observational and theoretical results from the THEMIS spacecraft, where chorus waves were modulated by Pc 4-5 pulsations. They attribute the modulation of chorus waves to variations in the ratio of resonant electrons to total electrons associated with the Pc 4-5 waves.

In the example presented here, we show similar results acquired by the Van Allen Probes, with the additional observation of widespread pulsating aurora at the footprints of the spacecraft. The observations in this case also differ form those in Li et al in the sense that chorus waves in this example occur at half the period as the Pc 4-5 waves (which may be poloidal mode waves). The implication is that pulsating aurora may be directly connected to Pc 4-5 pulsations (i.e., perhaps poloidal field-line resonances).

Two papers addressing poloidal mode waves are relevant to this work. One is a statistical study of ULF by Anderson et al. [JGR, 1990] that shows occurrences of radially polarized waves in the post-midnight region. Occurrence rates of these waves are much lower than pulsating aurora occurrences. On the other hand, the event shown here is clearly visible in the electric fields, but not the magnetic fields. The other paper that is relevant is James at et al [JGR, 2013], showing observations of poloidal modes in conjunction with substorm injections.

Taken together, these results imply that substorm injections drive poloidal modes, which modulate chorus that can scatter the energetic electrons that produce pulsating aurora.

Pulsating Aurora Observation & Conjunction with Van Allen Probes

Pulsating aurora was observed on 26 Jan 2013 across several THEMIS allsky imagers following two substorms. Allsky camera data from Gillam, Manitoba, showed pulsating aurora beginning at 0920 UT (visible as clouds moved away from the area), recorded until sunrise forced the camera to shut off at 1030 UT. A camera further west (The Pas) also showed pulsating aurora beginning at 0900 UT, filling the entire field-of-view of the camera and persisting with varying brightness until the camera also shuts off at 1030 UT. At Poker Flat, Alaska, pulsating aurora was observed beginning near 1130 UT (Figure 1).

During the event, some cloud cover occurred over the THEMIS camera array. However, we estimate that the spacecraft "entered" the auroral zone near 1000 UT and "exited" the region near 14:30 UT.

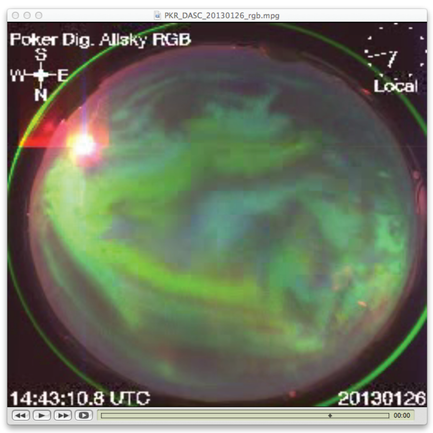


Fig. 1: Allsky camera data from Poker Flat, Alaska 1400 UT

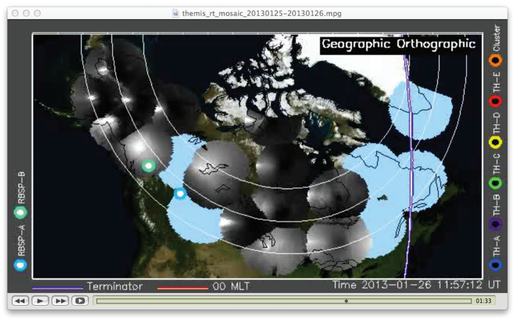


Fig. 2: The footpoints of RBSP-A and B at 1157 UT. Pulsating aurora was widespread, occurring at The Pas, Gillam and Poker Flat

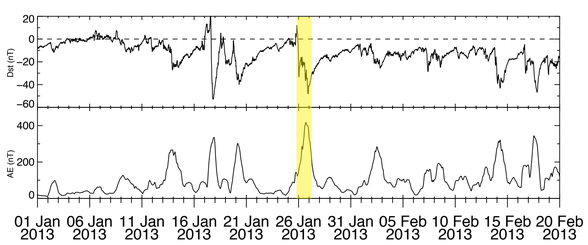


Fig. 3: Dst and AE indices for Jan-Feb 2013; Significant substorm activity occurs on the event date (26 Jan)

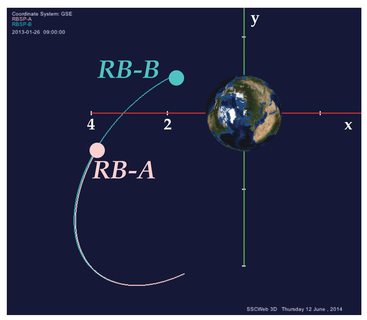


Fig. 4: Location of RBSP-A and B in the x-y GSM plane, from 0900 UT-1400 UT

Chorus Wave Modulations at 3 Hz

Magnetic field diagonal waveform spectra from EMFISIS-A on Van Allen Probes (Fig. 5a) shows modulated chorus. For this part of the orbit, 0.5 f_{ce} is near 1.5 kHz on all panels. The vast majority of the wave power resides in the lower band chorus.

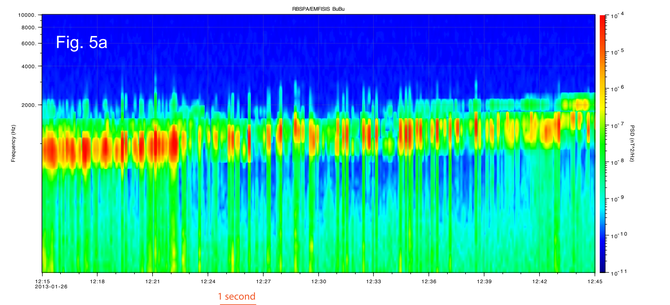
Zooming into chorus elements within each packet, Figs. 5b and 5c show EMFISIS-A WFR 6s continuous burst data of Bfield. FFT has been applied to get power spectral density (color scale). Fig. 5b covers 1207:07 UT - 1207:23 UT and precedes the interval shown in Figure 5a. Third panel (5c) covers 1219:18 UT - 1219:28 UT and lies within the interval shown in Figure 5a.

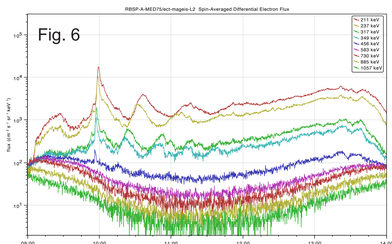
Chorus shows nice rising tone structure. Chorus elements in each figure show modulation at ~3 Hz.

There exists a well-known 3 Hz modulation associated with pulsating aurora, first reported by Royrvik and Davis [1977], and since observed frequently by ground-based measurements and (more often) using in situ data.

Wave-particle interactions involving modulations of 10's keV particles in the equatorial magnetosphere and whistler-mode chorus waves have been shown to be highly correlated with pulsating aurora: pointing to the effective source region of these auroral modulations [Jaynes et al., 2013; Nishimura et al., 2010].

A substorm injection, seen clearly in MagEIS-A data in Fig. 6, provides a seed population for pulsating aurora. Subsequent drift echoes present in flux data as well. Interval shown is 0900-1400 UT.





Field Line Resonance Observed by Van Allen Probes

Fig. 7 shows the dynamic spectra for all components of E and B fields on RBSP-A for 0700-1600 UT.

The compressional component of the magnetic field oscillates (with small amplitude) at 10 mHz (largely at RBSP-B), which can contribute to particle precipitation.

Compressional 10 mHz waves are known to drive the chorus. More analysis is required, though a compressional component was observed for this event and the FLR is likely a mixture of toroidal and poloidal modes.

Fig. 8 shows the MGSE electric field measurements for y and z components on RBSP-A as a time series over an interval where "monochromatic" Pc 4-5 pulsations are clear in the electric field data (but not so clear in magnetometer data).

The period of chorus waves observed (Fig. 5a) are precisely half of the period of the Pc 4-5 waves, and the intensity of the waves approximately correlates with the amplitude of the Pc 4-5 waves.

The coherence and periodicity of the modulated chorus waves and their correlation with the (large-scale) Pc 4-5 waves must mean that spacecraft are observing temporal effects, not spatial.

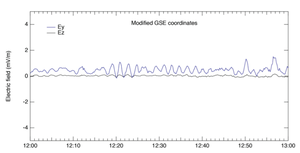


Fig. 8

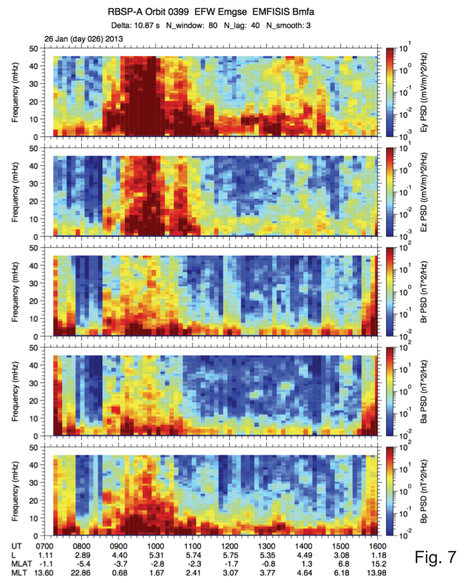


Fig. 7

(Figs. 7 & 8 courtesy of K. Takahashi)

Conclusions

Observations of modulated whistler-mode chorus waves and field line resonance from Van Allen Probes over a region of pulsating aurora occured on 26 Jan 2013, following two substorms where maximum AE reached ~400 nT.

Bursts of chorus emissions in conjunction with pulsating aurora are well-correlated with Pc 4-5 waves. Such waves may be driven via substorm injections and likely causes the chorus (e.g., Li et al., 2011). The injection also provides the seed population for pulsating aurora electrons.

This fortuitous set of observations reveals the following narrative: substorm injections provide a pulsating aurora seed population and free energy for wave growth in the outer magnetosphere. ULF waves then drive the modulation of chorus waves, resulting in periodic packets comprised of well-formed rising tones at ~3 Hz. Subsequently, the chorus enhances the scattering of 10's keV electrons and results in widespread and long-lasting pulsating aurora observed through ground-based instrumentation. **From field line resonance, to chorus wave modulations, to pulsating aurora: this event shows a well-sampled end-to-end observation of M-I coupling and helps to complete the picture of pulsating aurora sources and mechanisms.**