RENU2: Fine Structure Within Poleward Moving Auroral Forms

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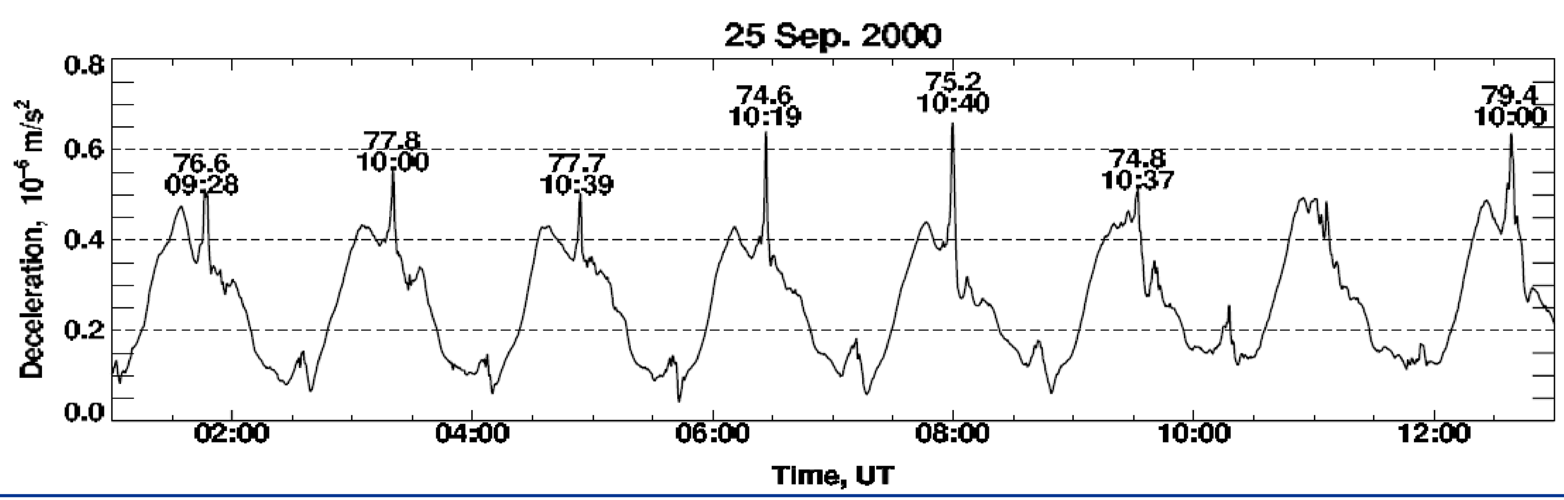
Abstract

The Rocket Experiment for Neutral Upwelling (RENU2) NASA sounding rocket mission launched into the dayside cusp region from the Andøya Space Center at 07:34 UT on 13 December 2015. The campaign included ground based imagers as well as the use of the EISCAT and SUPERDARN radars. The Electron Plasma (EPLAS) instrument provided by University of New Hampshire measured the energy distribution of electrons from 10 eV to 15 keV in 1 ms time steps. This allowed for *in-situ* measurements of small-scale structures within the Poleward Moving Auroral Forms (PMAFs) observed by RENU2 and by the imagers on the ground. These data are presented to demonstrate that PMAFs are not uniform entities, but are comprised of a number of small scale structures with Aflvenic signatures that likely interact with each other.

RENU 2 Background

Motivation: The objective of RENU2 was to investigate potential drivers of neutral upwelling in the cusp region. Such neutral density enhancements were seen from accelerometer data on the CHAMP satellite (see figure below from *Luhr*, 2004). Such enhancements were long thought to be driven by large scale joule heating, but more recent modelling efforts suggested that more fine scale electrodynamic effects may contribute. RENU2 was outfitted to measure these various inputs and the ionospheric response in order to provide constraints for modelling the different drivers.



Relevant Processes:

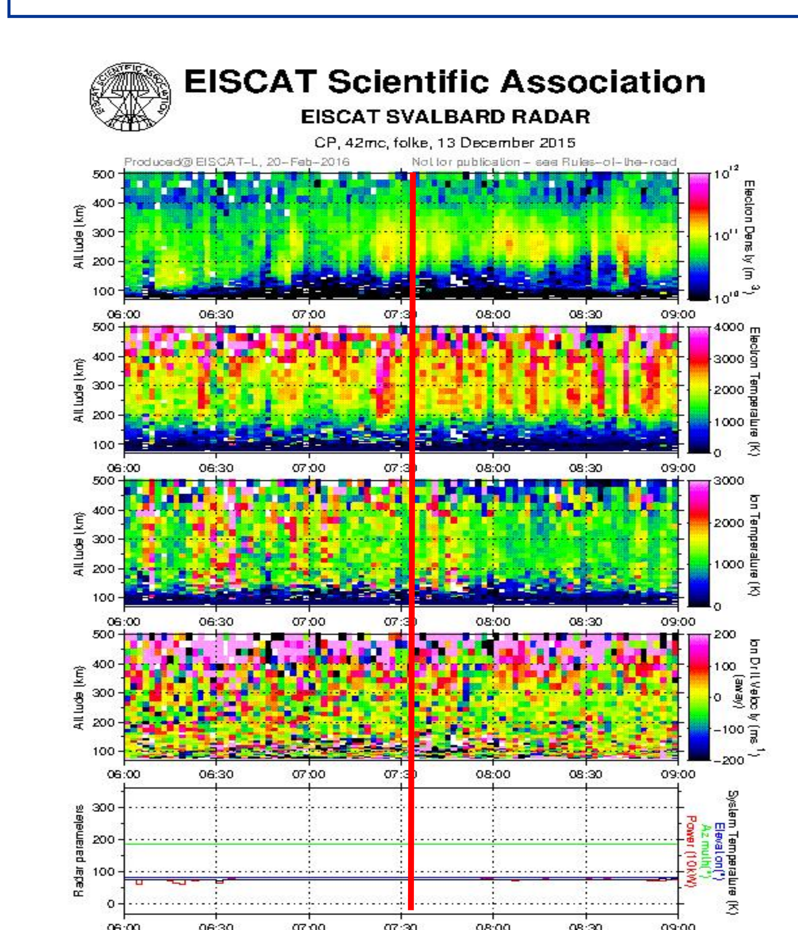
1. Joule heating of thermosphere and ionosphere causes neutral upwelling – Type 1
2. Soft electron (~100eV) precipitation heats ambient electron population, causes ambipolar field, lifts ions – Type 2
3. BBELF waves at higher altititudes (400 – 600 km) energize upwelled ions which then outflow

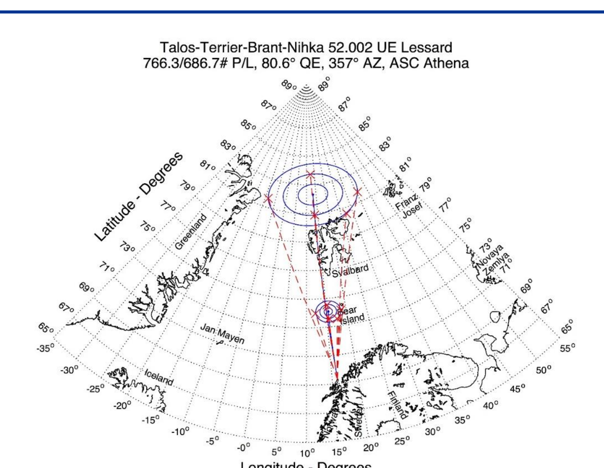
Proposed theories for small-scale neutral upwelling – primary driving mechanisms

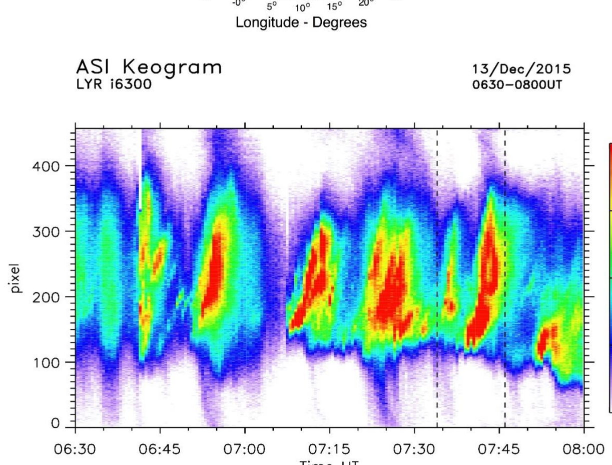
1. Upwelling fundamentally driven by Joule heating[2]
2. Type 2 ion outflow[3]
3. Soft electron precipitation, enhancing conductivities in F-region, enables increased Joule heating[4]
4. Direct particle heating with higher altitude Joule heating[5]

RENU2 Launch Conditions

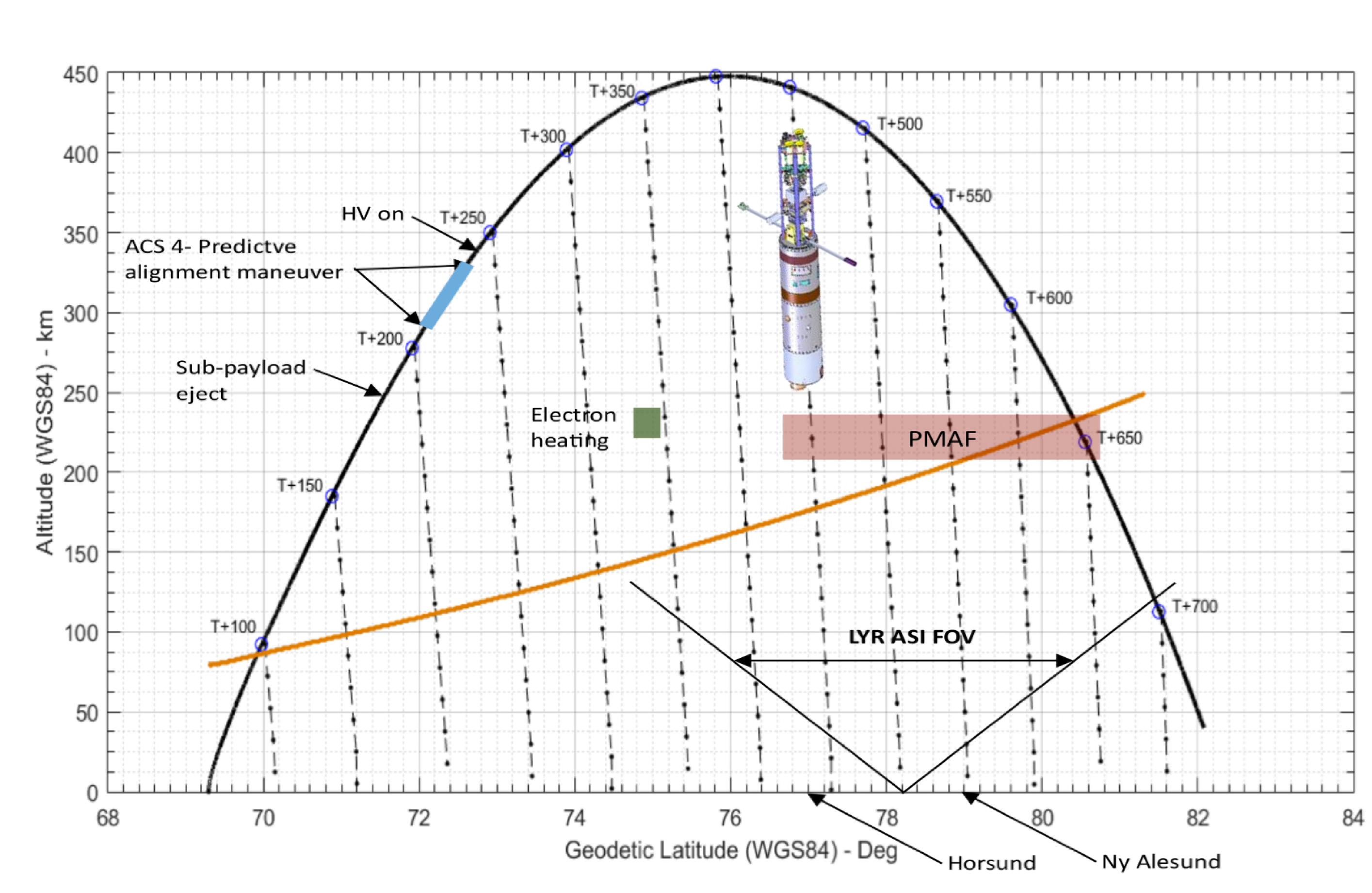
The RENU2 campaign also featured extensive ground support. All-sky imagers (ASIs) located at Longyearbyen and EISCAT provided critical context and diagnostics for launch criteria. Prior to launch, several Poleward Moving Auroral Forms (PMAFs) were observed passing overhead. PMAFs are faintly visible to the naked eye but show prominently in ASI data. EISCAT showed several transient electron density and temperature enhancements (consistent with PMAFs) and joule heating in the hour prior to launch. UNH induction coil magnetometer located at Hornsund also provided ULF spectra observed on ground throughout the campaign.



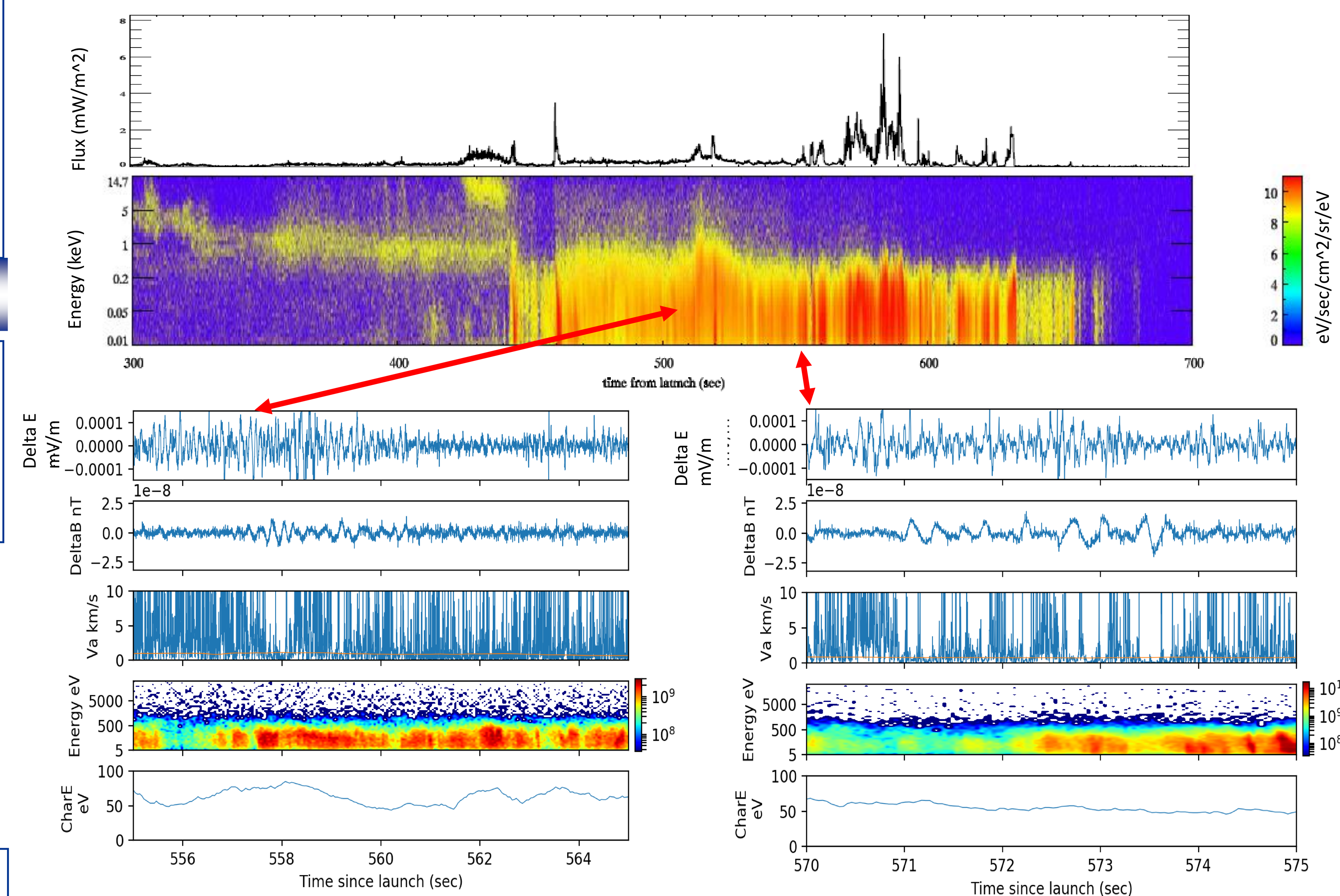




Left: EISCAT data depicts several transient F-region enhancements in ρ_e, T_e associated with PMAFs. Joule heating mostly in the hour pre-launch (launch indicated by red line). Weak ion upflow signatures seen just after launch. **Above Right (Top):** Diagrams show details of launch trajectory **Above Right (Bottom):** Keograms from KHO (Longyearben, Svalbard) show the PMAFs moving overhead. Right-most keogram depicts the PMAF that RENU2 flew through. **Below:** Rocket trajectory shown in relation to PMAF. Orange line depicts the terminator; payload was sunlit for a large portion of the flight.



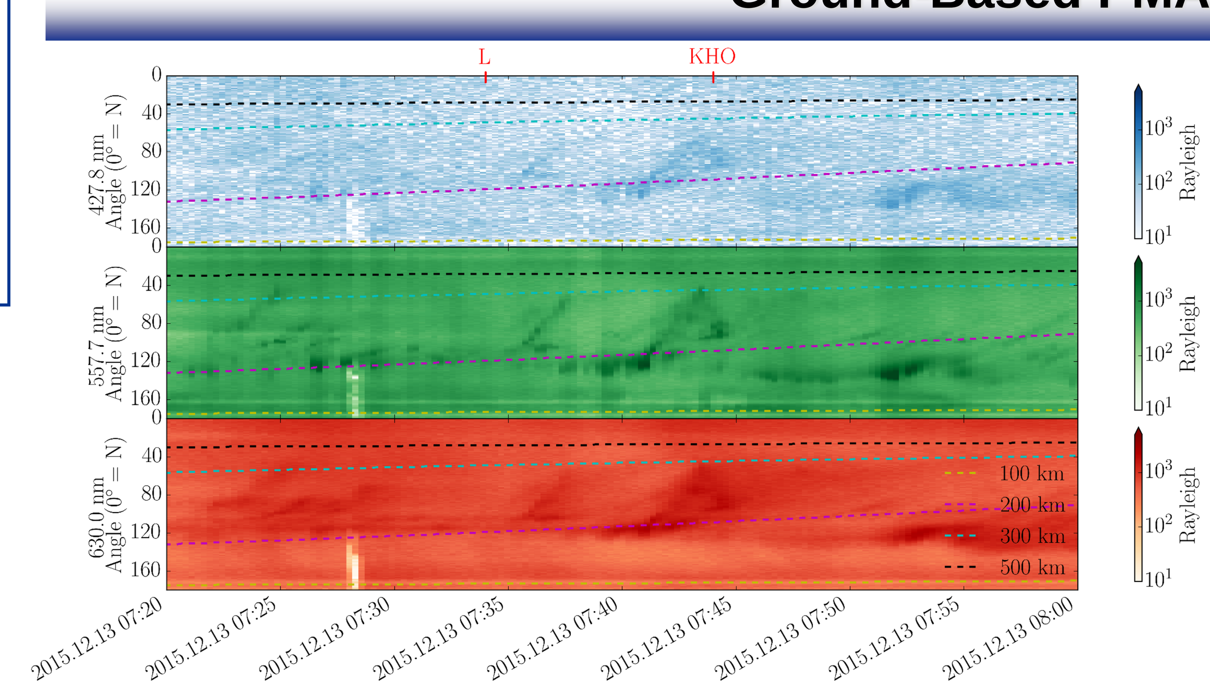
In-Situ Measurements

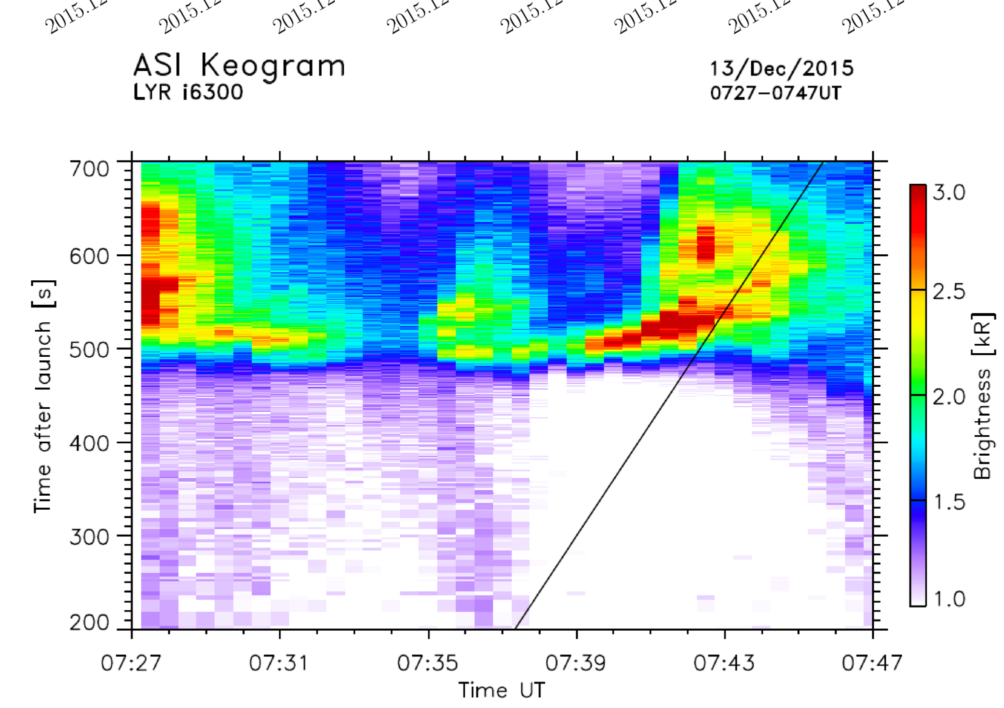


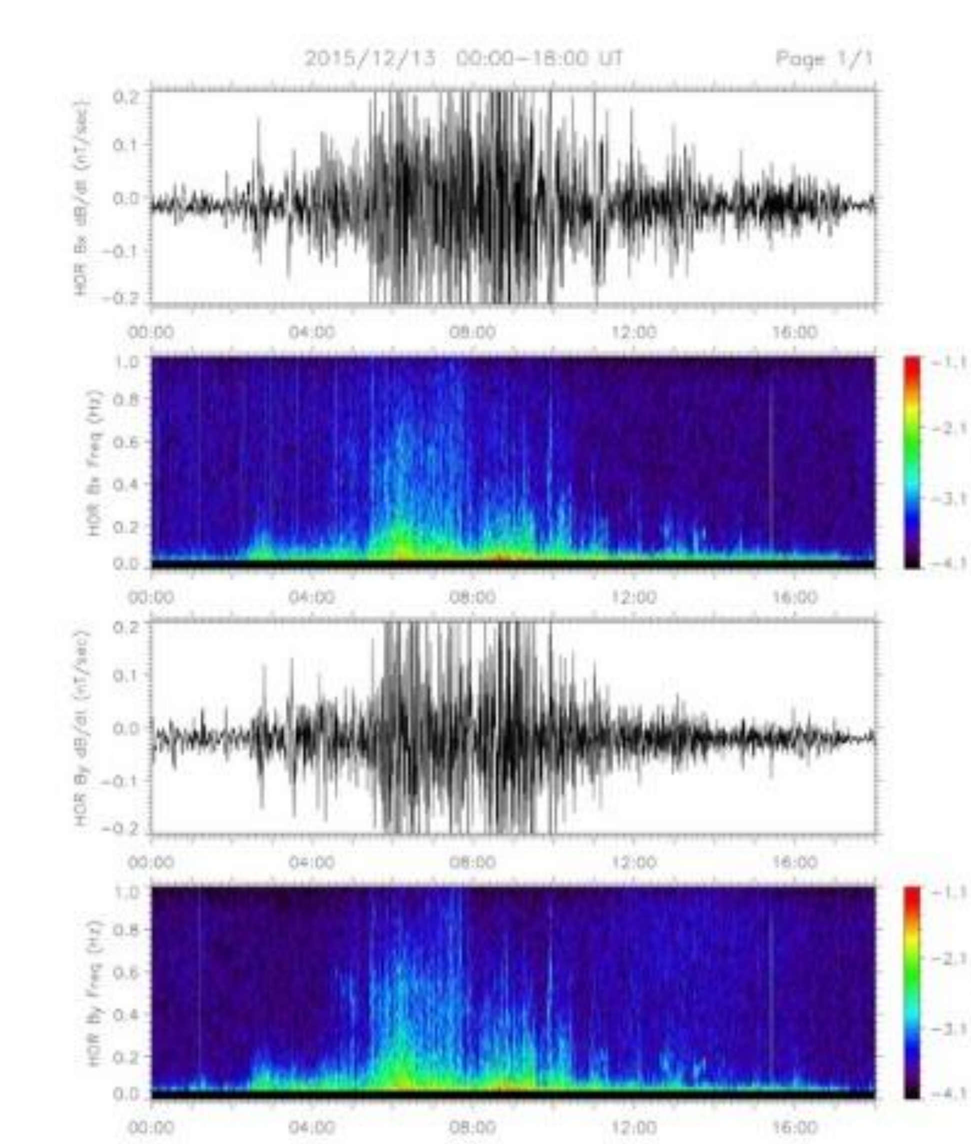
1.Energy flux carried by precipitating electrons **2.** Energy spectra of precipitating electrons as measured by UNH EPLAS instrument. EPLAS measures 360 degree FoV in 10 degree resolution. Energy sweep divided into 42 steps of 1ms, providing a full 360 spectra every 42ms. As rocket travels at 1km/s, EPLAS provides spatial resolution of 42m. Arcs within PMAF can be seen to vary on scale of 100s of meters to single kilometers. These data are only the electrons within the loss cone (about 40 deg. FoV for majority of flight). **3 and 4.** Close ups of fields and electrons data from selected arcs within the PMAF. Plot stack (top down): a) Perturbation of E b) Perturbation of E-field north-south b) Perturbation of B-field east-west c) Alfven speed computed as δE/δB (blue line) and as a function of density (orange line) d) Close of up electron energy spectra e) Characteristic energy of precipitating electrons.

Close up plots show small scale, periodic oscillations coincident with arc edges in EPLAS data. δE/δB gives Alfven velocity on the scale of 1 km/s for these oscillations. When these waves occur, δE/δB settles to the Alfven velocity computed by B/μρ. This suggests that electrons are accelerated by small scale Alfven waves. These waves are observed for time scales of .5-1s, giving spatial scales of similar order to the arc width observed by the EPLAS.

Ground-Based PMAF observations







Top Left: Scanning photometer data for 427.8, 557.7 and 640.0 nm emissions. Intensity in Rayleigh on log scale. Dotted lines show projections for distances to observed features. 30 second time resolution allows structuring within PMAF to be seen. **Bottom Left:** Keogram snapshot of RENU2 trajectory through PMAF. Note that although some structure is visible, the brightness variation is not as structured as the EPLAS data suggests.

Above: Search coil magnetometer data from Hornsund (located on Svalbard, very near the path of the rocket) shows broad band ULF activity for several hours before and after launch (7:34 UT). Such signatures are commonly seen in the cusp region and may be the signature seen on the ground of PMAF activity.

Conclusions and Future Work

- Poleward Moving Auroral Forms are not uniform bodies
- PMAFs consist of many arcs which stretch East-West for hundreds of kilometers, but the arc thickness (north-south) is on the order of hundreds of meters to kilometer scales.
- PMAFs are also highly varied in time. Small scale arcs brighten, grow, or shrink as the whole entity moves poleward. This is visible in the EPLAS data as an intensification of particle flux
- Thoguh PMAFs are composed mainly of soft (few hundred eV) electrons, those electrons deposit significant energy into the ionosphere (on the order of a few mW/m^2)
- More work needs to be done to pull small scale oscillations out of the fields data. Signatures shown are amongst the strongest signals. This is challenging as the signals are on the order of 10s of nT. More intense bursts see noisier signals. Sunlit ionosphere may be a factor with increased reflectance of Alfven waves.

References: Lühr, H., M. Rother, W. Köhler, P. Ritter, and L. Grunwaldt (2004), Thermospheric up-welling in the cusp region: Evidence from CHAMP observations, Geophys. Res. Lett., 31, L06805, doi:10.1029/2003GL019314.

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