UV Observations of Atomic Oxygen in the Cusp

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Abstract

The Rocket Experiment for Neutral Upwelling (RENU) 2 launched into the dayside cusp on 13 December, 2015. The sounding rocket payload carried a comprehensive suite of particle, field, and remote sensing instruments to characterize the thermosphere in a region where pockets of enhanced neutral density have been detected [Lühr et al, 2004]. An ultraviolet photomultiplier tube (UV PMT) was oriented to look along the magnetic field line and remotely detect neutral atomic oxygen (OI) above the payload. The UV PMT measured a clear enhancement as the payload descended through a poleward moving auroral form, an indicator of structure in both altitude and latitude. Context for the UV PMT measurement is provided by the Special Sensor Ultraviolet Imager (SSULI) instrument on the Defense Meteorological Space Program (DMSP) satellite, which also measured OI as it passed through the cusp. UV tomography of SSULI observations produces a two-dimensional cross-section of volumetric emission rates in the high-latitude thermosphere prior to the RENU 2 flight. The volume emission rate may then be inverted to produce a profile of neutral density in the thermosphere. A similar technique is used to interpret the UV PMT measurement and determine structure in the thermosphere as RENU 2 descended through the cusp.

Motivation

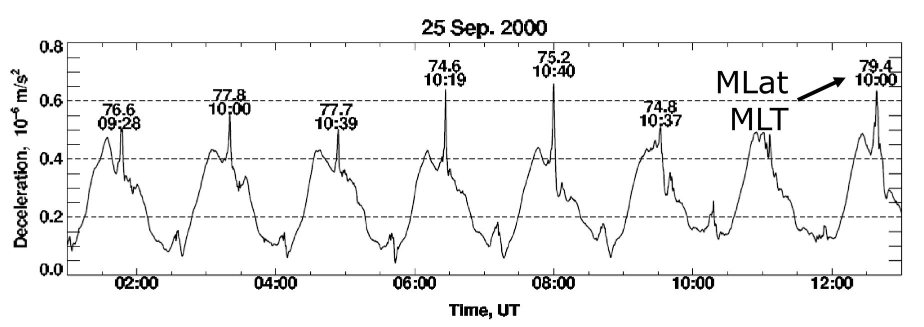


Figure: Air drag measured by the CHAMP accelerometer [Lühr et al, 2004] shows spikes in relative density near the cusp. Average relative enhancement ~1.33.

Relative cusp density enhancements correlate with measurable parameters:

- Enhanced electron temperature (T_e)
- Vertical plasma flows (v_z)
- IMF B_z amplitude (~ 30 min. prior)
- Small-scale field aligned currents

These helped determine proper conditions for the RENU 2 sounding rocket launch to measure physical processes in the thermosphere

Primary questions for RENU 2 analysis

1. What environmental drivers are responsible for neutral upwelling in the cusp?
2. How are the cusp density enhancements structured in latitude/altitude?

1. RENU 2 Mission Details

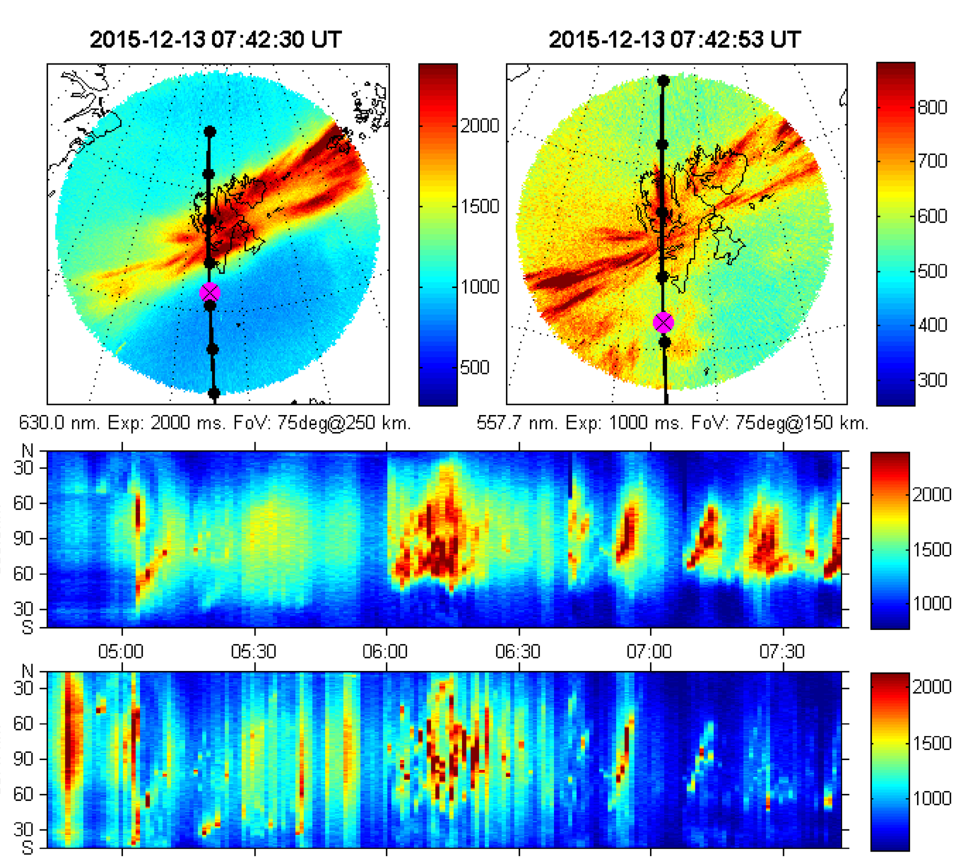
1a) Indicators monitored prior to the RENU 2 launch:

ACE – B_z turns south ~ 0510 UT

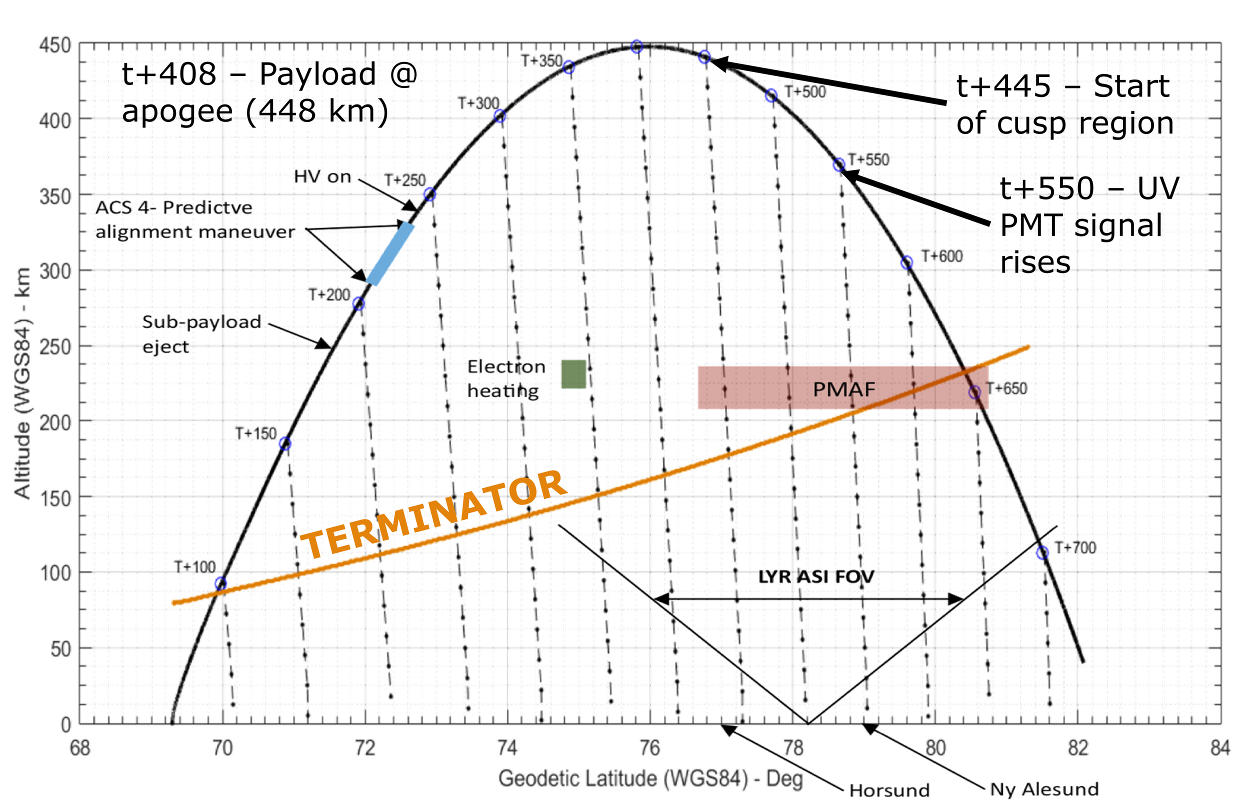
EISCAT – ISR measurements show increase in T_e after second PMAF, ~0720 UT

All-Sky Imagers (UiO) – Monitor 557.0 nm & 630.0 nm emissions

- Top: Real-time display included the nominal RENU 2 trajectory with 50 sec. increments (black dots) and apogee (pink dot)
- Bottom: Keogram of real-time data provides a time history of auroral activity

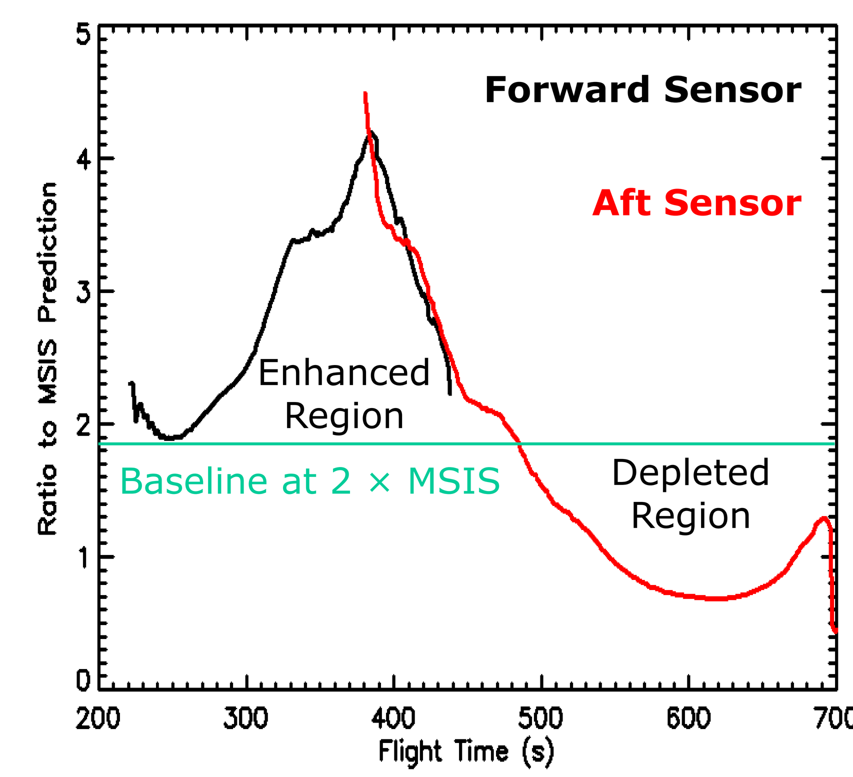


1b) RENU 2 launched at 0734 UT and descended into the cusp through a region of poleward moving auroral forms (PMAFs). Launch call was made after the third PMAF to ensure adequate heating of the thermosphere



NASA Mission 52.002

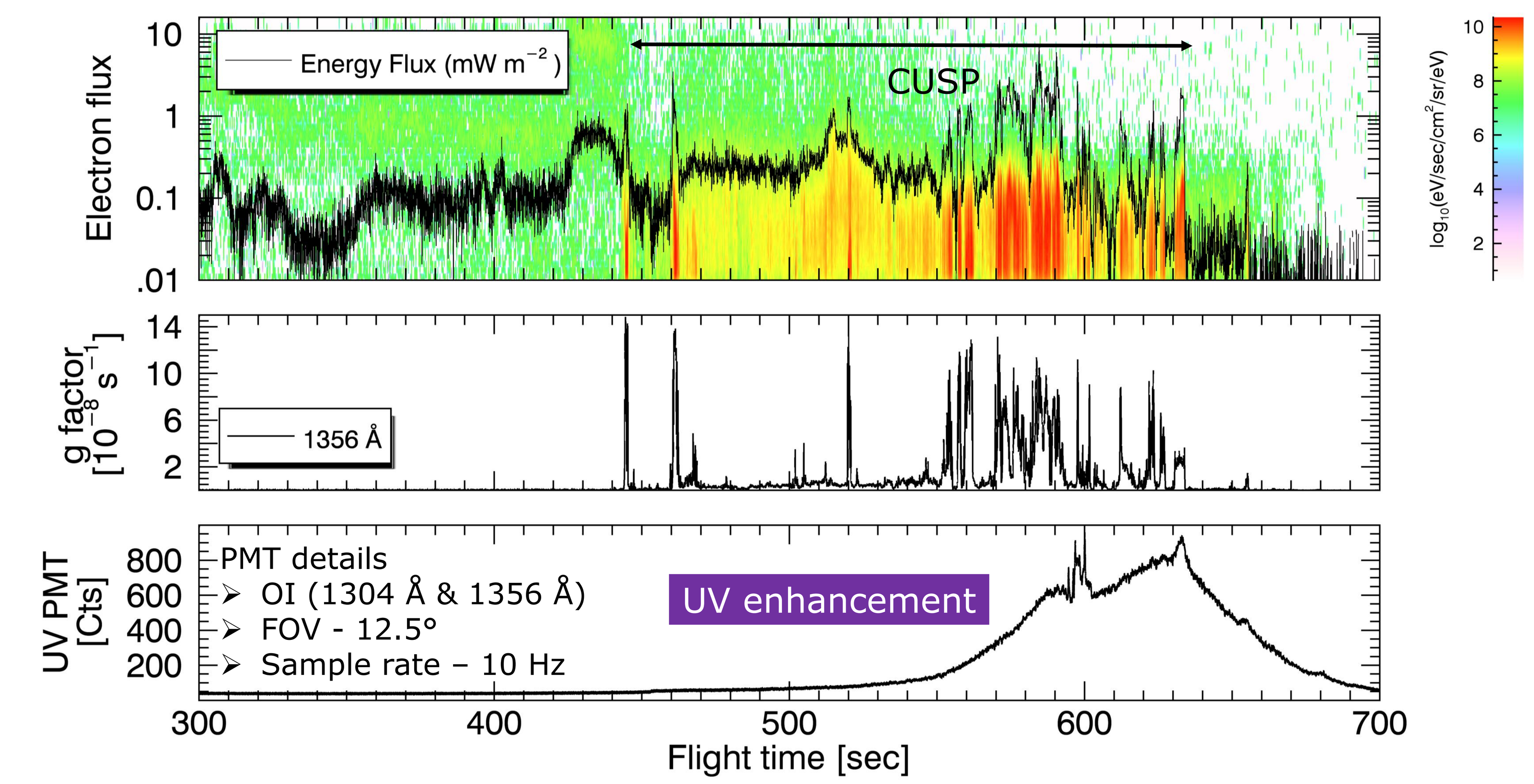
2. RENU 2 results



2a) RENU 2 Ion Gauges measured *in situ* neutral density. Two primary features, relative to 2 x MSIS prediction:

1. Relative density is *enhanced* on the upleg
2. Relative density is *depleted* on the downleg

More complicated than solely an enhancement!



2b) Additional RENU 2 results provide clues about the structure and behavior of the thermosphere

Top: EPLAS energy spectrum of electrons in loss cone

Middle: Excitation rate factor (g_O) calculated for $O + e^-$ (135.6 nm)

Bottom: UV PMT sees strong enhancement above the depletion measured by the ion gauges

What is the g factor?

Excited oxygen atoms emit photons at a rate proportional to the rate factor, g_O. One way to excite particles is by collision

$$O + e^- \rightarrow O^*(^5S) \rightarrow O(^3P) + h\nu$$
$$O_2 + e^- \rightarrow O + O^*(^5S) \rightarrow O(^3P) + h\nu$$

Precipitating electrons are the dominant source of collisions to produce OI (λ = 135.6 nm) as seen on RENU 2

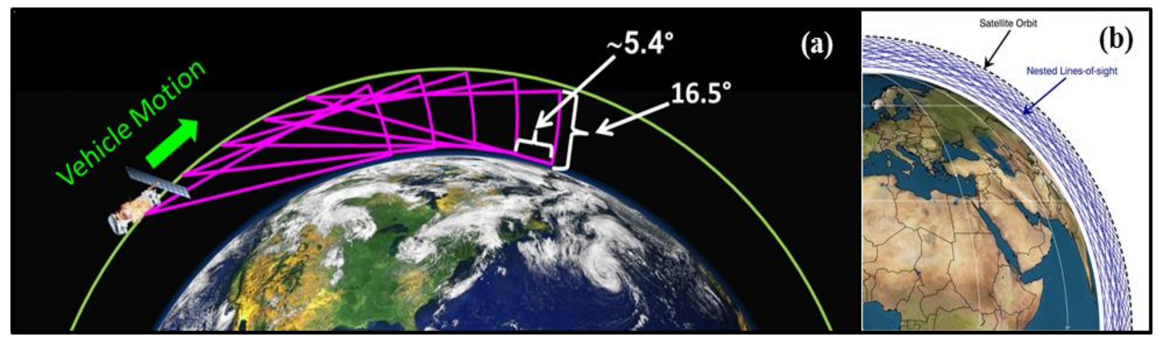
$$g_O(z,\theta) = \int_0^\infty \sigma_O(E)\, \varphi(E,z,\theta)\, dE$$

$\varphi(E)$ → electron flux
$\sigma_O(E)$ → collision cross-section

Volume emission rate (ε_O) from UV PMT measurement and g_O will be used to infer a number density of emitters, n_O

$$\varepsilon_O(z,\theta) = g_O(z,\theta)\, n_O(z,\theta)$$

3. Special Sensor Ultraviolet Limb Imager (SSULI) results



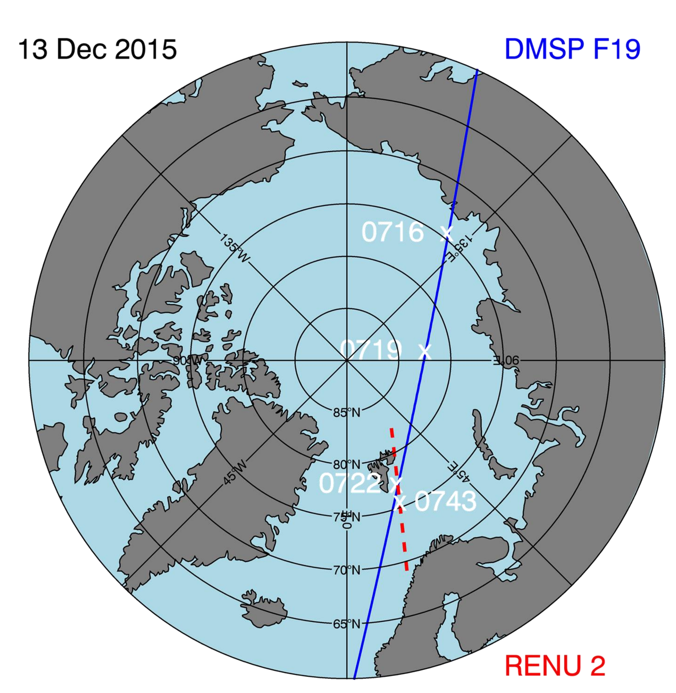
SSULI is a UV spectrograph on DMSP, oriented to observe the limb of the Earth along the orbital track

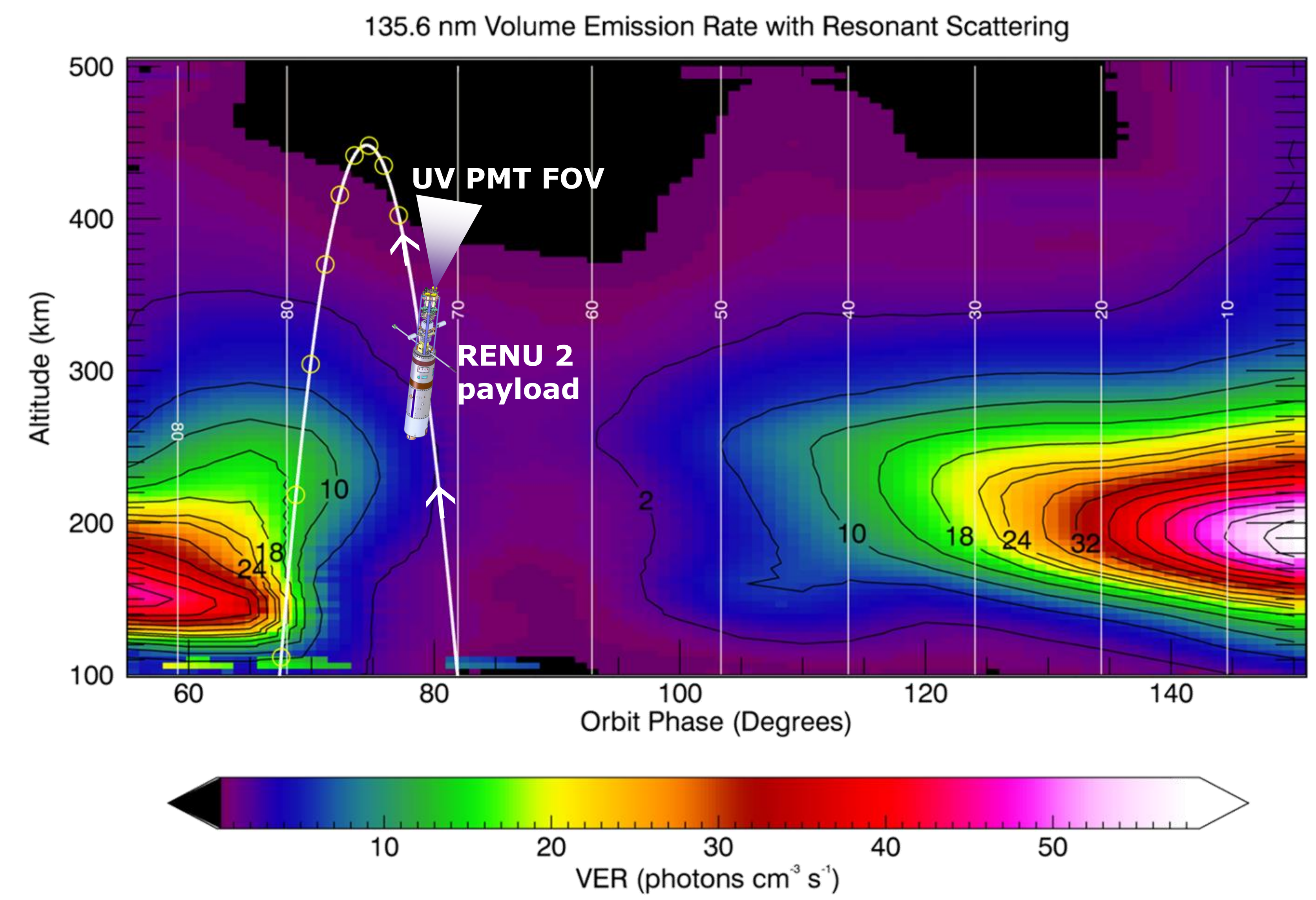
- 80 - 170 nm spectral range; 1.8 nm spectral resolution
- 100 - 750 km altitude range; 10-15 km spatial resolution
- Full scan every 92 seconds

3a) The DMSP F19 orbit and RENU 2 trajectory intersect ~20 min apart.

DMSP moves top to bottom on the map (solid blue line); three points in time are marked in white.

RENU 2 flew poleward out of Andøya, Norway (red dashed line). The apogee at ~0743 UT is marked in white.





3b) The Volume Emission Rate Tomography (VERT) technique uses SSULI intensity measurements (I_{1356}) to reconstruct ε_O by implementing a fast, non-negative iteration based on the Least-Squares Positive Definite (LSPD) algorithm.

$$I_{1356} = 10^{-6} \sum \int_0^\infty T(|\tau(s) - \tau(0)|, |t(s) - t(0)|)\, \varepsilon(z(s), \theta(s))\, ds$$

The Holstein transmission function, T, accounts for scattering (τ) and absorption (t) of photons along the path length, ds.

Conclusions

✓ The RENU 2 UV PMT observed fine-structure of OI in the cusp
- Sharp rise/fall in signal implies latitudinal structure above payload
- Signal dropout prior to absorption altitudes supports idea of latitudinal structure

✓ Large-scale, 2 dimensional structure from SSULI provides critical context for RENU 2

Future plans

- Approximate column emission rate from UV PMT signal to estimate neutral densities
- Invert the SSULI tomographic image into a two-dimensional neutral density profile

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