Thermosphere Density and Wind Profiles During an Auroral Substorm from the Dissipation Sounding Rocket Mission

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Introduction

The comingled ionosphere/thermosphere (IT) acts as the transition region between Earth's atmosphere and space. In the high latitude IT energy flowing from the Sun and magnetosphere is dissipated through processes like Joule heating. Joule Heating is a frictional heating due to opposing motion of neutral gas and ions. This low altitude heating is one mechanism that drives neutral gas vertically, called neutral upwelling.

The Dissipation Sounding Rocket mission will answer questions regarding thermospheric wind, density and composition dynamics and structures driven by Joule heating due to electromagnetic forcing during active aurora.

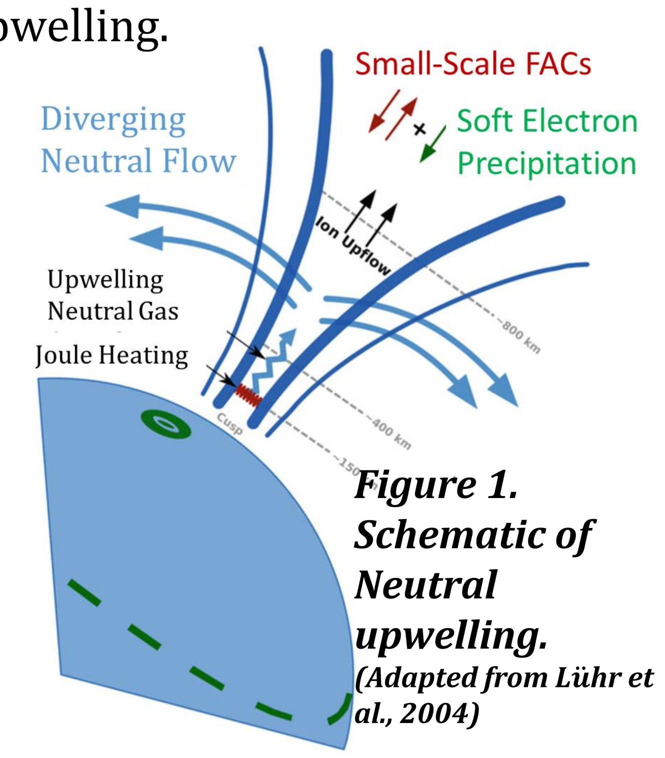


Figure 1. Schematic of Neutral upwelling. *(Adapted from Lühr et al., 2004)*

Launch Conditions

Dissipation launched into a well-developed auroral display on November 8, 2023, with an apogee of 321 km. The rocket was launched slightly after the onset of a substorm allowing time for the thermosphere to heat and react to the enhanced geomagnetic activity.

Figure 2. The Poker Flat all-sky camera shows the aurora observed while the rocket, bright spot towards center, was flying through the field of view. Courtesy of D. Hampton

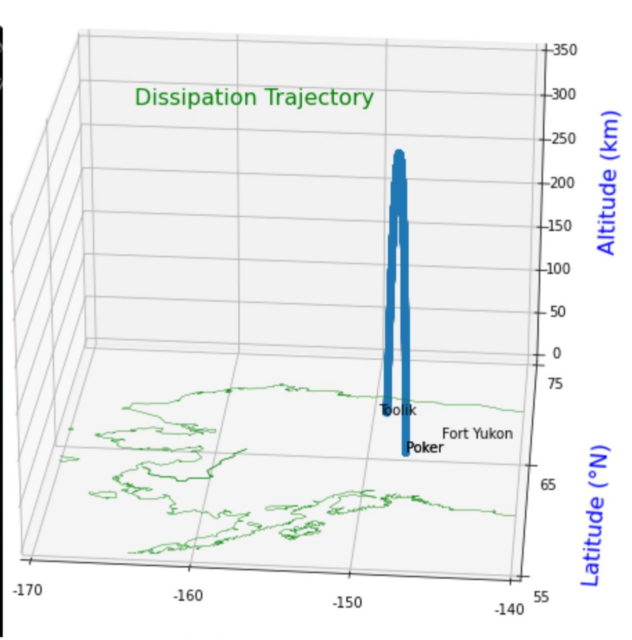


Figure 3. Dissipation trajectory over Alaska from Poker Flat Research Range

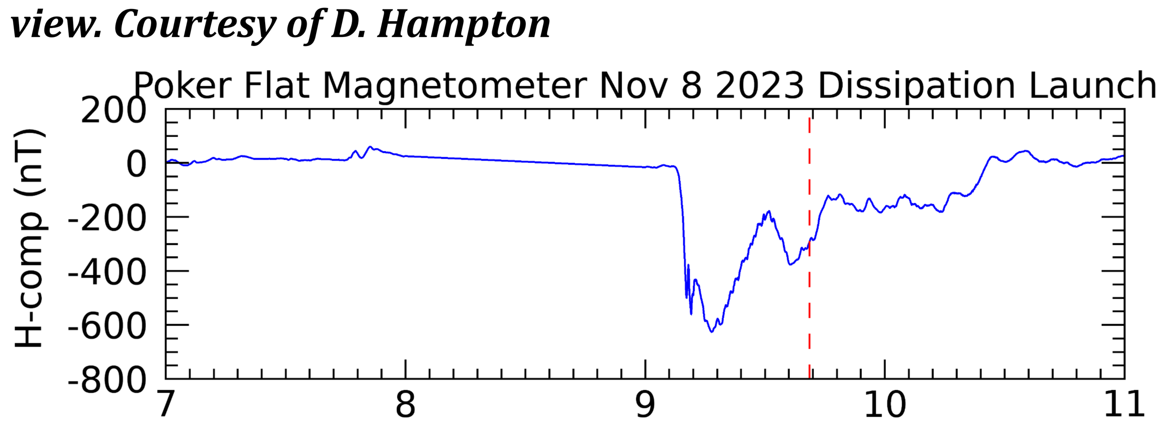
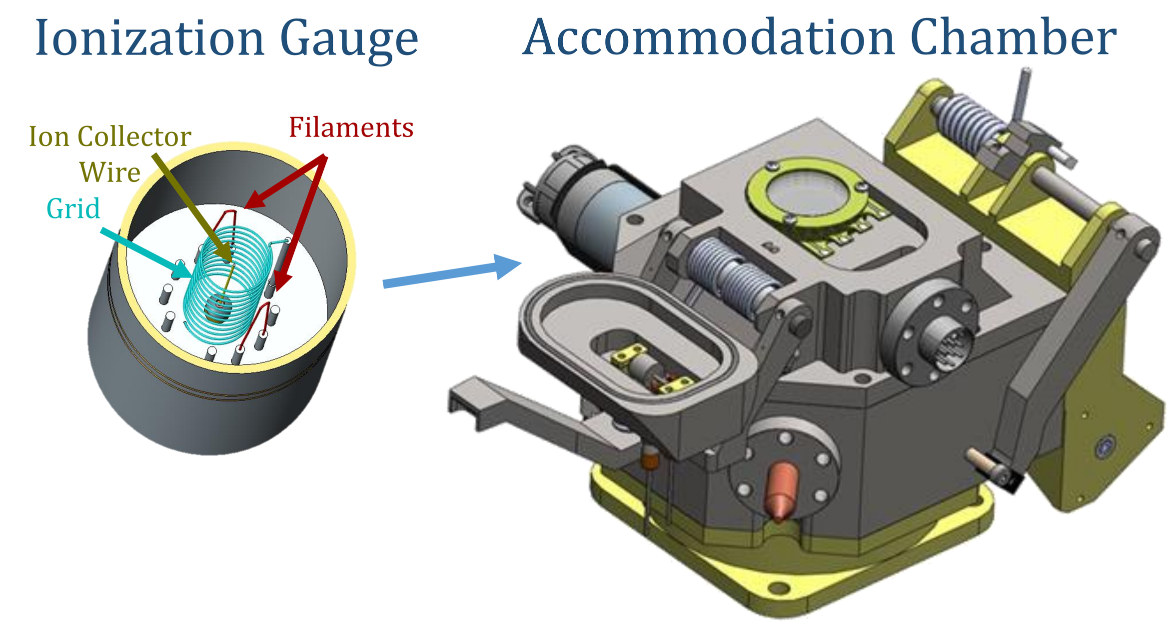


Figure 4. Poker Flat Magnetometer H-Component Dipping negative several minutes before launch. Red line depicts Dissipation T_0 launch time. (Magnetometer data, Geophysical Institute, UAF 2023. Retrieved from Research Computing Systems 25 May 2023.)

Thermosphere Density and Temperature

The Ionization Gauge (IG) on Dissipation is a Bayard Alpert IG to measure number density (pressure) of neutral gas.



The accommodation chamber allows for analysis of the number density and temperature of the ambient gas based on kinetic theory with few assumptions.
Assuming flux balance and accounting for the ram velocity :

$$n_a\sqrt{T_a} = n_g\sqrt{T_g}\left\{e^{-S^2} + S\sqrt{\pi}[1+\mathrm{erf}(S)]\right\}^{-1}$$

$$S = \frac{|v|\cos(\alpha_{att})}{\sqrt{\frac{2k_BT_a}{\bar{m}}}}$$

Where n_a is ambient density, T_a is ambient temperature, n_g is gauge density, T_g is gauge temperature, α_{att} angle of attack of the rocket relative to the IG aperture.
A "hypsometric" approach assuming hydrostatic equilibrium of a stratified fluid according to

$$\int_{p(z_1)}^{p(z_2)} \frac{dp}{p} = \int_{z_1}^{z_2} -\frac{g}{RT}dz$$

is used to iterate the values for ambient temperature and density to calculate both density and temperature profiles.

$$P = C * \left(\frac{I_{collected}}{I_{emission}}\right) \qquad P = nk_BT \rightarrow n = \frac{P}{k_BT}$$

C: sensitivity factor

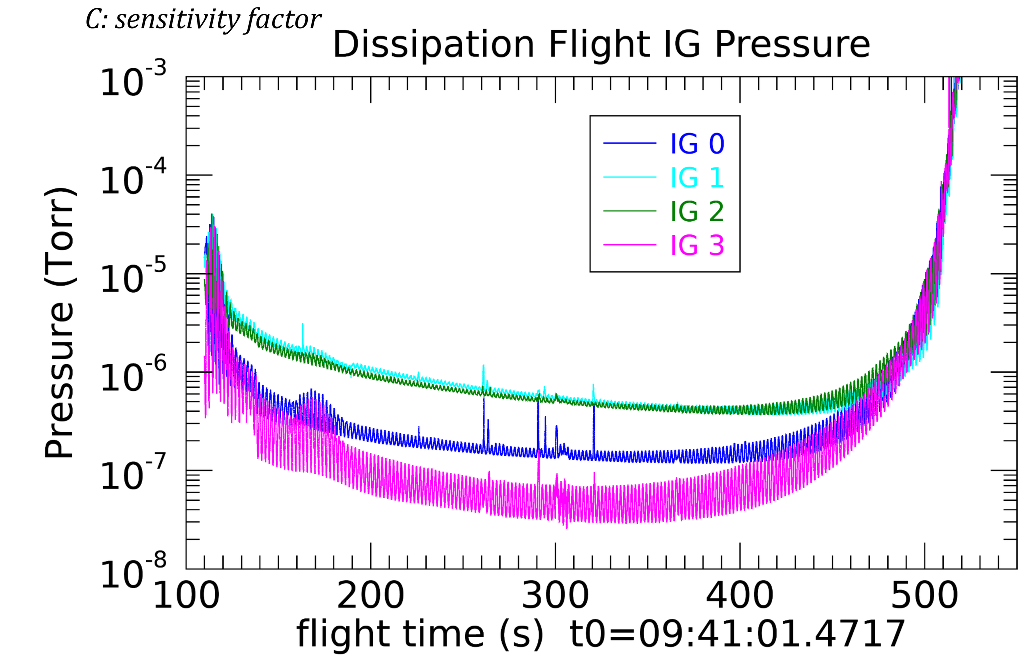


Figure 5. IG pressure over entire flight from 4 Radial Ionization Gauges

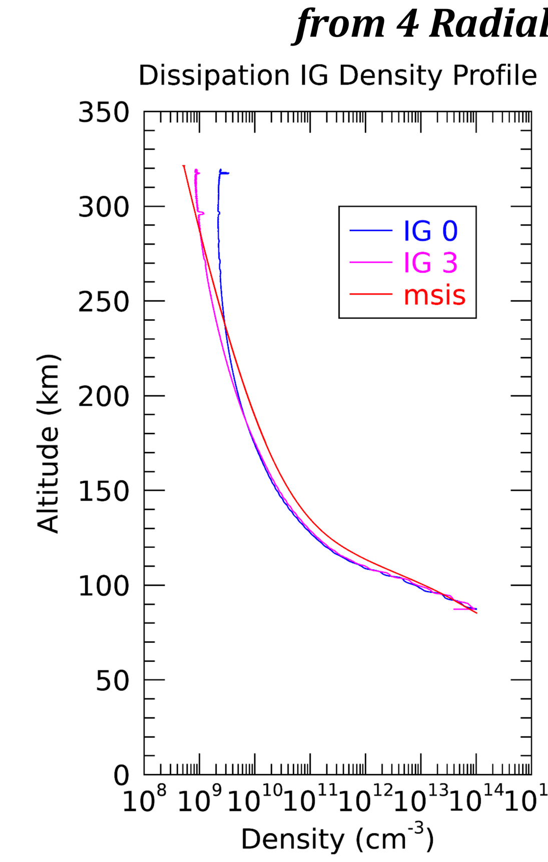


Figure 6. Density Profile from IG 0 (blue), IG 3 (magenta), NRL MSIS model (red)

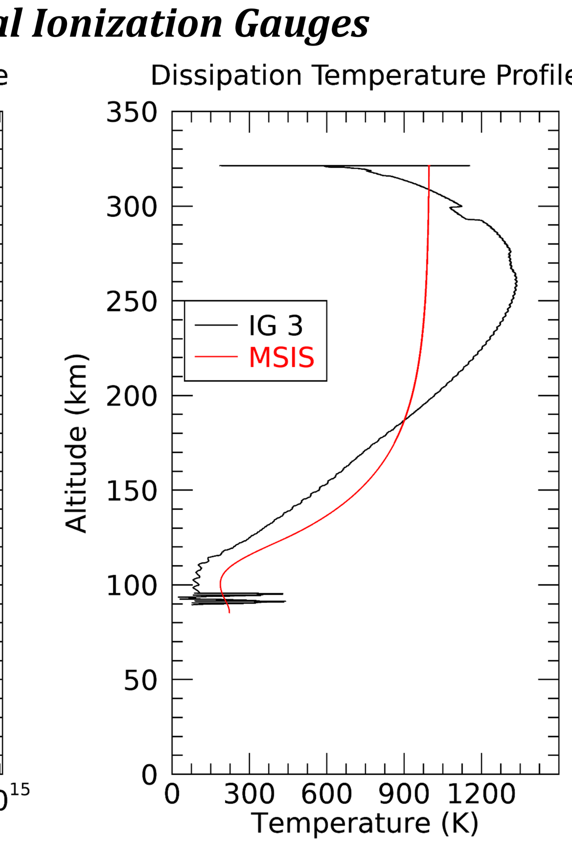


Figure 7. Temperature Profile from IG 3 (black), and NRL MSIS model (red)

Wind Analysis

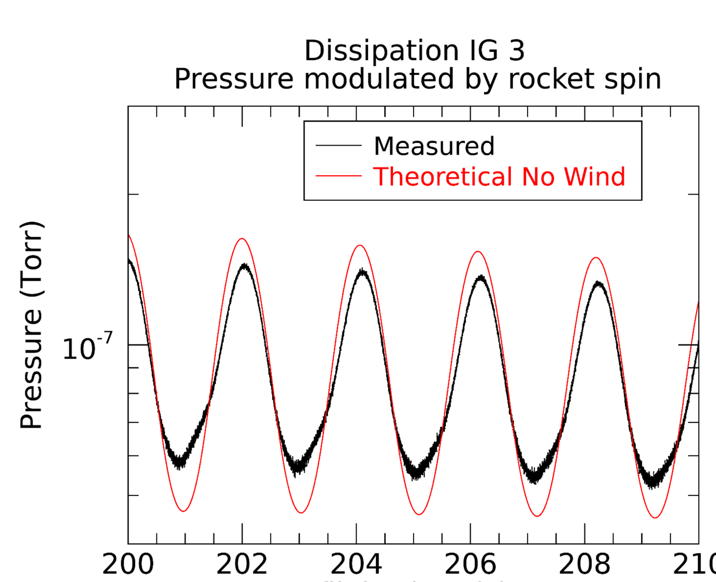


Figure 10. Measured IG pressure (black), modulation is due to rocket spin and wind. The theoretical (red) curve represents the expected IG pressure if no wind was present.

Analysis of wind measurements from the IGs is ongoing.

Due to the payload orientation of the IGs on a spinning payload *In-situ* neutral wind can be measured.

IG pressure is modulated as the payload spins

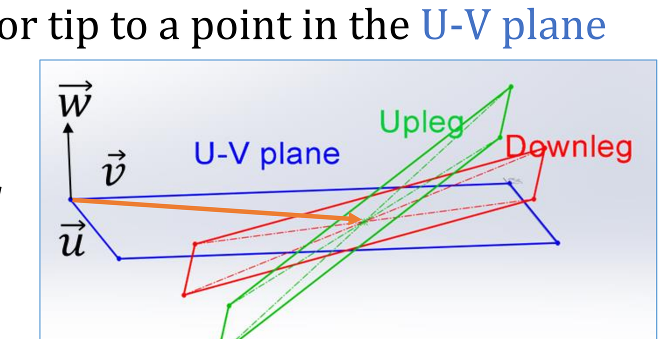
No Wind ➡ Pressure peak when IG aligned with ram

Wind ➡ Pressure peak is a superposition of the rocket velocity and the wind velocity.

Two assumptions to get vector magnitude & direction

1. Difference between Upleg and Downleg winds is negligible
   ↳ Constrains magnitude of wind to a line
2. Vertical winds are negligible
   ↳ Constrains wind vector tip to a point in the U-V plane

Figure 9. Schematic of Wind Triangulation Calculation. The resulting wind vector points to the intersect of these planes, drawn in orange



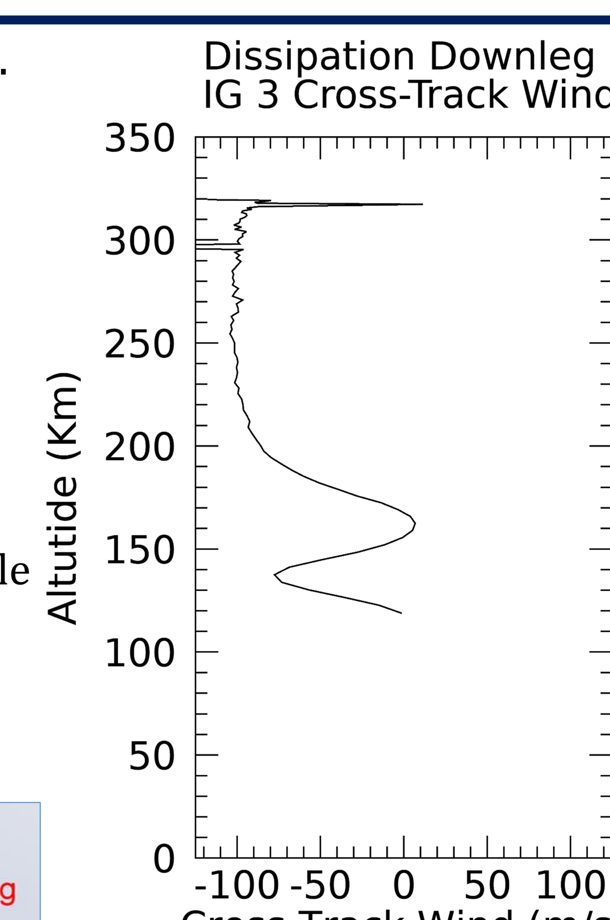


Figure 10. A Preliminary Cross-Track wind can be calculated as $w_{ct} = tan(\theta_{peak} - \theta_{ram}) \cdot \vec{v}$

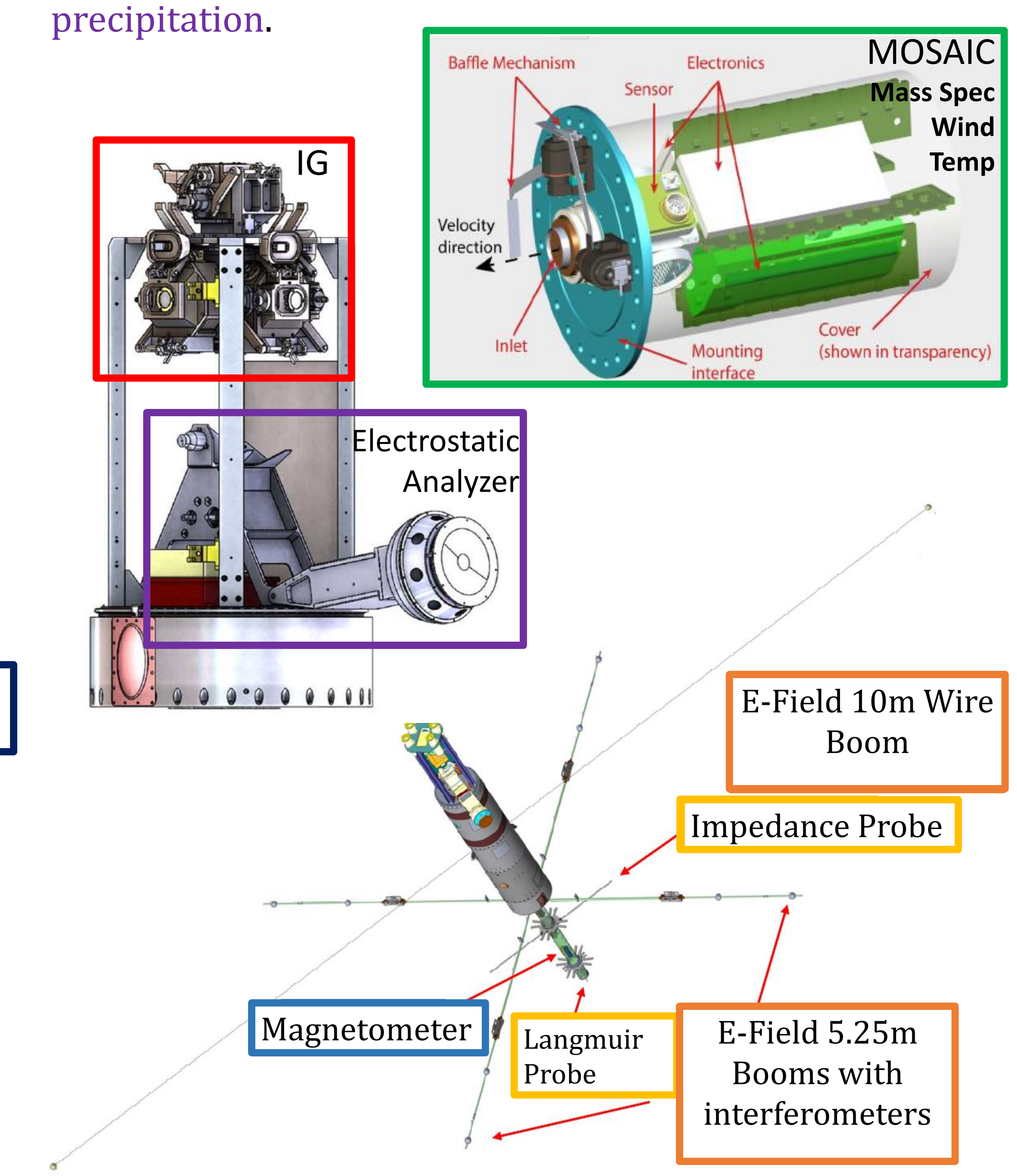
Joule Heating

- Enhanced field aligned currents during auoral activity can enhance Pedersen currents and leads to Joule heating.
- Heating can also occur from soft particle precipitation.
- Joule heating varies with altitude because Pedersen conductivity and winds are altitude dependent.
- The low altitude heating drives neutral upwelling.
- Outstanding questions remain about how these energy sources are contributing to low altitude heating and how the thermosphere responds through composition, density, temperature and wind changes.

To solve the Joule Heating equation each component was measured by an instrument on the rocket.

$$Q_j = \sigma_P(E + U \times B)^2$$

Additionally, measurements were made to quantify the response of the thermosphere to electromagnetic energy drivers like field aligned currents and soft electron precipitation.



Continued Analysis

- Dissipation launched into active aurora to study the thermosphere response to Joule heating.
- The presented neutral density and temperature analysis of the IG data will be fine tuned.
- Wind measurements will be analyzed as described.
- The *in-situ* and ground-based data will be combined to achieve the science goals of this mission.