The Thermal Gated Ion Time of Flight (TIGTOF) Instrument Overview

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Abstract

The Thermal Ion Gated Time of Flight (TIGTOF) is being developed as a low-cost plasma instrument designed to measure in-situ O^+ and N_2^+ thermal ion fluxes during Type II ion upflow events. TIGTOF is expected to resolve relative abundances as low as 5% and is able to resolve mass variation as low as 12%, allowing it to distinguish between O^+ and N_2^+ particles at rocket altitude. TIGTOF is part of the instrument payload of the Cusp Region Experiment (CREX2), scheduled to launch from Andøya Space Flight Center in December 2019/January 2020 into the same event in which the Rocket Experiment for Neutral Upwelling (RENU2) observed N_2^+ in December 2015. TIGTOF will also be launched on the Loss through Auroral Microburst Pulsations (LAMP) rocket from Andøya Space Flight Center in December 2020/January 2021. The information provided by this instrument will further our understanding of Type II ion upflow and better inform our atmospheric models by providing proper characterization of the energy budget.

Ion Outflow

Understanding the evolution of magnetospheric dynamics provides insight into planetary atmospheres. One aspect of this involves the net loss of atmospheric particles to space through a process called planetary escape, in which ions are accelerated to velocities sufficient to escape Earth's gravitational field. Ion Outflow is the process through which ions achieve energies sufficient for planetary escape. This net acceleration is achieved via a two-step process, illustrated by Figure 1.

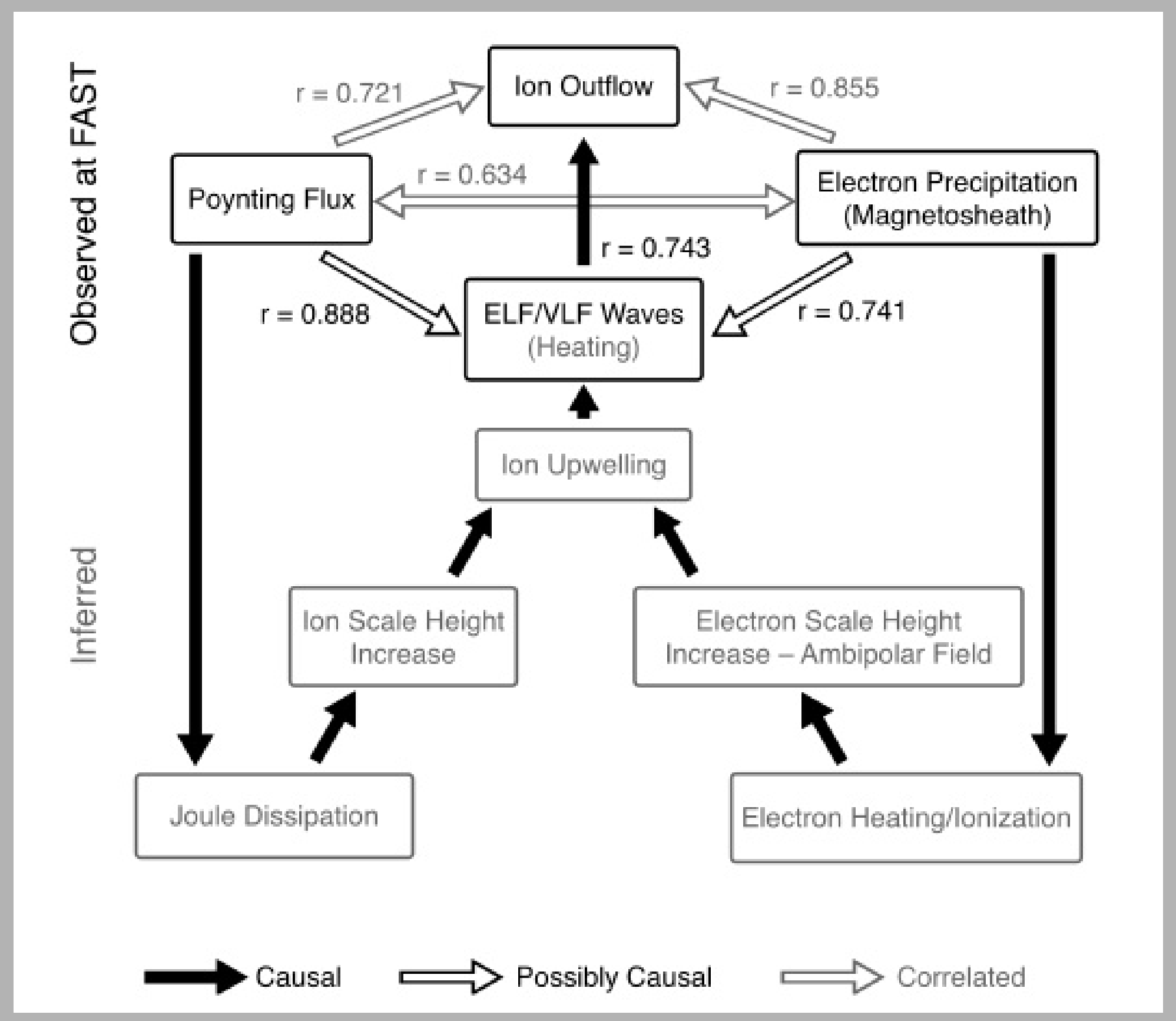

Figure 1: Flow chart relating factors contributing to ion outflow [Strangeway et al., 2004]. The first step in this process is called Ion Upflow, in which ions are accelerated but do not achieve escape velocity. Upflow can result from two distinct processes: Type I (Joule heating), and Type II (electron precipitation) respectively. In the second step, Ion Outflow, additional energization processes must occur to accelerate ions to escape velocity. This usually occurs through wave-particle interactions (WPIs). Without these higher-altitude interactions, upflowing ions will eventually return to their lower altitudes, producing net downflow. At the low altitudes of ionospheric sounding rockets (several hundred km), the downflow signature can be prevalent; this is seen both as a downflowing vertex of energetic ion conics [Arnoldy et al., 1996], and as an overall downflow of the bulk thermal ion population.

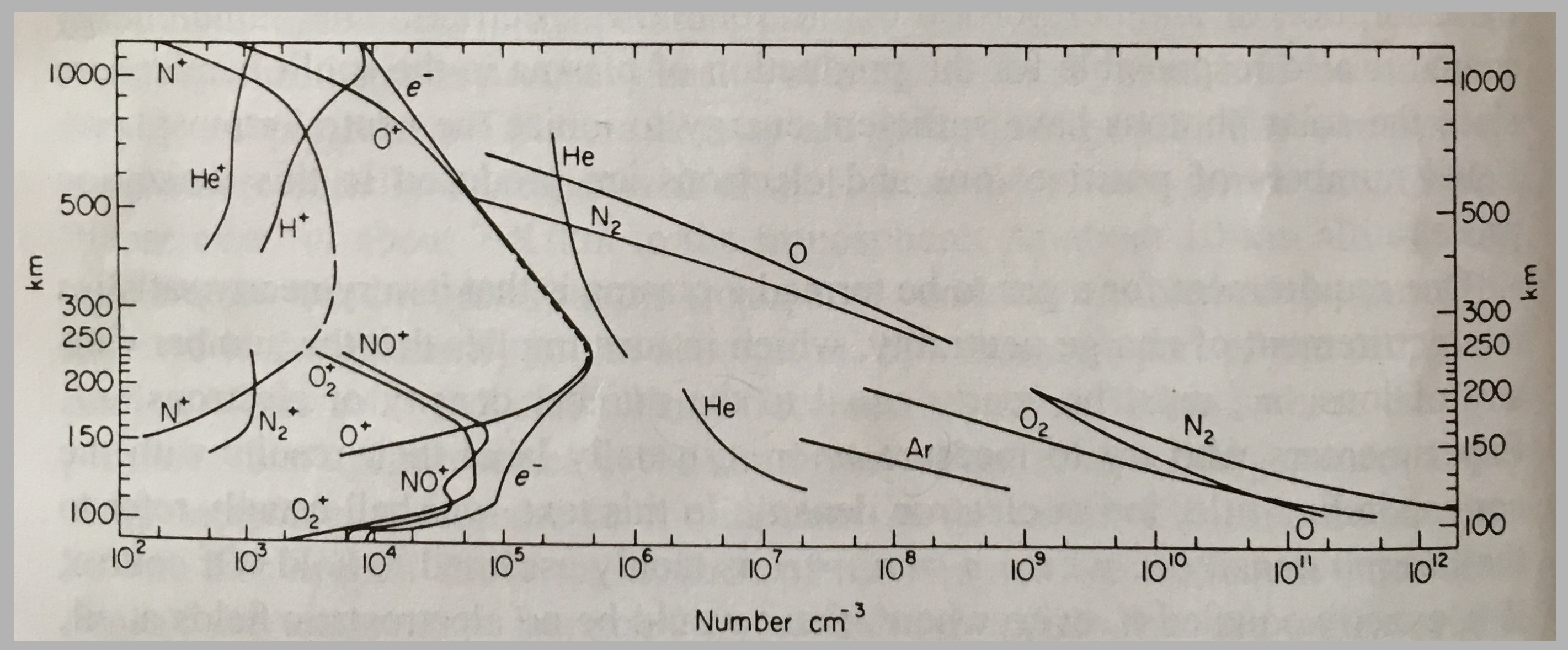

Figure 2: Density profile of the sunlit ionosphere [Kelley et al., 1989]. Precipitating electrons (~ 100 eV) couple energy most efficiently between ~ 230 to 250 km. Low collision frequencies at these altitudes cause ion populations to become gravitationally stratified, leading to O^+ being the dominant ion species with a significantly lower N_2^+ population also present. The expected relative densities do not appear to be consistent with the relative upflowing fluxes of these species, which highlights our lack of understanding of these processes.

O^+ and N_2^+

The AKEBONO satellite (apogee ~ 3,000 km) observed high-altitude N_2^+, confirming that N_2^+ does indeed achieve escape velocity. N_2^+ accounts for only 10% of the total ion population, but contributes ~ 20% of the mass (since N_2^+ is 28 amu and O^+ 6 amu). Hence, N_2^+ provides a significant contribution to the energy budget that ion upwelling models must account for, especially during storm activity [Yau et. al., 1992]. Note that the expected relative densities of O^+ and N_2^+ in the ionosphere do not appear to be consistent with the observed relative upwelling fluxes of these species, which highlights our lack of understanding of these processes. Despite these observations of outflowing N_2^+, we know very little about N_2^+ upwelling at lower (ionospheric) altitudes.

Thus far, the only in-situ observations of N_2^+ were made during a Type II ion upwelling event were from the Rocket Experiment for Neutral Upwelling (RENU2, apogee ~ 450 km) using an upward-looking photo-multiplier tube (PMT) that provided optical evidence of N_2^+ above the main payload (Jim Hecht, Aerospace, personal communication, 2019). In general, the role of N_2^+ ions in Type II ion upwelling events is not well understood and requires further investigation.

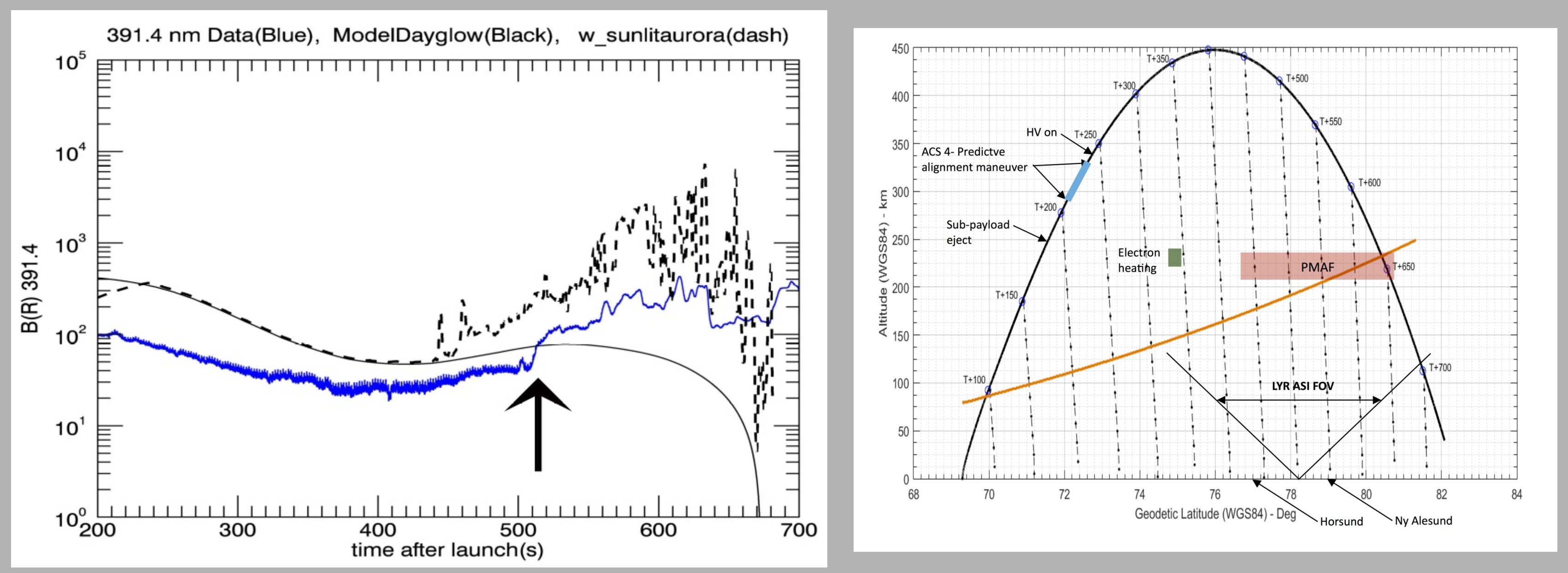

Figure 3: (left) Flight data from RENU2. The arrow indicates an abrupt increase in N_2^+ emission, suggesting an increase in N_2^+ density. Increased N_2^+ emission is likely caused by resonant scattering of sunlight off of ground-state N_2^+ ions. Hence, an increased signal implies an increased ion density. (right) Flight trajectory of RENU2. The orange line denotes the shadow.

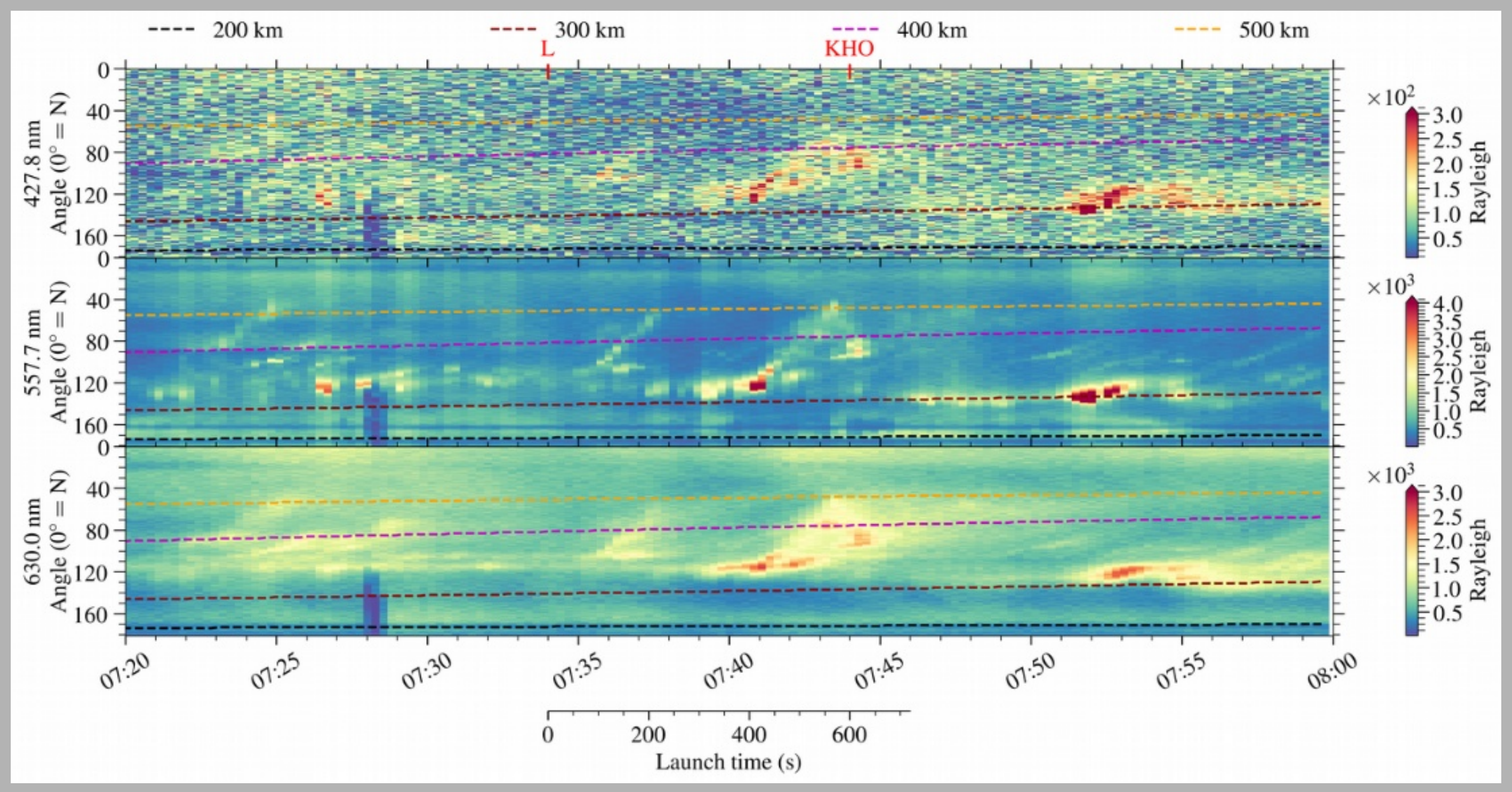

Figure 4: RENU2 MSP ground data. The dashed lines indicate a given altitude where the atmosphere is sunlit (eg. > 150 km) south of any one of the altitude lines. The time at which the payload passes the same latitude as the Kjell Henriksen Observatory is denoted by the "KHO" label. Analysis of the N_2^+ emissions (427.8 nm) between 07:40 and 07:45 UT indicates that the emissions are likely the result of resonant scattering of N_2^+ ions above the shadow height.

Instrument Overview

TIGTOF is a Retarding Potential Analyzer (RPA) that utilizes a gated Time of Flight (TOF) method to provide information regarding ion mass. This process is controlled by the three concentric screens across the instrument aperture (See Figure 5).

The selection screen voltage sweeps through the allowed energies, toggling on/off every ~ 12 μs in order to admit or reject incident ions. The delay between the opening of this gate and the arrival of particles at the central anode is the TOF. Combining TOF with the known path length provides the minimum velocity of the ion, and thereby, its mass.

Instrument Details

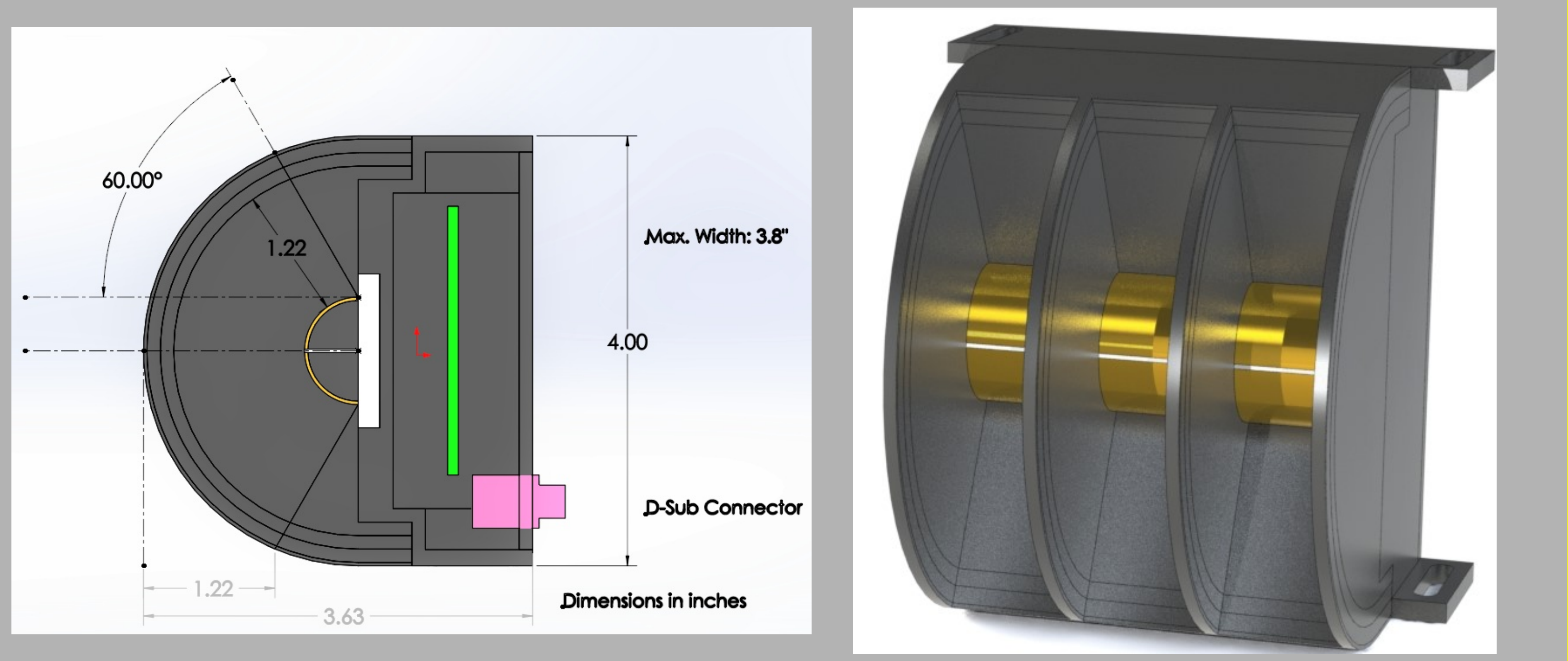

Figure 5: TIGTOF cross-section. Incident ions pass through the ground, selection, and acceleration screens (from left to right) respectively, before reaching the anode pictured at the center of curvature, characterized by a +/- 60 degree field of view. At the anode, collected charge is measured using a fast low noise electrometer circuit, which produces a waveform determined by the combination of arrival times for each mass group. Protons are collected initially (lower admitted energy), while heavier ions are added later on (as the admitted energy increases during the sweep). The resulting waveform shape is used to determine the relative contributions from each ion species (and therefore, mass group).

Since the anode averages over current and not individual ions, this technique requires either high fluxes or long accumulation times in order to gain statistically significant results for species that have small relative concentrations. TIGTOF's estimated performance specifications are summarized in Figure 6.

Attribute	Requirement	Details
Mass	~ 0.644 kg	
Energy Range	0.006 eV to 6 eV	
Energy Resolution	0.06 eV	- Determined by the intermediate (selection) screen sweeping voltage, controlling the allowed energies of incident ions
Mass Resolution	~ 12%	- Limited by timing and variation in the TOF path length determined by ions' incident angle to the aperture surface
Field of View	+/- 60 degrees	- Determined by pitch angle range of RENU2 flight data - Instrument facing in RAM direction

Figure 6: Instrument specifications for TIGTOF. TIGTOF is designed to resolve relative abundances as low as 5%, and variation in ion mass to ~ 12%, allowing the instrument to easily distinguish H^+ from more massive ions, and to distinguish between O^+ and N_2^+.

Future Work

NASA Wallops has agreed to allow the inclusion of TIGTOF on the CREX-2 and LAMP rockets. CREX-2 is scheduled to launch from Andøya Space Flight Center in December 2019 into the same type of event in which RENU2 observed N_2^+. This launch opportunity will allow TIGTOF to accumulate the flight heritage necessary so that it may be flown on future missions. TIGTOF was integrated into CREX-2's payload this summer at NASA Wallops Space Flight Facility.

LAMP is currently scheduled to launch from Andøya Space Flight Center in December 2020, one full year after CREX-2. The experience gained during CREX-2's integration campaign, as well as data from the flight itself will allow us to greatly improve upon TIGTOF's initial design in preparation for its flight on LAMP.

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