Density Profile Results From Endurance Sounding Rocket Mission

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Endurance Mission

The 47.001 Endurance Sounding Rocket launched into open magnetic field lines through the polar cap on May 11, 2022 from Ny Alesund, Norway with an apogee 768 km.

Fig. 1 Endurance Launch

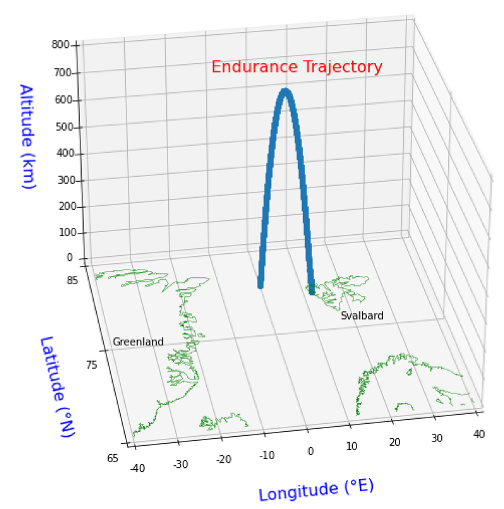


Fig. 2 Endurance Trajectory

This mission was the first direct *in-situ* measurement of the Earth's ambipolar electric field. The ambipolar electric field is a driver of the polar wind that leads to ionospheric outflow. This poster will focus on the neutral density measurements made by two ionization gauges (IG) on the payload.

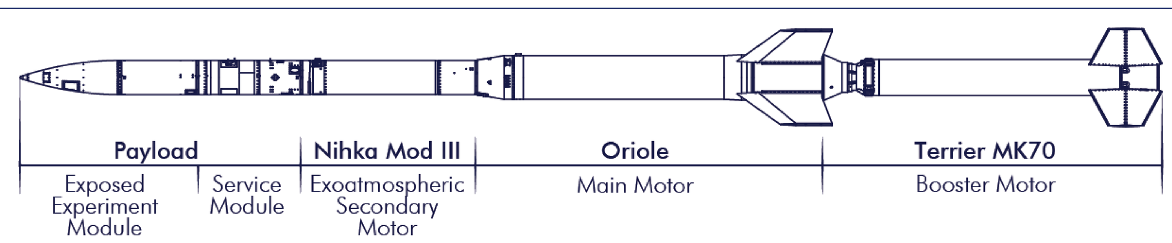


Fig. 3 Endurance was the first three stage Oriole-IIIA Rocket.

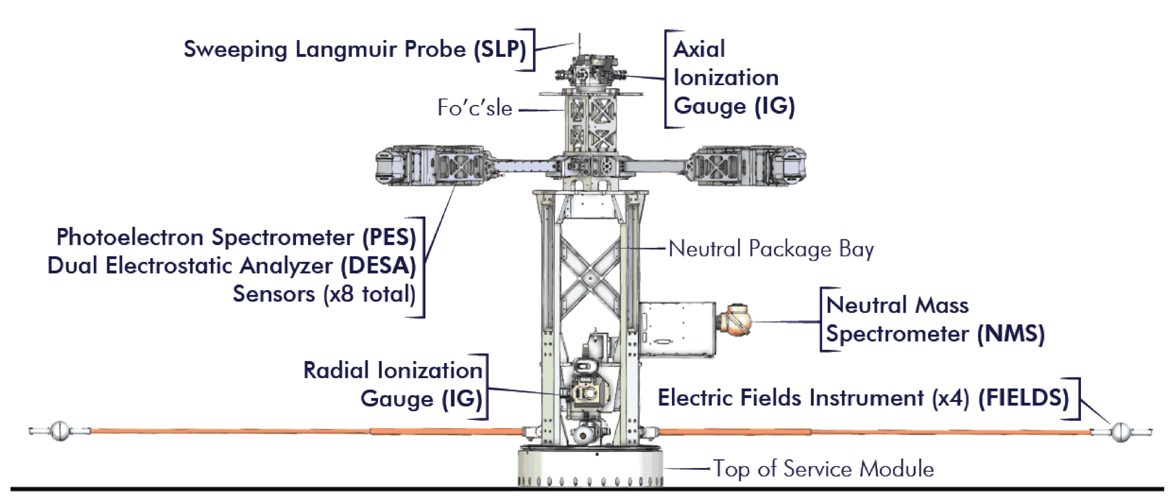
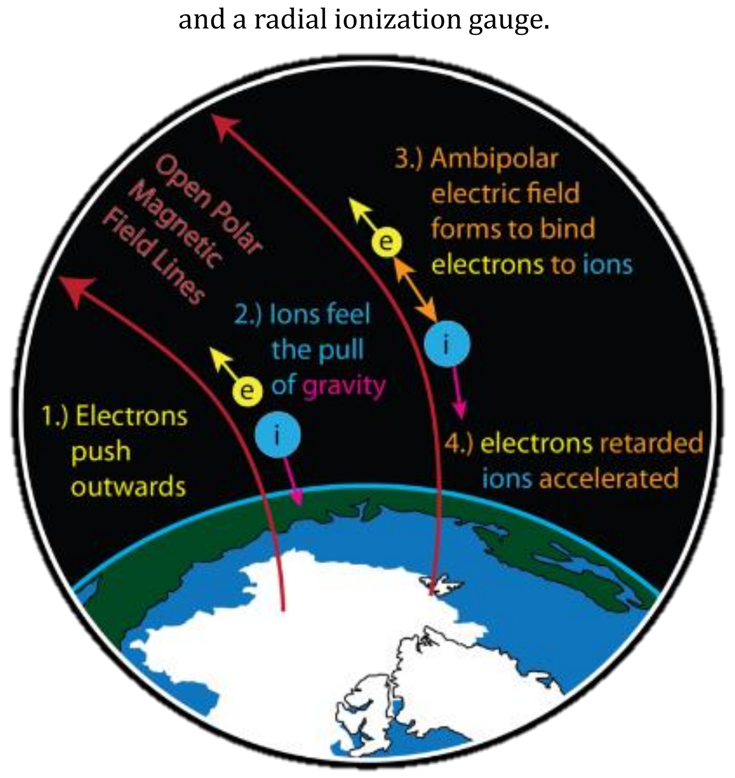


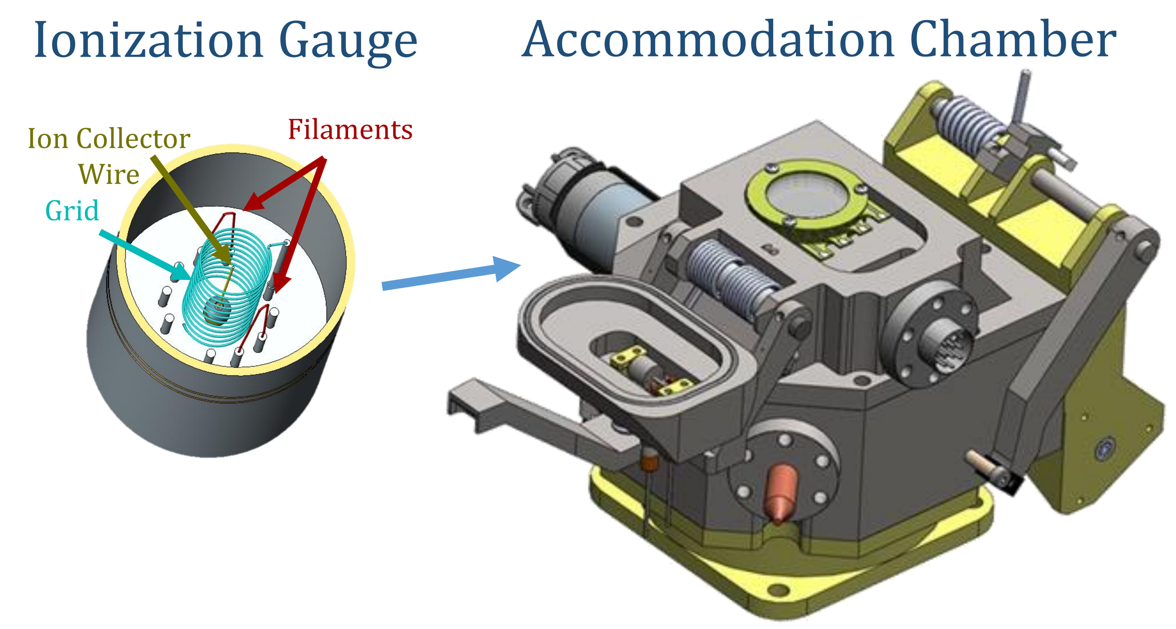
Fig. 4 The science payload included an axial ionization gauge and a radial ionization gauge.



Neutral density, composition, and temperature profiles are a necessary measurement for this mission to understand:

- Where collisions and ionization take place
- How the transport of electrons are impacted by collisions with neutrals
- Photoelectron generation, ion production, and transport of the ions

Ionization Gauge



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This Bayard Alpert hot filament Ionization Gauge measures the pressure (density) of a volume of gas.

- An emission current is applied to the yttria coated iridium wire filament to boil off electrons.
- These electrons partially ionize the gas.
- The ions are accelerated by a biased spiral grid towards the center and collected by the ion collector anode wire.
- The neutral gas pressure is proportional to the ratio of the collected current to the emission current by a gauge sensitivity factor, *S*.

$$P = S * \left(\frac{I_{collected}}{I_{emission}}\right) \qquad P = nk_BT$$

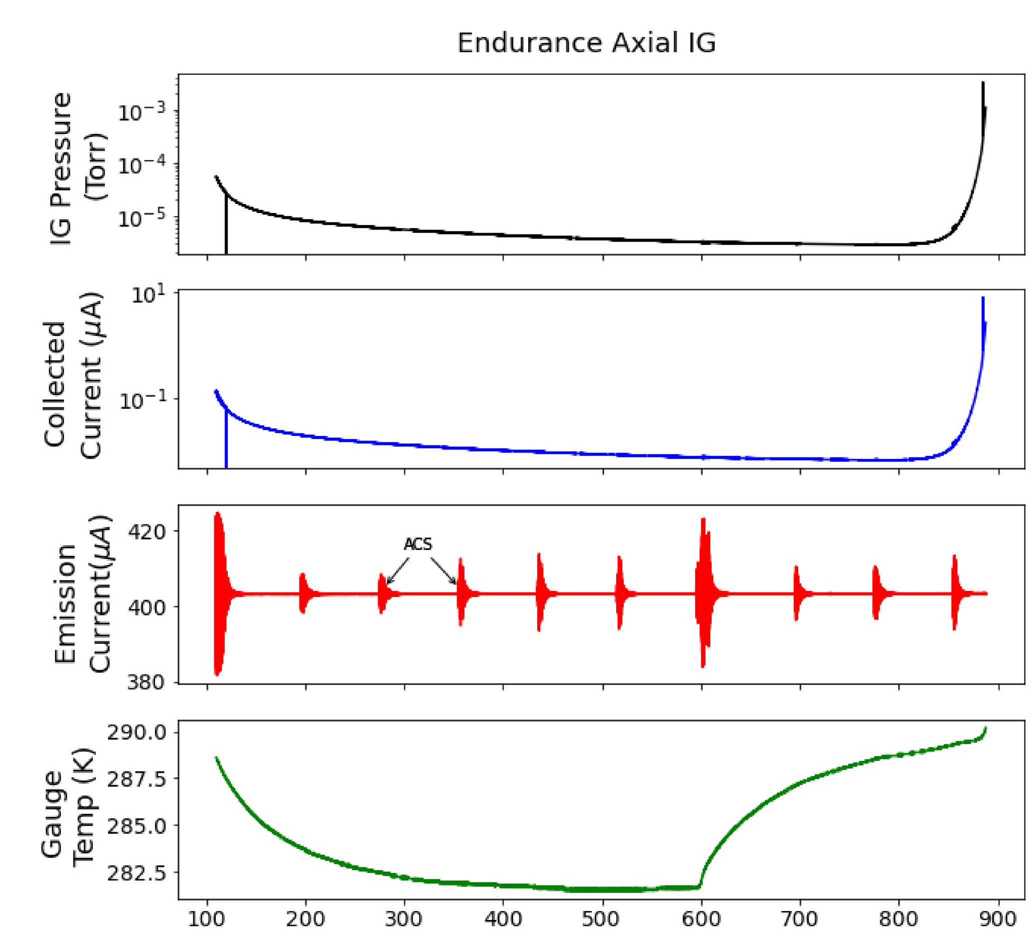

Fig. 7 Endurance Axial IG pressure, collected current, emission current and gauge temperature over the entire flight.

IG Analysis Results

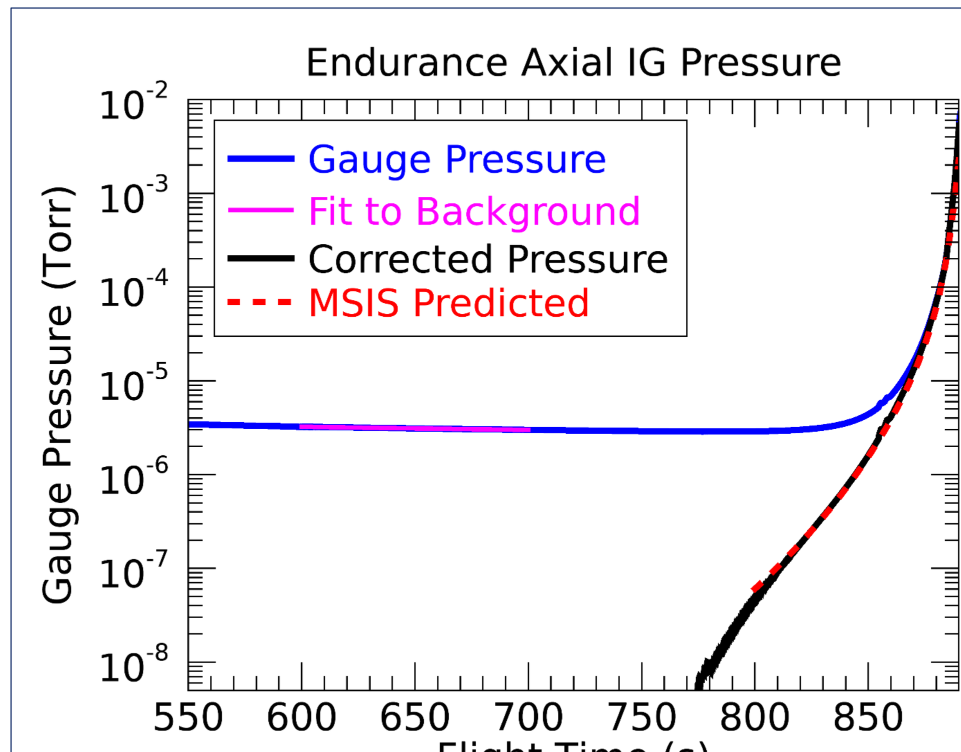

Fig. 8 The IG gauge pressure (blue) is much higher than expected at high altitudes, so a background pressure (pink) was subtracted from the gauge pressure resulting in a corrected gauge pressure (black). This background pressure was found by fitting a second-order exponential to the data near apogee which is outside of our science range and extending that fit to the downleg times.

This flight up to an apogee of 768 km is the highest the ionization gauge instruments have flown on a rocket mission. IGs have been a reliable measurement for temperature and density profiles on numerous missions and were chosen for this mission because they have good sensitivity up to about 500 km.

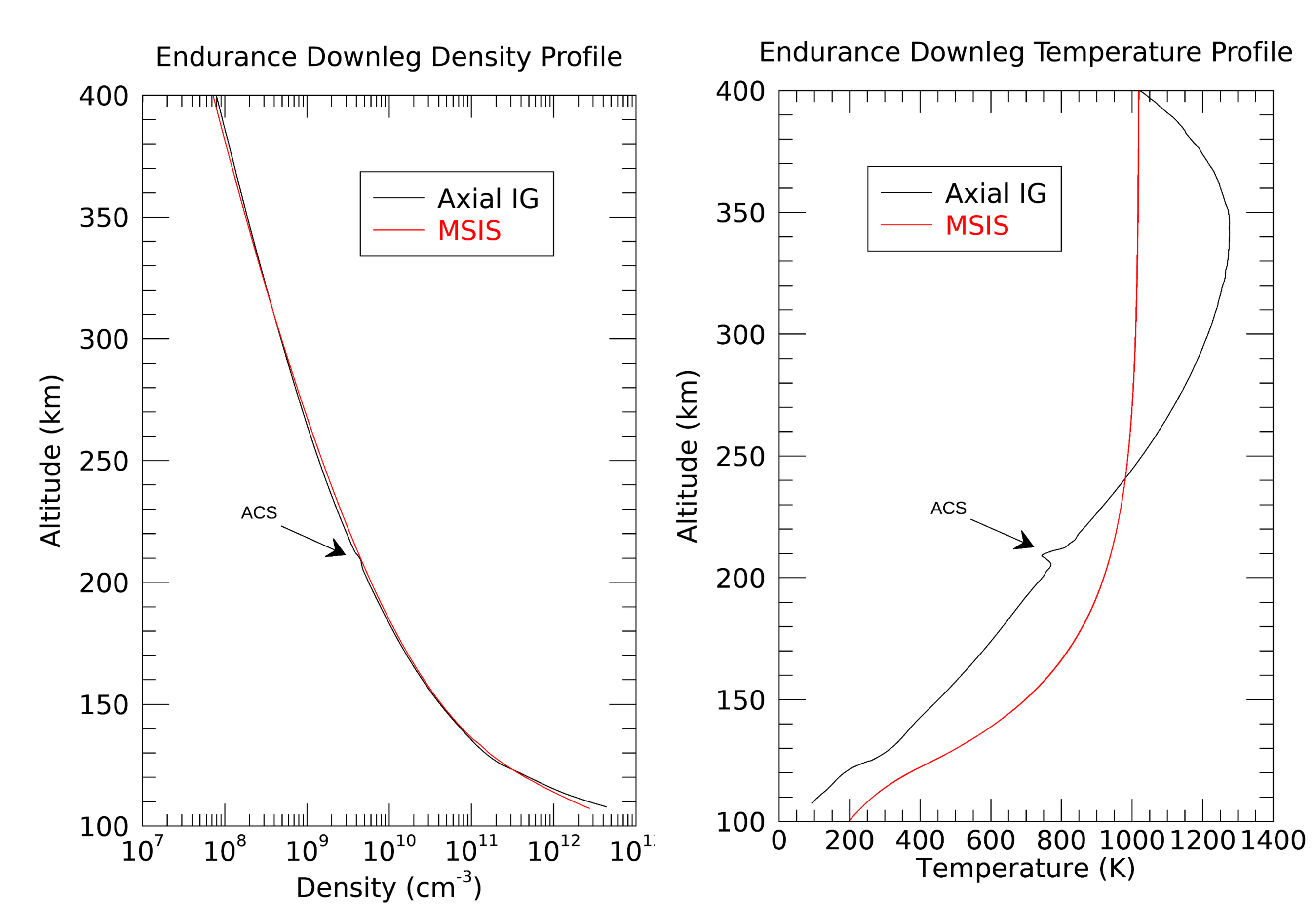

Fig. 9 A) Endurance Axial IG downleg density profile. B) Endurance Axial IG downleg temperature profile. The NRLMSISE-00 atmospheric model (MSIS) shows a similar profile to the data.

Analysis Approach

The accommodation chamber allows for analysis of the density and temperature of the ambient gas based on kinetic theory given the following assumptions:

- The mean free path is greater than the gauge dimensions
- The molecules follow a Maxwellian velocity distribution
- Gas accommodates to the chamber temperature quickly

Assuming flux balance and accounting for the ram velocity of the rocket leads to the following relation between gauge density and temperature and ambient density and temperature.

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

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

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.

Endurance Science

The resulting density and temperature profiles will be an input to the Polar Wind Outflow Model (PWOM) to produce a high-resolution simulation of the ambipolar electric field.

Photoelectron spectrometer on Endurance measured the ambipolar field. Electrons with known energies are present due to the photoionization of atmospheric molecules. These electrons are decelerated by Earth's ambipolar field as they attempt to escape from Earth's atmosphere. The electric potential drop below the rocket will be determined by the shift in the energy spectra according to known spectral features.

This mission flew almost vertically along the B-field to measure the spectra of these electrons as a function of altitude.

[1]Collinson,G.,et al.,2022,doi:10.1007/s11214-022-00908-0
[2]Clemmons,J.H.,et al.,2009, DOI 10.1007/s11214-009-9489-6
[3]Glocer,A.,et al.,2009,doi:10.1029/2009JA014053
[4] Picone, J. M., et al., 2002, doi: 10.1029/2002JA009430