First Results from the Endurance Neutral Mass Spectrograph

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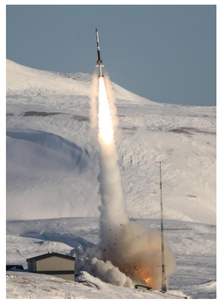
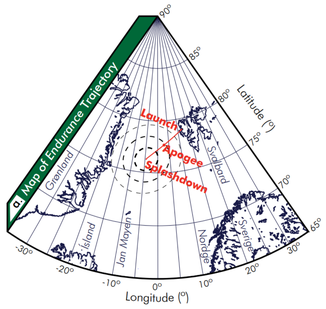
Introduction

In May 2022, the *Endurance* sounding rocket [1] was launched on open field lines to directly measure Earth's ambipolar electric field. This was accomplished by measuring photoelectrons energy peaks.

Since photoelectron-neutral collisions broaden these peaks and each species have different cross-sectional areas, a measurement of neutral composition is required.

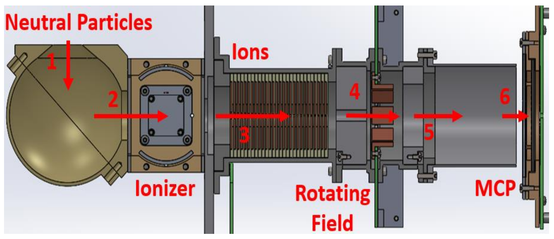
To support this science objective, the Neutral Mass Spectrograph (NMS) [2] was flown to measure the composition of the major thermospheric species (*He*, *O*, N_2, O_2).





NMS Concept and Design

The NMS is designed to measure the composition major neutral species of the thermosphere utilizing a rotating electric field. A diagram is shown below.



1. Atmospheric particles enter the accommodation chamber
2. Neutral particles ionized
3. Electrical optics collimate incoming ions
4. A rotating electric field imparts a perpendicular impulse
5. Lenses focus and guide ions
6. Ions are measured by a micro-channel plate (MCP) detector

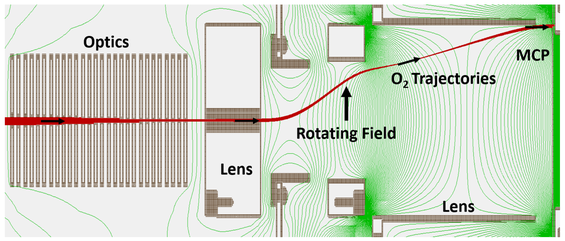
The time of flight is measured by taking the angular difference $\Delta\theta$ between the impact location and orientation of the rotating electric field. This is converted into a mass spectrum using a scaling factor,

$$\frac{\Delta\theta}{\sqrt{m}} = \frac{2\pi f d}{\sqrt{2E}}$$

where m is mass, f is rotating electric field frequency, d is the distance from the rotating field to the MCP, and E is the energy of the ion along its trajectory.

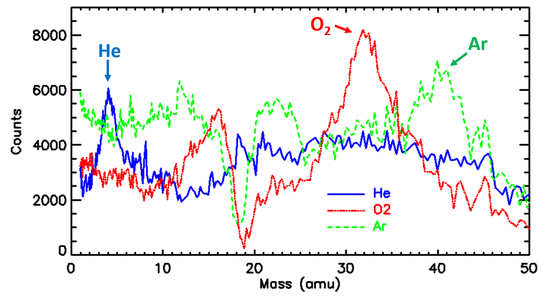
SIMION Simulations

The NMS was modeled in SIMION, a software package specializing in electric fields [3]. Simulations lead to the selection of optic voltages for best mass resolution. Below is a cut-away of the SIMION model of the NMS with potential contours in green.

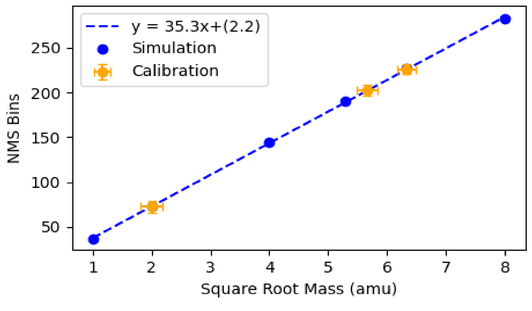


NMS Calibration

The NMS was calibrated in a vacuum chamber with various gasses used to fill the chamber for testing (e.g., *He*, O_2, *Ar*).



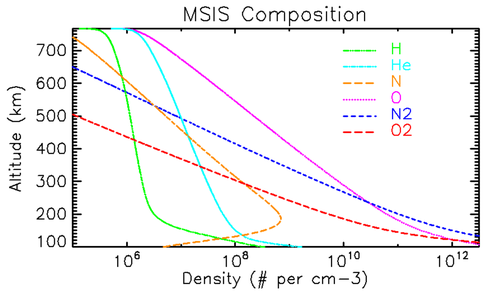
Above are spectra from calibration. A background spectrum was subtracted. The source is currently being investigated.



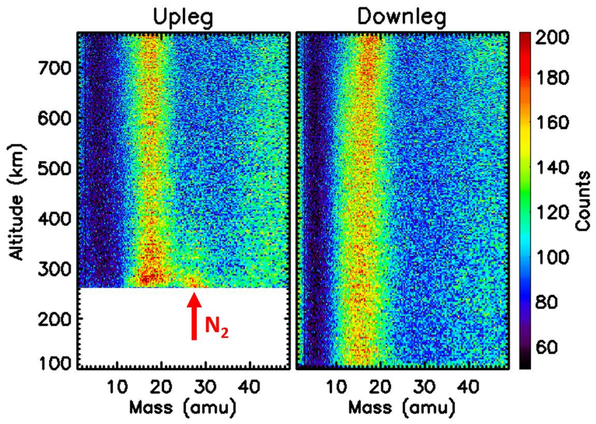
With the given mass and peak location, the scaling factor was calculated, shown above. Calibration and simulation results were consistent. Mass resolutions for both are shown below.

Mass	Calibration	Simulations
He	4±0.77 amu	4±0.05 amu
O_2	32±2.03 amu	32±0.49 amu
Ar	40±2.03 amu	40±0.65 amu

Endurance NMS Flight Results

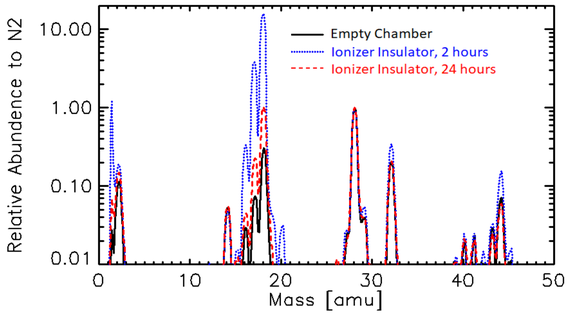


A plot of the expected composition profile is shown above, based on the NRLMSISE-00 (MSIS) atmospheric model [4], with densities scaled to account for the ram velocity of the rocket.



The composition profile from the flight is shown above.

- Measurements of the ambient atmosphere (e.g., upleg N_2)
- A background is observed, e.g., the high peak near 18 amu

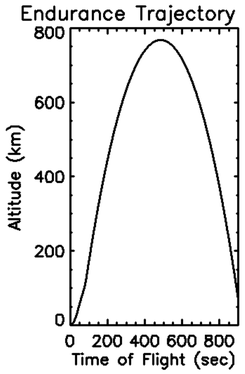


Composition of the ionizer insulator and empty vacuum chamber using a reference RGA relative to N_2.

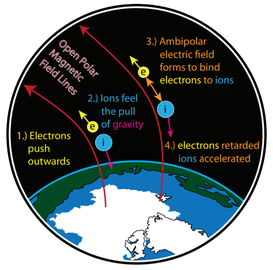
- Insulator material, 3D-printed Ultem, has a prominent peak near 18 amu compared to the empty chamber due to outgassing
- The insulator composition spectrum closely resembles background spectrum seen in calibration and in flight
- Outgassing spectrum changes with time
- Characterizing this spectrum may lead to improvements to the *Endurance* NMS dataset

The Endurance Mission

The *Endurance* sounding rocket launched successfully on May 11th, 2022 from Svalbard, Norway onto open field lines to measure Earth's ambipolar electric field *in situ*. It reached an apogee of 768 km, and after a flight of over 15 minutes, it splashed into the Greenland Sea.



Earth's ambipolar electric field is a key factor in *O+* ion outflow [5]. To make this measurement, on-board was a suite of instruments to measure photoelectron peaks and place those measurements into context. Photoelectrons, emitted from atoms at well-known energies, are decelerated by the ambipolar electric field. When measured, the change in the photoelectron energy peaks provides a measurement of the ambipolar electric field.



Summary and Future Work

Key Points:

- Calibration and simulation results are consistent
- The NMS operated successfully in-flight
- Background spectrum likely due to the ionizer insulator, though further work is needed to get the most out of this dataset

Future Work:

- Identical NMS will be built for TOMEX+ (launch August '24)
- Characterize outgassing of insulator material with next NMS
- Mitigate *Endurance* NMS background spectrum

Acknowledgments

The authors look forward to incorporating these results into the larger science of the mission and are thankful to all members of the *Endurance* team for a successful mission.

References

[1] Collinson, G., et al., 2022, doi: 10.1007/s11214-022-00908-0
[2] Clemmons, J. H., et al., 1998, doi: 10.1063/1.1148933
[3] Dahl, D. A., 2000, doi: 10.1016/S1387-3806(00)00305-5
[4] Picone, J. M., et al., 2002, doi: 10.1029/2002JA009430
[5] Glocer, A., et al., 2009, doi: 10.1029/2009JA014053