Laboratory Characterization of a UV Spectrograph for Polar Night Nitric Oxide Measurement

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Introduction

Auroras occur when charged particles from the solar wind follow Earth's magnetic field lines into the polar regions, where they interact with the atmosphere and trigger chemical and physical processes. These interactions cause molecular nitrogen (N_2) to dissociate into nitrogen (N) which then reacts with molecular oxygen (O_2) to form nitric oxide (NO). During polar winters, the reduced sunlight slows the photodissociation of NO, increasing its lifetime and enabling its downward transport into lower stratospheric altitudes where it catalytically destroys ozone (O_3). The polar night thus provides a unique environment and is critical to understanding the altitude profile of NO and how the removal of sunlight yields increased aurora-produced NO concentrations reaching lower altitudes.

Figure 1: PolarNOx 2020 Launch from Poker Flat Research Range, Alaska

Most NO measurement techniques require sunlight, thereby limiting observations in the polar night. The 2020 **PolarNOx** (Polar Night Nitric Oxide) sounding rocket mission in **2020** (Solar Minimum) provided a significant advancement by detecting a large abundance of NO peaking at a lower altitude than is observed outside the polar night.

The **PolarNOx 2026** flight will enhance understanding of NO in the polar night by making observations under elevated geomagnetic conditions (Solar Maximum), when much larger NO abundances are likely to descend into the lower atmosphere.

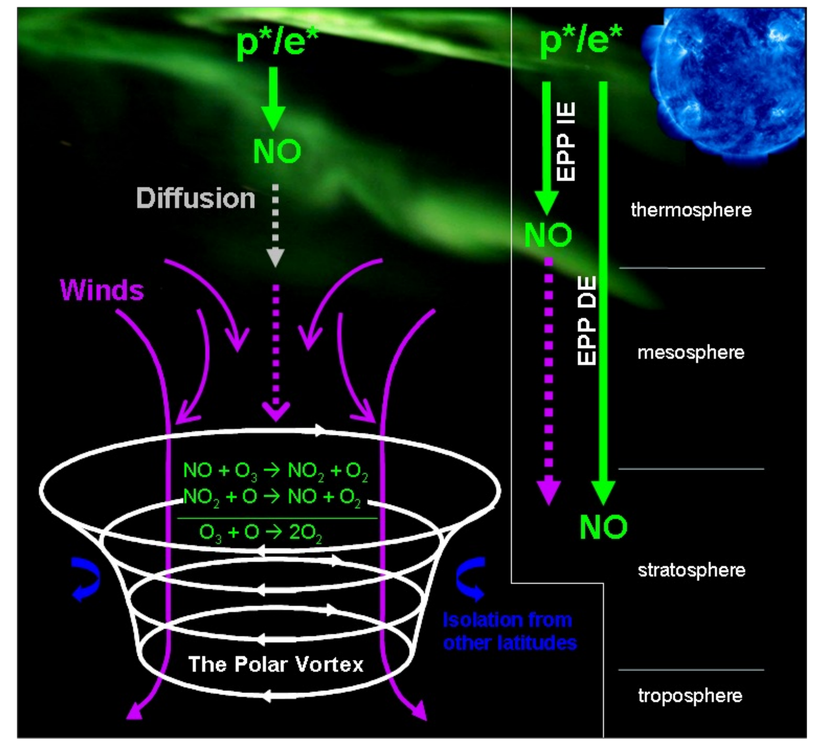

Figure 2: Nitric Oxide Transport in the Polar Night

Sounding Rocket Geometry

- Sounding rockets allow In-Situ measurements especially for data to be collected from altitude ranges that are difficult to access.
- The payload consists of a Cassegrain telescope (40 cm aperture and 3000 mm focal length) and 2.6 mm focal plane aperture that limits the spectrograph's field of view to 3 arcminutes section.
- The spectrograph has 0.035nm resolution, using classical optics with a plane grating with 3600 lines per mm, and a Teledyne e2V SIRIUS – CIS115 detector.

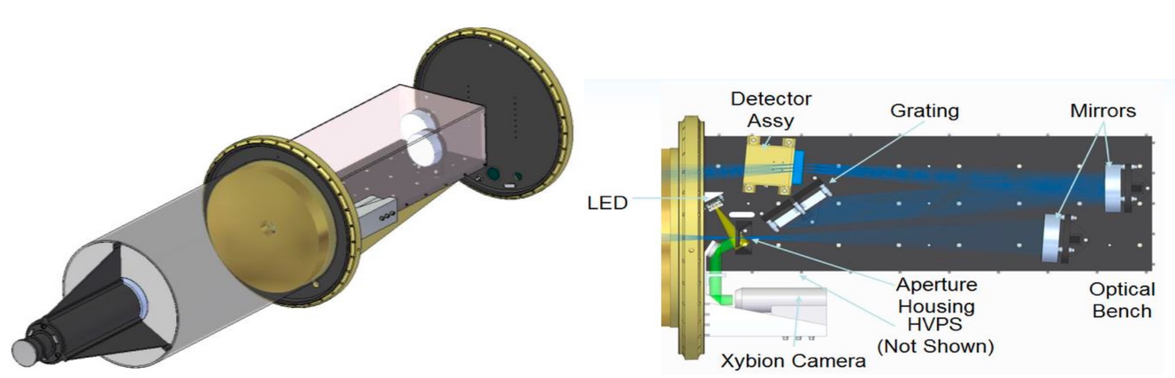

Figure 3: PolarNOx Telescope and Spectrograph Assembly

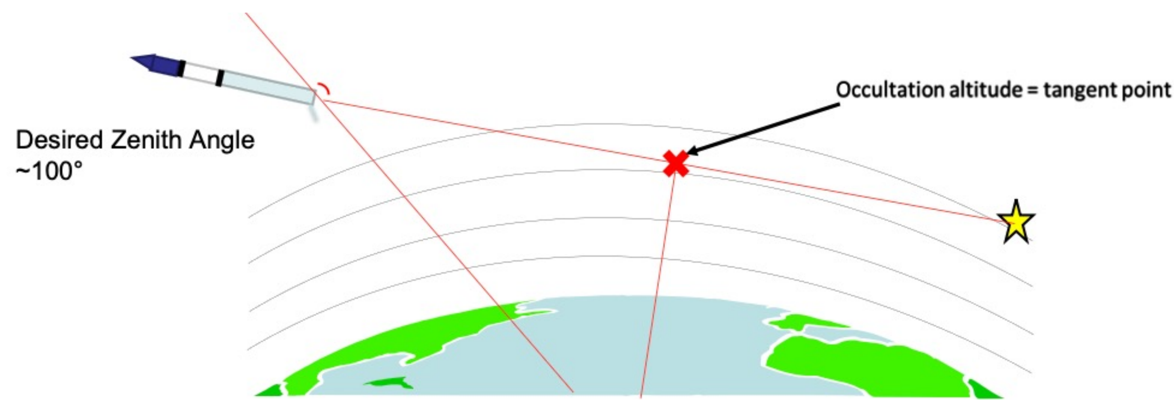

Figure 4: Stellar Occultation

- The rocket uses stellar occultation, a technique measuring atmospheric attenuation by observing a star through the atmosphere.
- Light from the star Algenib (γ-Pegasi) is attenuated through the lower atmosphere to observe the resulting NO emission spectrum.
- Utilizing the position geometry of the star, rocket, and moon, ensuring the moon would not block the path of light, the optimal launch time was calculated to be 01/30/2026 at13:25:00 UTC with a nominal apogee of 245km and a zenith angle of 99.54°.

Research Objective

- To validate the instrument's performance, post the 2020 flight and assess its ability to be reused for the 2026 mission.
- To ensure the instrument's capability to detect and resolve Nitric Oxide (NO) absorption features in the ultraviolet spectrum under simulated polar night conditions.
- To assess the spectrograph's spectral resolution, radiometric response, and sensitivity to temperature.
- To familiarize running the instrument in testing environment.

Conclusion & Future Work

- Laboratory characterization confirmed the spectrograph's ability to detect and resolve NO absorption features within the ultraviolet spectrum, achieving a spectral resolution of ~0.03 nm
- Detector efficiency was measured at 1.3% using a NIST-traceable deuterium arc lamp, indicating reduced sensitivity during the 2020 flight.
- Further characterization of the detector revealed a ~70-minute warm-up period is required to achieve stable performance.
- The PolarNOx 2026 mission, uses a CIS115 detector optimized for 215 nm and recoated mirrors, with ~15x improvement in sensitivity.
- As part of the mission plan, a direct study will be done comparing detectors from the 2020 and 2026 flight using similar calibration procedures.
- This comparison will validate the improvements in sensitivity and resolution for NO detection made since the 2020 flight.

Laboratory Data Analysis

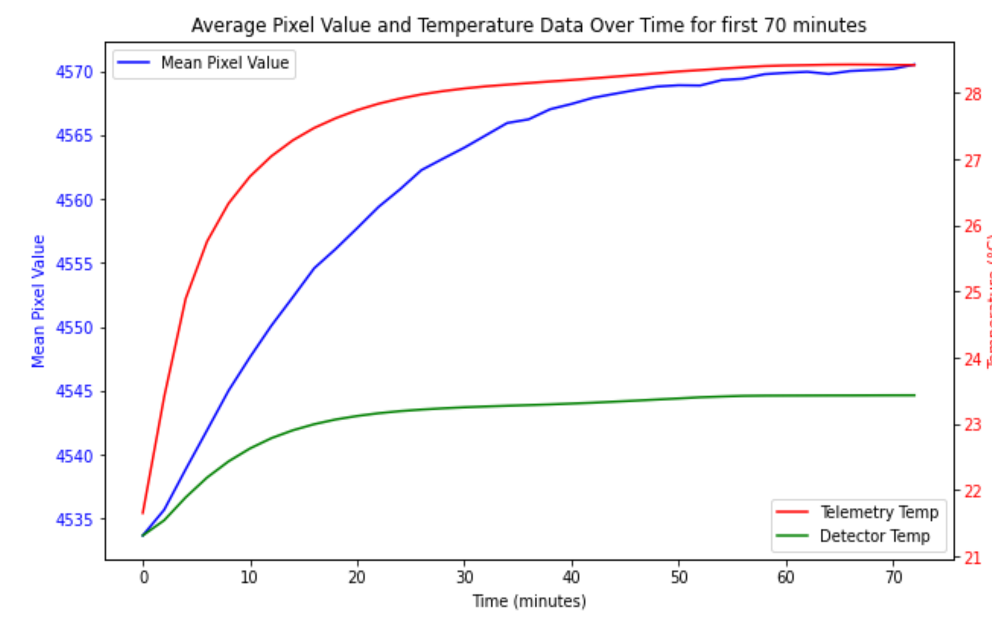

Figure 5: Average pixel value (Pixels) and Temperature (deg C) as a function of Time (Minutes)

The detector's response shows a clear increase in mean pixel values with rising temperature stabilizing after approximately 70 minutes. Both telemetry (red) and detector(blue) exhibit similar stabilization trends. These results highlight the importance of a thermal warm-up period to ensure consistent and accurate measurements during flight.

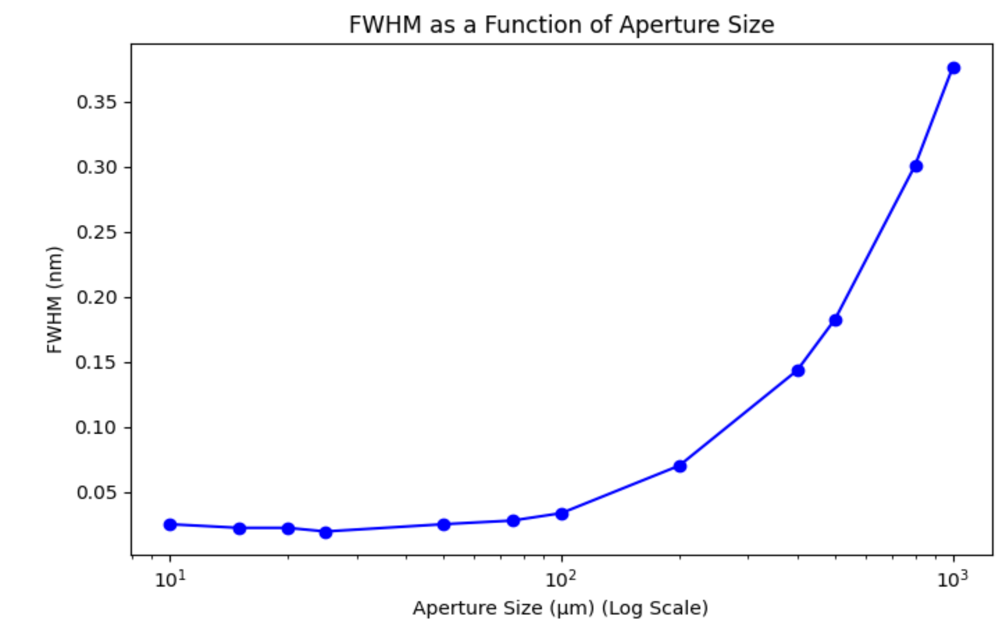

Figure 6: Full Width Half Maximum (nm) as a function of Aperture Size (μm)

Spectral resolution of the spectrograph characterized using the 214.7 nm Tellurium (Te) emission line, Full Width at Half Maximum (FWHM) was measured across a wide range of aperture sizes. As the aperture size decreases, the resolution improves, with apertures below 100 μm approaching the spectrograph's intrinsic limit. The resolution stabilizes at 0.03 nm, confirming the instrument's capability for high-resolution NO detection.

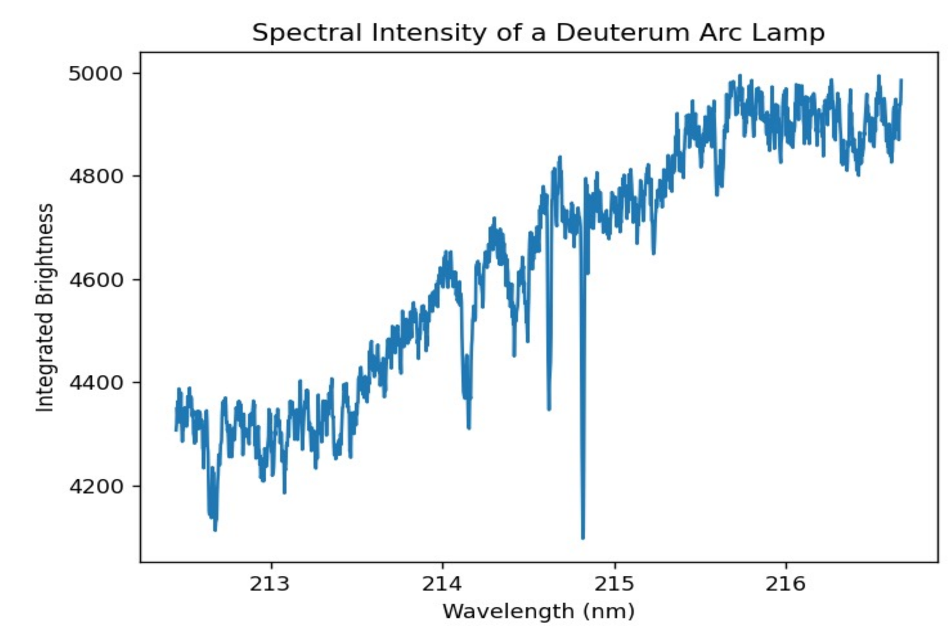

Figure 7: Spectral intensity as a function of Wavelength (nm)

The detector's efficiency was measured using an irradiance-standard deuterium arc lamp, calibrated with traceability to the National Institute of Standards and Technology (NIST). The measured efficiency was 1.3%, indicating the instrument has low sensitivity.

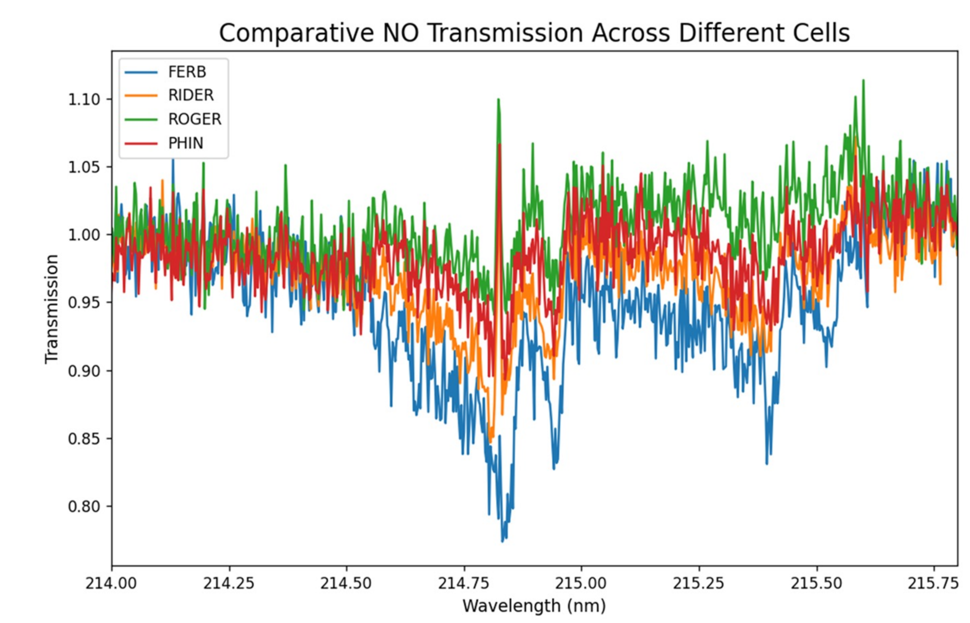

Figure 8 : NO transmission for 4 different gas cells

Normalized transmission spectra using a UV light source through four NO gas cells. Distinct NO absorption features are observed near 214.8, 215, 215.4 and 215.6 nm, consistent across all cells. These results validate the spectrograph's high spectral resolution and demonstrate the effectiveness of the optical setup in simulating atmospheric NO absorption conditions.

Acknowledgement

We Would like to express our sincere gratitude to our Co-I, Dr. Bill McClintock for his many valuable contributions to this project, particularly as the designer of the UV spectrograph.

References

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