How significantly does Earth's atmosphere affect our ability to investigate the atmospheric spectra of exoplanets?

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New Paltz Honors

Introduction

- High-resolution spectroscopy can resolve individual lines in stellar and exoplanetary spectra, but it is only possible with ground-based instruments.
- Ground-based spectrographs introduce telluric contamination (the spectral imprint from the Earth's atmosphere) which must be accurately corrected.
- Observations of exoplanet WASP33b were conducted using the GRACES high-resolution spectrograph on the Gemini North telescope

Research Goals

Compare telluric contamination correction accuracy from observation files for varying:

1. Absorption depths 2. Wavelength regions & molecular species 3. Observation conditions

Methods

Modeling Telluric Lines

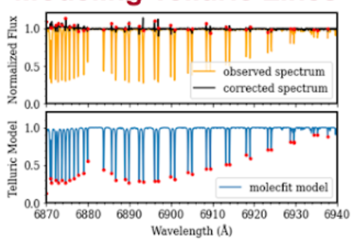

Fig. 1 Region of an observed and modeled spectrum containing O_2 telluric lines. The peaks are identified in red.

Atmospheric Parameters

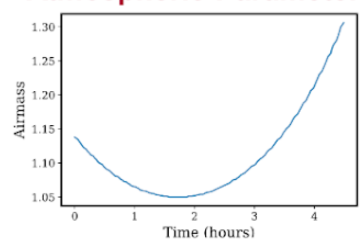

Fig. 2 Change in airmass over time. Compared to temperature, humidity, and pressure (which were linear), airmass was determined to be the atmospheric parameter that was most dominant.

Statistical Assessments

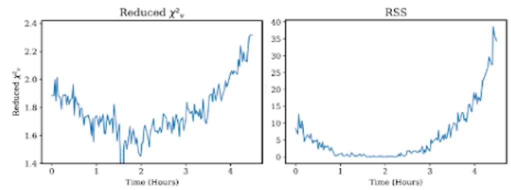

Fig. 3 Reduced Chi-Square (χ^2_ν, left) and Residual Sum of Squares (RSS, right) results across all telluric depths and the full spectrum. Stellar spectrum removed by dividing by the lowest airmass spectrum. RSS results divided by the number of peaks for a per peak value.

Absorption Depths

Shallow vs. Deep Tellurics

The influence of airmass remains dominant across all depth ranges and assessment methods. Shallow tellurics generally demonstrate superior correction accuracy.

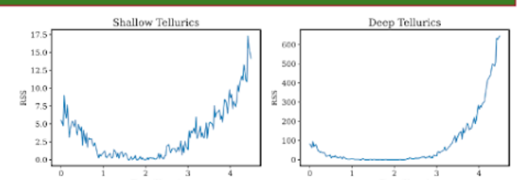

Fig. 4 RSS test results on the shallow (0 to 10%, left) and deep (90 to 100%, right) telluric absorption lines. Assessed for the full spectrum.

Wavelength Regions & Molecular Species

O_2 and H_2O Absorption

Airmass dependency increased for O2 and H2O absorption as wavelength increased, though this may be attributable to the increased quantity of lines. Observations within the 7585-7750Å and 8800-10350Å regions should prioritize low airmass.

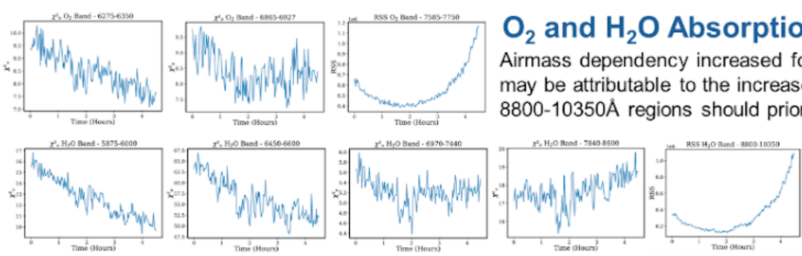

Fig. 5 Statistical assessments across all depths by wavelength regions within O_2 (top) and H_2O (bottom) contamination regions. Each wavelength band represents a distinct region of absorption.

Observation Conditions

Ideal Observations

The ideal correction values (RSS values near 0) were identified in the statistical assessment. The times corresponding to those values could be used to isolate ideal airmass conditions. Ideal airmass is ≤1.07 and reasonable corrections can be conducted at airmass up to 1.10.

$$Airmass = \frac{1}{\cos(\theta)}$$

Eq. 1 Airmass equation. Ideal airmass is 1 at a zenith angle (θ) 0.

The angle represents how far from zenith (overhead) observations could potentially be made. Using this equation, the zenith angle of the ideal airmass (1.07) is found to be approximately 20.84°. The reasonable airmass (1.10) has a zenith angle corresponding to approximately 24.62°.

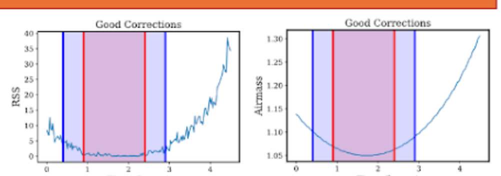

Fig. 6 RSS test results (left) with ideal (red) and good (blue) corrections. These windows were then translated to the airmass plot (right).

Conclusions

1. Telluric corrections at varying depth ranges have similar airmass dependency, though shallow telluric corrections generally perform better than deeper absorption.
2. Low airmass should be prioritized for observations within the O_2 7585-7750Å and H_2O 8800-10350Å regions. Further work may help to isolate the cause as dependent on wavelength or peak quantity
3. For ideal corrections, airmass ≤1.07 attainable at a zenith angle ≤20.84° should be prioritized. For reasonable corrections, an airmass ≤1.10 attainable at a zenith angle ≤24.62° can be used.

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