High Resolution Transmission Spectrum of Earth's Atmosphere

- Seeing Earth as an exoplanet using a lunar eclipse

Fei Yan[1,2], Robert Fosbury[2], Monika Petr-Gotzens[2], Gang Zhao[1], Wei Wang[1], Liang Wang[1], Yujuan Liu[1]
[1] *NAOC (National Astronomical Observatories, Chinese Academy of Sciences)*
[2] *ESO (European Southern Observatory)*

Introduction and observation

With the rapid developments in the exoplanet field, more and more terrestrial exoplanets are being detected. Characterizing their atmospheres using transit observations will become a key datum in the quest for detecting an Earth-like exoplanet. The atmospheric transmission spectrum of our Earth will be an ideal template for comparison with future exo-Earth candidates. A lunar eclipse -- which has a similar configuration to that of an exoplanet transit -- provides us an opportunity to obtain Earth's transmission spectrum. The geometry of a lunar eclipse is shown in Figure 1.

a) Exoplanet transit : *b) Lunar eclipse:*

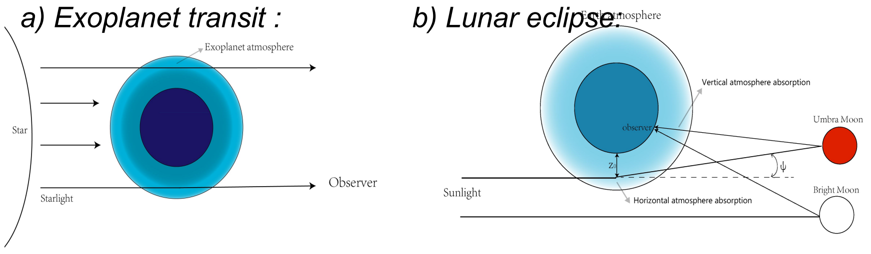

Figure 1. Geometry of an exoplanet transit and a lunar eclipse. The geometries are similar, becuase the starlight/sunlight transit the atmosphere horizontally.

We observed the total lunar eclipse on December 10, 2011 with the High Resolution Spectrograph (HRS) mounted on the 2.16-m telescope at Xinglong Station, China. The ratio of the two spectra -- *umbra Moon* spectrum and *bright Moon* spectrum -- are used to obtain the transmission spectrum. This ratio cancels out the vertical atmospheric absorption, lunar surface albedo effect, solar spectral features and the intensity-wavelength response of the spectrograph. In the obtained transmission spectrum (Fig. 2), molecules including **O_2, O_3, $O_2 \cdot O_2$, NO_2 and H_2O** are detected.

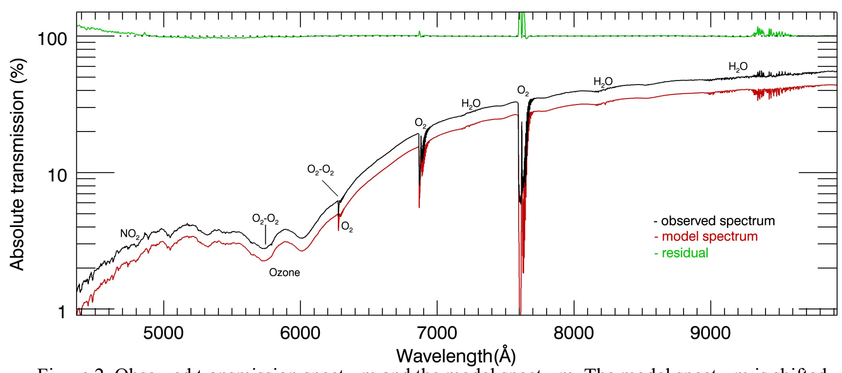

Figure 2. Observed transmission spectrum and the model spectrum. The model spectrum is shifted down by 20% for clarification.

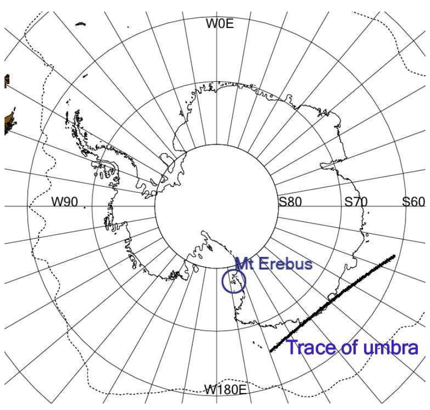

Figure 3. The geographical coordinates of the atmospheric minium altitude z_0 (shown in Fig. 1) during the umbra spectrum observation. The trajectory is above the coast of the Antarctic Ocean.

Model the telluric transmission spectrum

A 1-dimensional line-by-line atmospheric spectral model is built to fit the observed transmission spectrum. The best-fit model spectrum is shown in Figure 2 with the red line, and the contributions of each detected molecules are shown in Figure 3. The detail spectra of O_2 and NO_2 are shown in Figure 4 and Figure 5, repectively. From the model-fit, the column densities of the atmospheric species are calculated. The effective altitude for the transmission spectrum is estimated to be approximately 12.5 km by the model calculation.

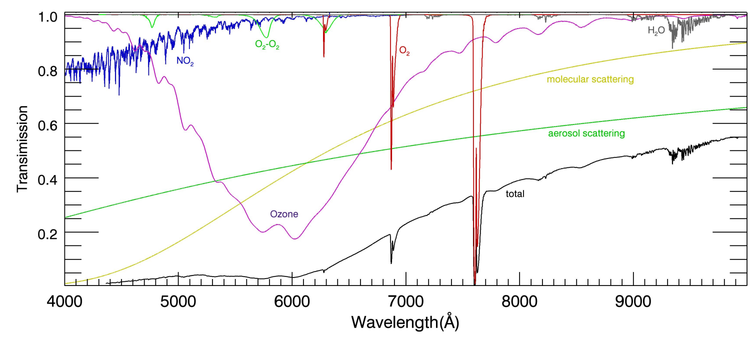

Figure 3. Contributions of the atmospheric species used in the best-fit model spectrum. The H_2O absorption is weak while the O_3 absorption band is very strong around 600 nm.

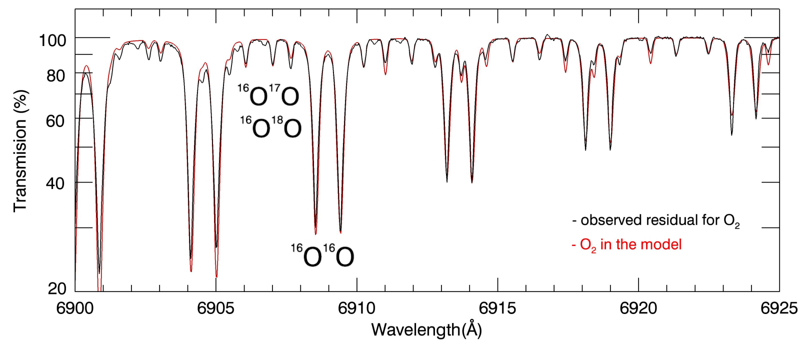

Figure 4. The observed spectrum of oxygen lines and the model spectrum.The **O_2 isotopes** are clearly detected.

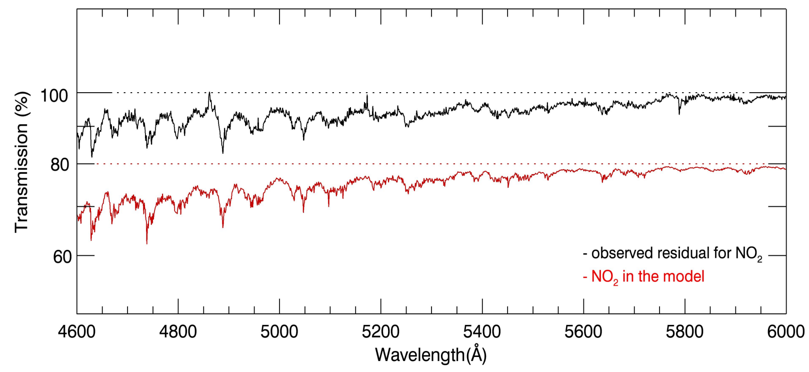

Figure 5. NO_2 observed spectrum and the model spectrum. NO_2 in the stratosphere is mainly produced by the oxidation of bio-signature gas --N_2O

Conclusions

We have obtained a **high resolution and high signal-to-noise ratio** transmission spectrum of Earth's atmosphere.

For the 3 atmospheric bio-signatures of Earth (*Seager 2010*) - O_3, O_2, N_2O:

- a.) **Ozone**'s absorption around 600 nm is the most prominent absorption feature in the spectrum - promising molecule for exo-Earth detection.
- b.) O_2 lines are resolved and **O_2 isotopes** are clearly detected
- c.) **NO_2** is detected and its presence in the stratosphere could indicate the existence of N_2O

H_2O absorption is rather weak in our spectrum and its detection in Earth-like exoplanets may not be an easy task.

Fei Yan
PhD student
bhyanfei@gmail.com