Sensitive Probing of Exoplanetary Oxygen in the Mid-Infrared

Nature Astronomy,
January 2020

Thomas J. Fauchez¹,²,³, Geronimo L. Villanueva¹, Edward W. Schwieterman⁴, Martin Turbet⁵, Giada Arney¹, Daria Pidhorodetska¹,⁶, Ravi K. Kopparapu¹, Avi Mandell¹ and Shawn D. Domagal-Goldman¹

thomas.j.fauchez@nasa.gov | 240-264 0192

¹NASA Goddard Space Flight Center.
²Universities Space Research Association (USRA- GESTAR).
³GSFC Sellers Exoplanet Environments Collaboration (SEEC).
⁴University of California, Riverside
⁵Observatoire Astronomique de l’Université de Genève, Versoix, Switzerland.
⁶University of Maryland Baltimore County/CRESST II
Oxygen absorptions within JWST spectral range

Before this work:

- The O$_2$ A-band at 0.76 µm in the visible
- The O$_2$-O$_2$ Collision-Induced Absorptions (CIAs) at 1.06 and 1.27 µm in the Near Infrared
Oxygen absorptions within JWST spectral range

Before this work:

• The O$_2$ A-band at 0.76 μm in the visible

• The O$_2$-O$_2$ Collision-Induced Absorptions (CIAs) at 1.06 and 1.27 μm in the Near Infrared

Inelastic collision in a gas producing distinct spectral features
Oxygen absorptions within JWST spectral range

Before this work:

• The $O_2$ A-band at 0.76 $\mu$m in the Visible

• The $O_2-O_2$ Collision-Induced Absorption (CIA) at 1.06 and 1.27 $\mu$m in the Near Infrared

After this work:

• The $O_2$-$X$ CIA at 6.4 $\mu$m in the Mid-Infrared (JWST MIRI range)
Why was it previously missing?

- No CIA included in some RT models
- Incomplete / obsolete spectral databases
- Only $\text{O}_2$–$\text{O}_2$ feature at 6.4 $\mu$m is included in HITRAN, not $\text{O}_2$-$\text{X}$ features
- Overlapping with $\text{H}_2\text{O}$ absorption band
The Mid-Infrared O$_2$-X CIA in the Earth Science literature.

Fig. 3. Comparison between measured transmission features for the 1.6 mm spectral region and calculated transmission features for the 1.6 mm spectral region. The solid line is for O$_2$ absorption only (same as Figure 2); the dashed line is for O$_2$ absorption only (same as Figure 2). Points (open circles) and solid squares represent observed and calculated transmissions, respectively. The solid squares are the selected lines shown to be relatively free of line absorption lengths.

Fig. 7. Absorption spectrum of the Earth's atmosphere at 14.5 km (128 mbar) and the calculated spectrum using PSG, with the absorption components and their sum.

Rinsland et al., 1982

Rinsland et al., 1989
Simulated transmission spectra of TRAPPIST-1e with JWST MIRI

$O_2$-X CIA is very sensitive to the oxygen pressure and dominates the 6 to 7 $\mu m$ region
Modern Earth-like atmosphere

TRAPPIST-1e as a benchmark..

**Within 5 pc from the Sun:**
O$_2$-X CIA at 6.4 $\mu$m is the *only* O$_2$ feature potentially detectable with JWST

**Beyond 5 pc:**
Not detectable with JWST
Desiccated $O_2$-dominated atmosphere

TRAPPIST-1e as a benchmark.

**Up to 25 pc from the Sun:**
- Both the $1.27\,\mu m$ $O_2$-$O_2$ and $6.4\,\mu m$ $O_2$-$X$ CIAs could detect dense $O_2$ desiccated atmospheres.
- The $6.4\,\mu m$ $O_2$-$X$ CIA requires less transits than the other $O_2$ features.

Image courtesy of NASA/GSFC/Fred planners-Griswold

Artist illustration of TRAPPIST-1e with a desiccated $O_2$-dominated atmosphere
Conclusions

The 6.4 μm O₂-X CIA may be the most detectable O₂ feature for transit observations.

✓ **Within 5 pc:**
  ➢ The only O₂ feature to detect modern Earth levels of oxygen detectable at 5 sigma.

✓ **Beyond 5 pc (up to ~ 25 pc):**
  ➢ Desiccated dense O₂ atmospheres in less transits than the other O₂ features