

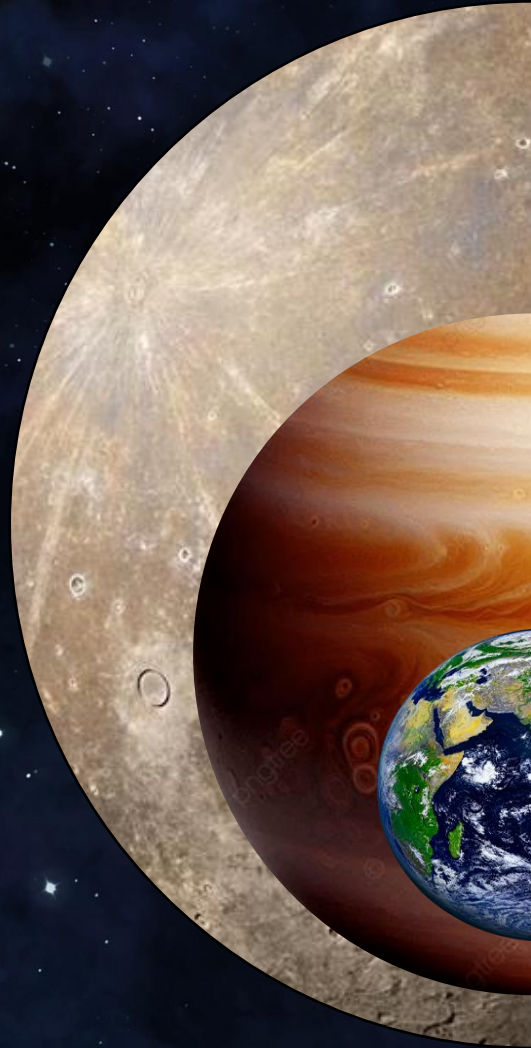
Characterizing Nearby Non-Transiting Rocky Worlds in the Mid-Infrared

Kevin Stevenson

Johns Hopkins University
Applied Physics Laboratory

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Big Science Questions: Occurrence, Diversity, Habitability



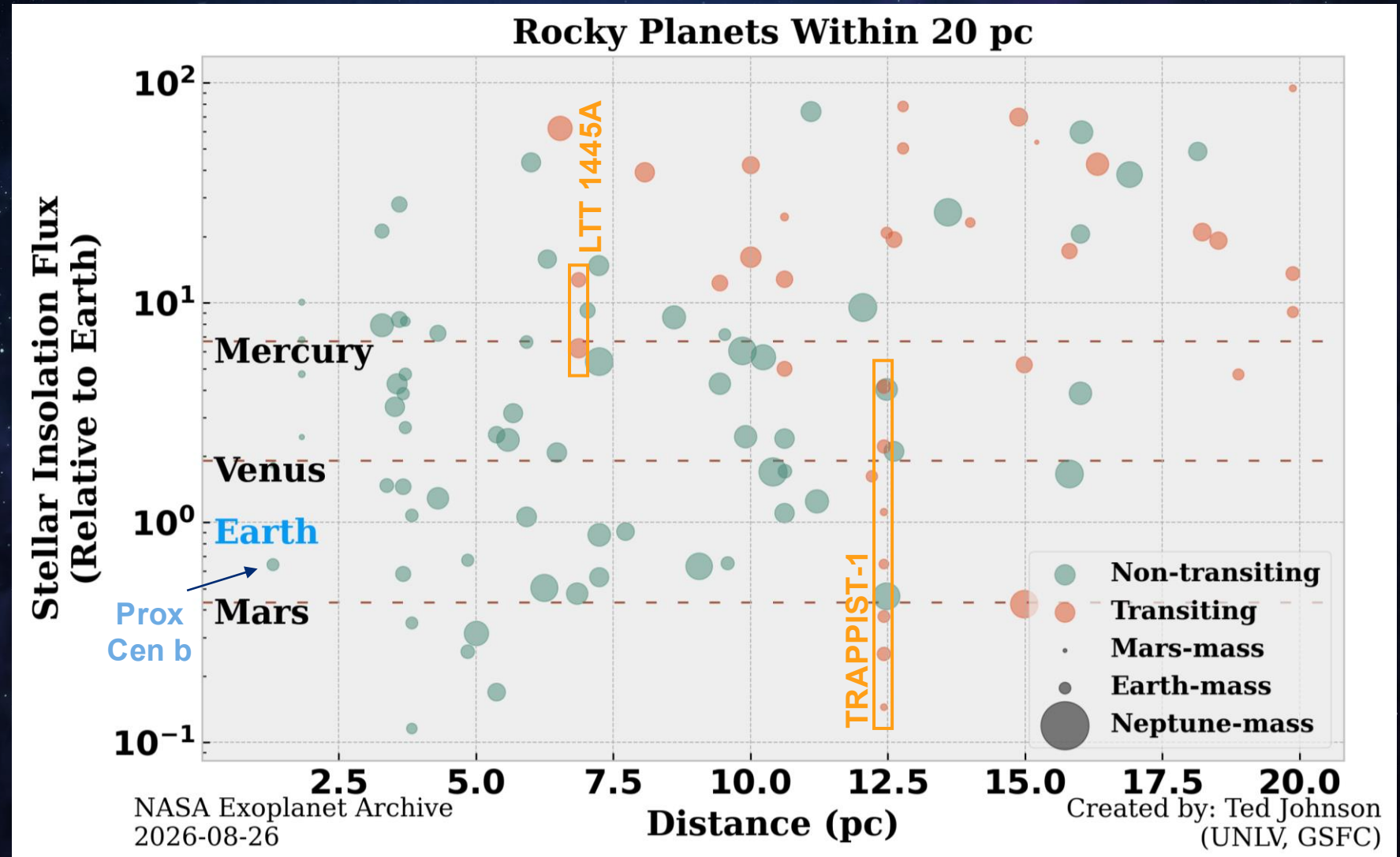
How common are atmospheres on rocky planets orbiting M dwarfs?

What range of climate states exists among the nearest rocky worlds?

Which nearby rocky planets are most likely to be habitable?

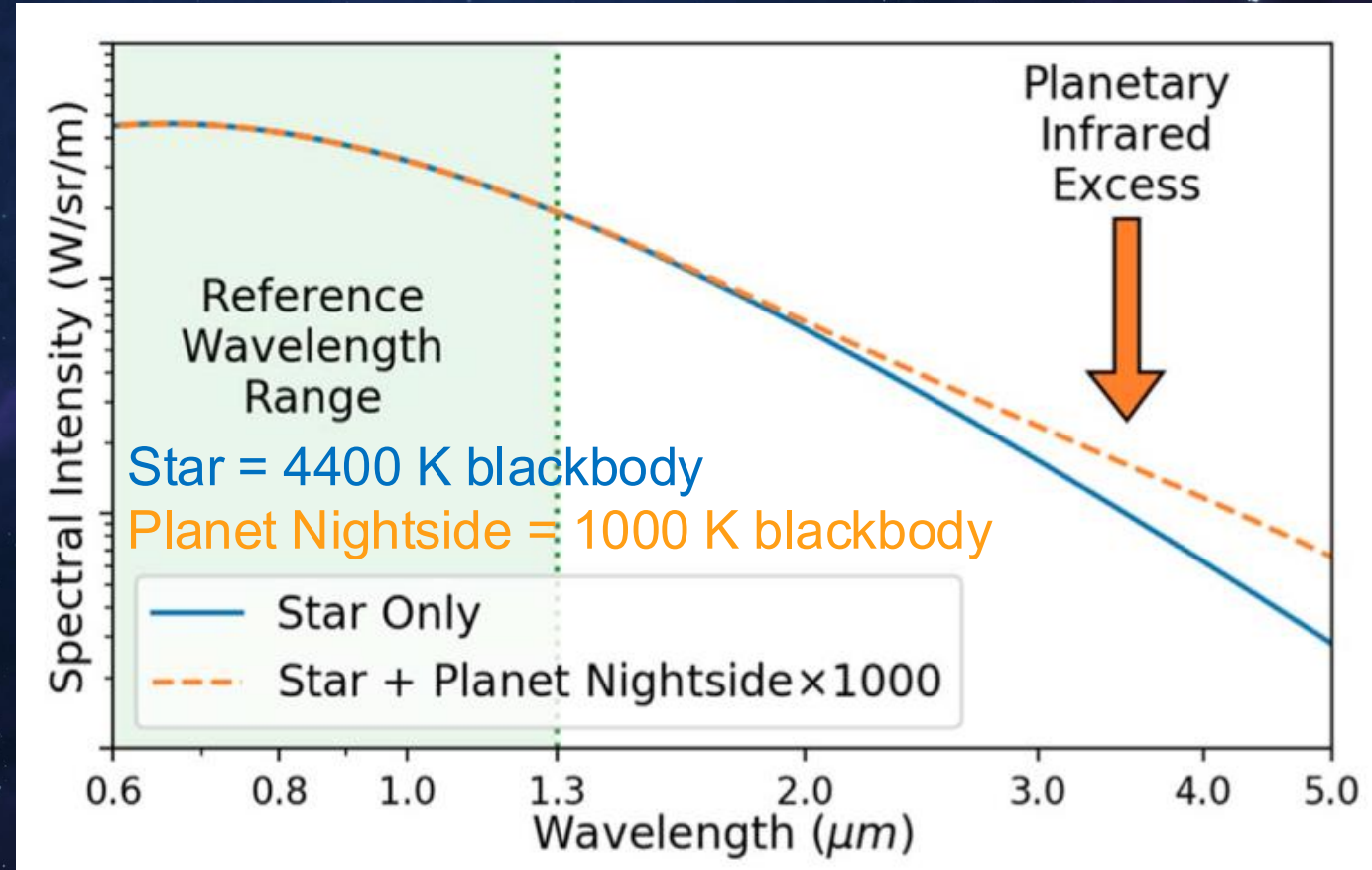
Most Planets Are Non-Transiting

- 37 nearest, known exoplanets are non-transiting
- How can we study the atmospheres of our nearest neighbors?
- Can use Planetary Infrared Excess (PIE) to measure thermal emission



First Slice of PIE

- Planetary Infrared Excess (PIE)
 - Meant for characterizing the atmospheres of both transiting and non-transiting exoplanets
 - Capture the short-wavelength (Wien) side of a planet's blackbody and peak emission
- Conceptualization
 - Use reference point in wavelength to constrain stellar spectrum
 - Extrapolate best-fit stellar model to longer wavelengths
 - Inferred infrared excess originates from planet



Growing Appetite for PIE

20+ Theory/Modeling Papers

- Stevenson, K. B., ApJL, 898, L35 (2020); arxiv:2007.11438
- Edwards et al., AJ, 161, 266, (2021), arXiv:2101.10317
- Arcangeli et al., A&A, 646, A94, (2021), arXiv:2103.15124
- Lustig-Yaeger et al., ApJL, 921, L4 (2021); arxiv:2110.02247
- Haqq-Misra et al., Acta Astronautica, 198, 194, (2022), arXiv:2206.00030
- Mandell et al., AJ, 164, 176 (2022); arXiv:2207.13727
- Limbach et al., MNRAS, 517, 2622, (2022), arXiv:2209.12914
- Mayorga et al. ApJ, 956, 74 (2023); arXiv:2309.15267
- Hammond and Komacek, ApJ, 968, 43, (2024), arXiv:2405.06615
- Macdonald et al., ApJ, 981, 3, (2025), arXiv:2407.17600
- Hammond et al., ApJ, 984, 181, (2025), arXiv:2504.00978
- Deming et al., arXiv e-prints, arXiv:2601.20966, (2026)
- Johnson and Mandell, arXiv e-prints, arXiv:2602.07127, (2026)

3 Observation/Demonstration Papers

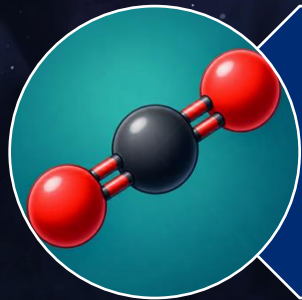
- Limbach et al., ApJL, 973, L11, (2024), arXiv:2408.16813
- Limbach et al., ApJL, 984, L28, (2025), arXiv:2504.16982
- Lustig-Yaeger et al., ApJL, 994, L4 (2025); arXiv:2510.06169



Exoplanet detection using
machine learning



Nightside characterization
without phase curves



Molecular feature
detection without eclipses

Exoplanet Detection Using ML - Methodology

LTT 9779 b, a hot Neptune

 Star: G7, 5480 K
 Planet: $T_{\text{eq}} = 1980 \text{ K}$, $0.4 R_{\text{Jup}}$, $0.1 M_{\text{Jup}}$
(Ashtari et al. 2026, Jenkins et al. 2020)

WASP-17 b, a hot Jupiter

 Star: F6, 6550 K
 Planet: $T_{\text{eq}} = 1750 \text{ K}$, $1.9 R_{\text{Jup}}$, $0.5 M_{\text{Jup}}$
(Lustig-Yaeger et al. 2025, Southworth et al. 2012)

Eureka! Stage 4 Data

Generate unbinned Stage 4 Light Curve files from Stage 3 files generated for Ashtari et al. 2026 and Lustig-Yaeger et al. 2025.

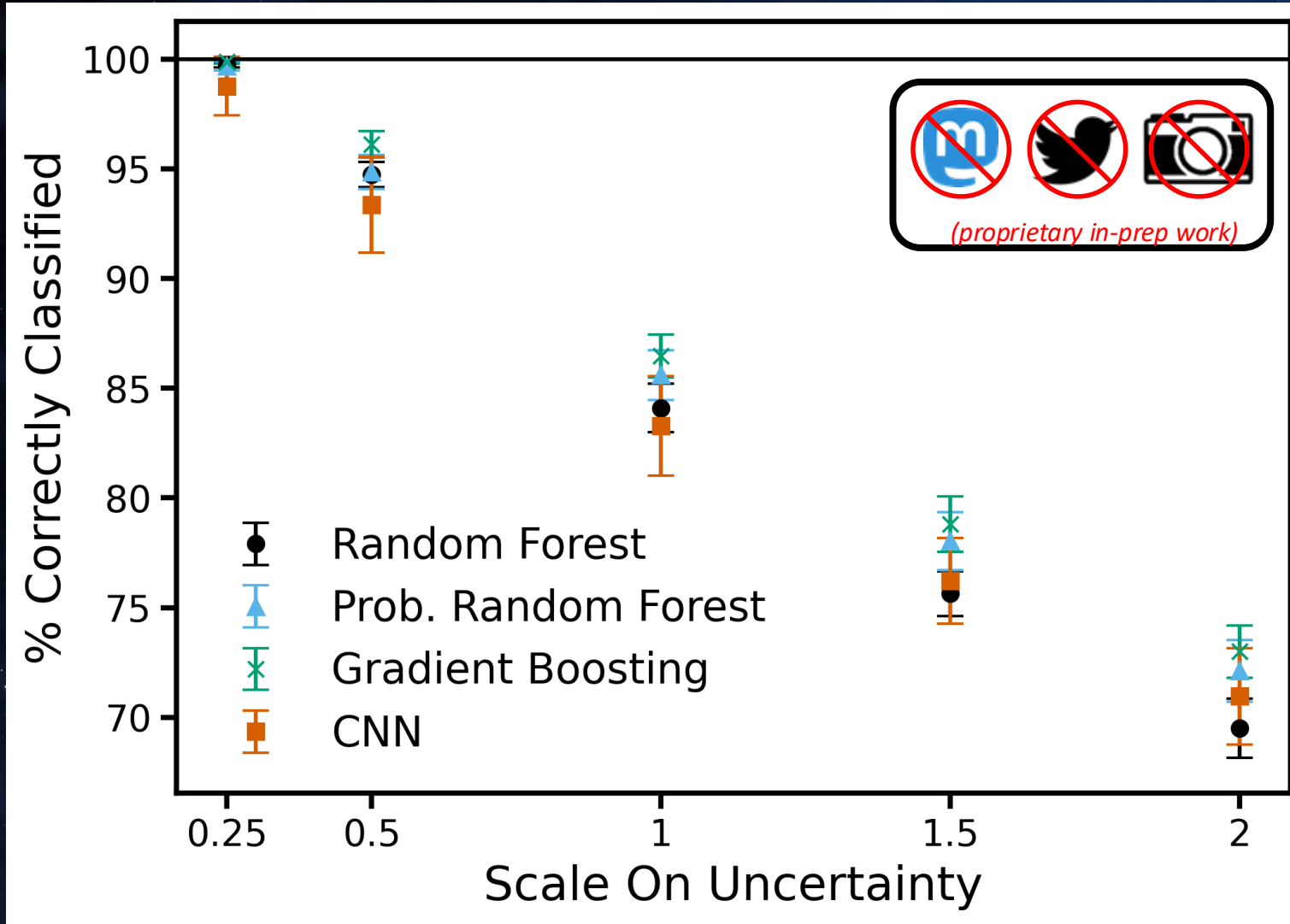
Post Processing

- Select star-only and star+planet time steps
- Remove outliers: time steps with white light > 3 sigma from the local mean
- Replace NaNs with average values at each wavelength
- Normalize each spectrum by its average flux over the observed wavelengths

Generating Train/Test Data

- Build a template spectrum for each object (star-only or star+planet within each system)
- Generate simulated perturbed observations within scaled uncertainties
- Bin wavelengths to 80 points

ML Correctly Classifies Planet vs. No Planet



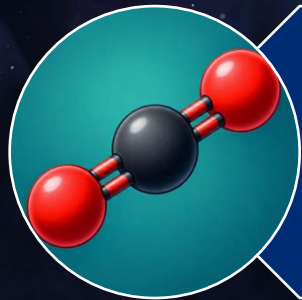
- JWST/NIRSpec
- 85% accuracy
- Hot Neptune
- LTT 9779b: 7.2 sec
- 2m MIR telescope
- 85% accuracy
- Prox Cen b: 43 min
- LTT 1445Ab: 31 min
- LHS 1140b: 2.5 days



Exoplanet detection using
machine learning

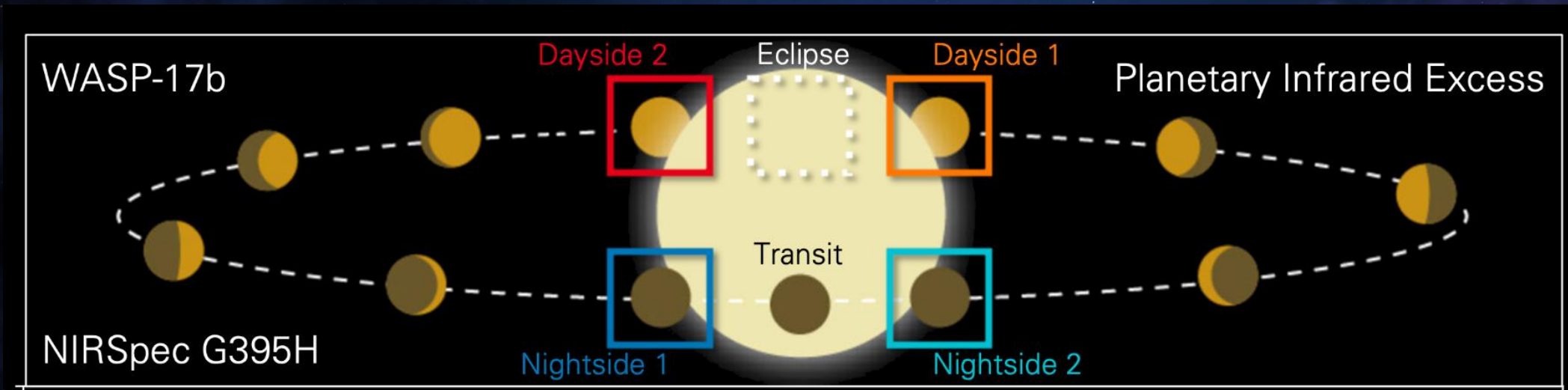


Nightside characterization
without phase curves



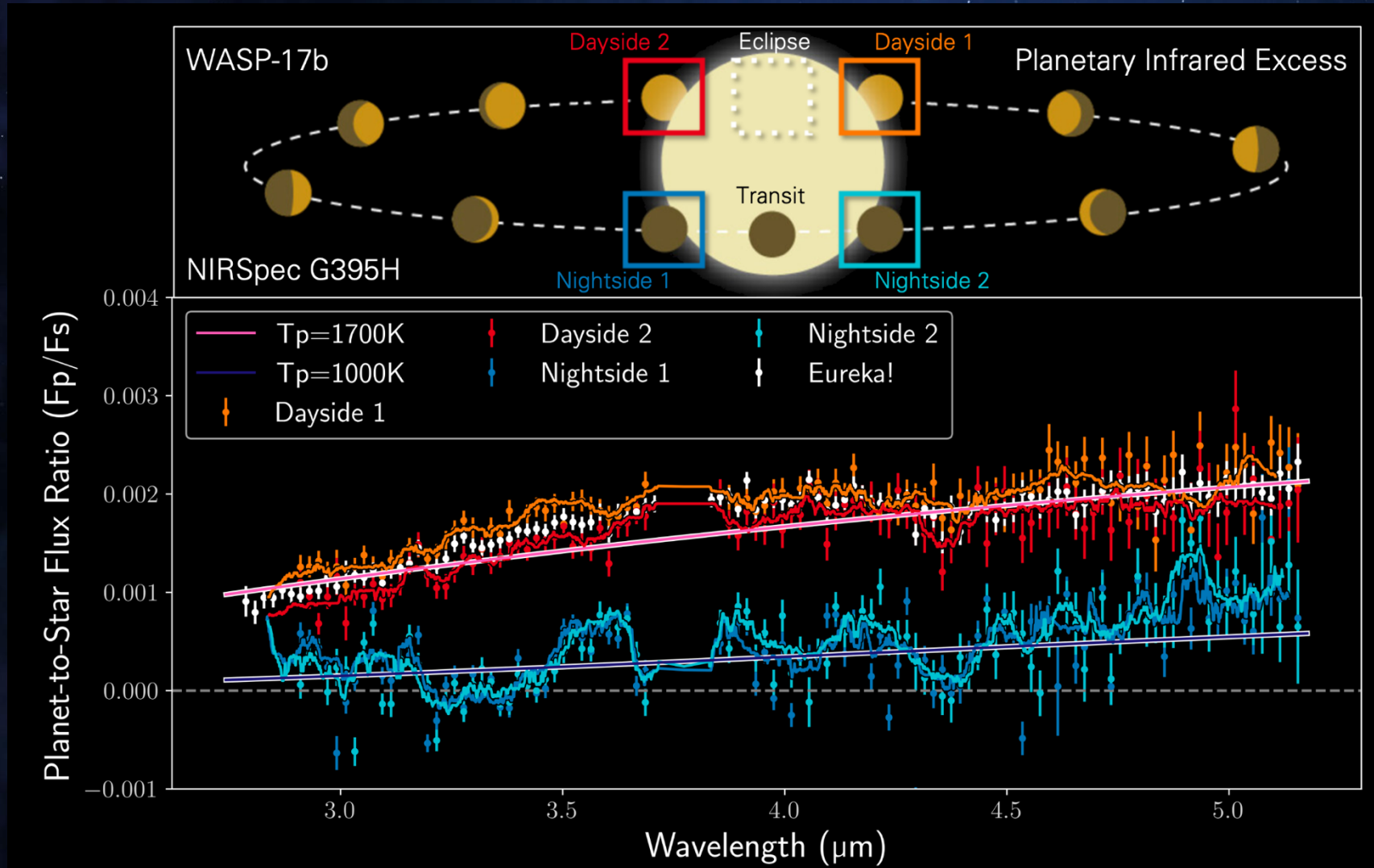
Molecular feature
detection without eclipses

Nightside Characterization of WASP-17b



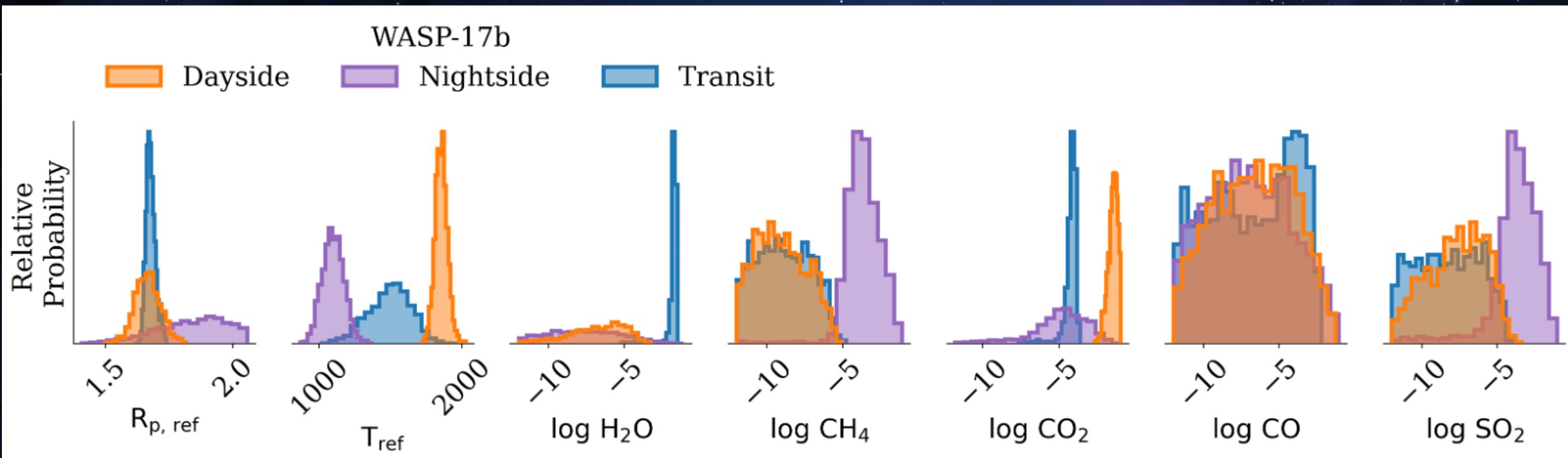
WASP-43b Phase
Curve
Credit: Guangwei Fu

Dayside & Nightside Emission Spectra Using PIE



Good agreement between PIE spectra and eclipse spectra

Comparison of Retrieval Results



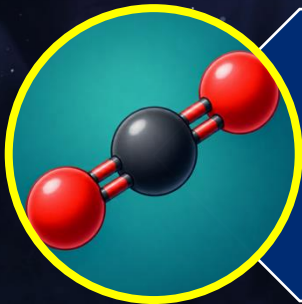
Nightside detection of photochemical products (CH_4 and SO_2)



Exoplanet detection using
machine learning



Nightside characterization
without phase curves



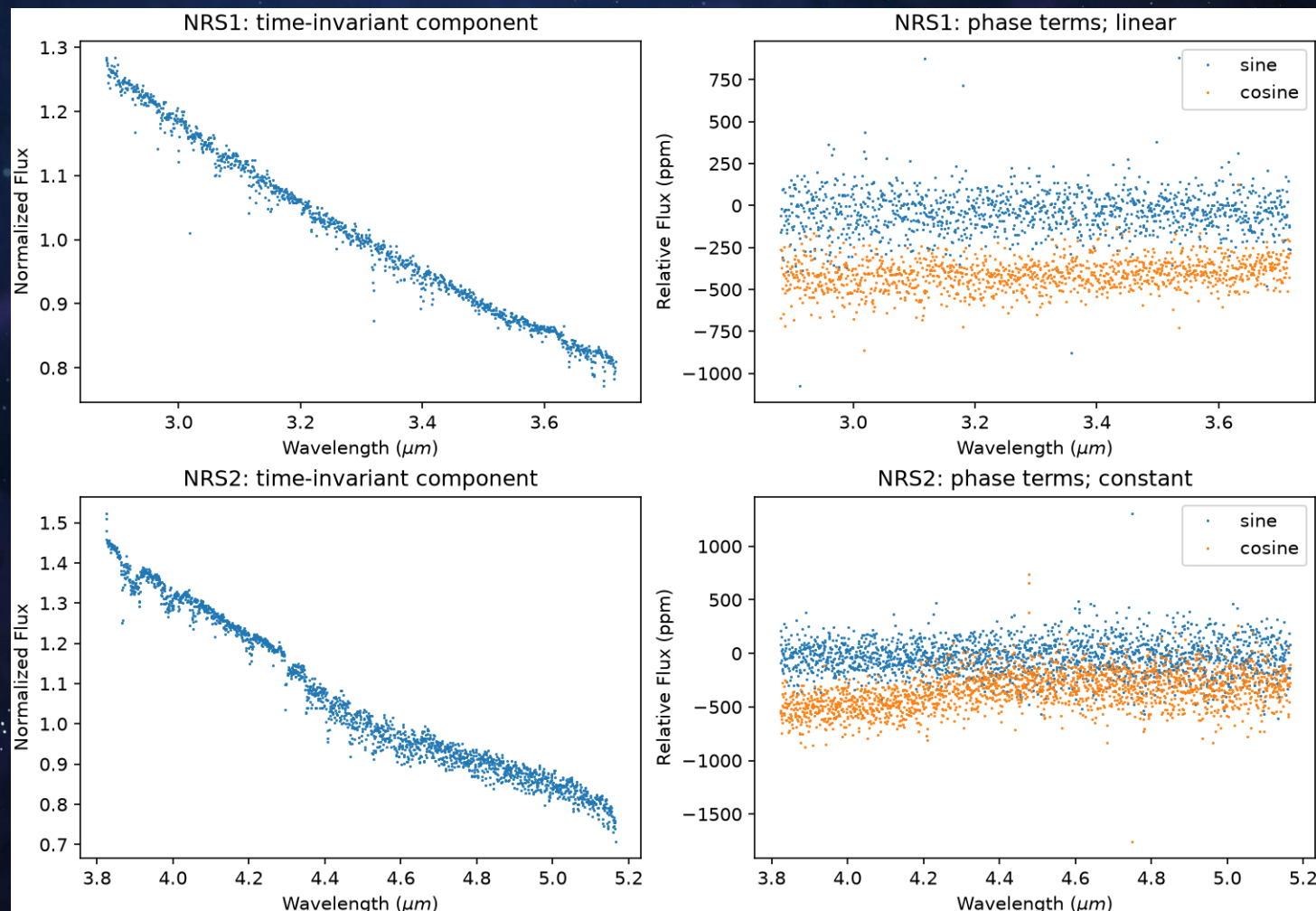
Molecular feature
detection without eclipses

Molecular Feature Detection in Unresolved Exoplanet Spectra

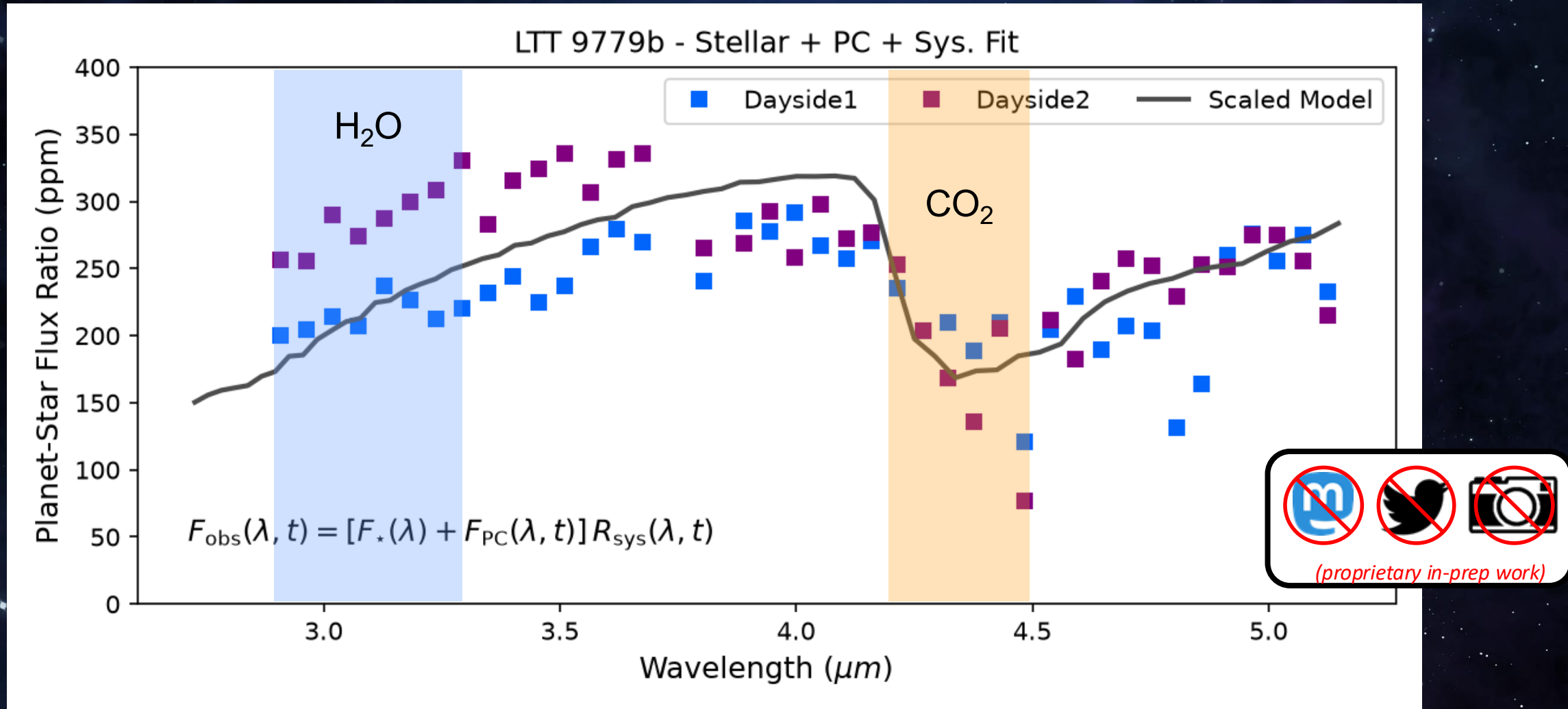
Can we detect molecular features in a planet's atmosphere without transits or eclipses?

$$F_{\text{obs}}(\lambda, t) = [F_{\star}(\lambda) + F_{\text{PC}}(\lambda, t)] R_{\text{sys}}(\lambda, t)$$

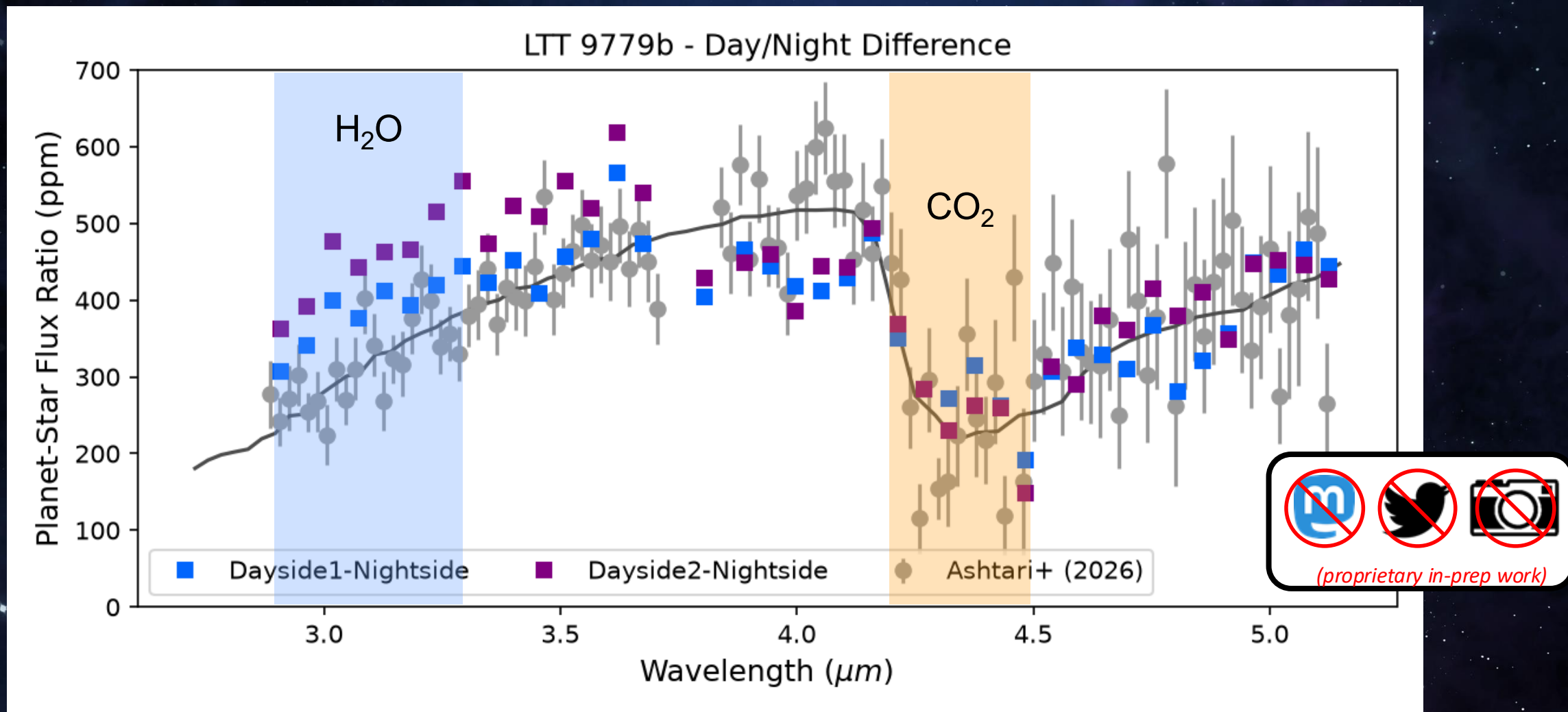
- LTT 9779b
- Phase curve
- JWST NIRSpec
- GO-3231 (PI: Crossfield)

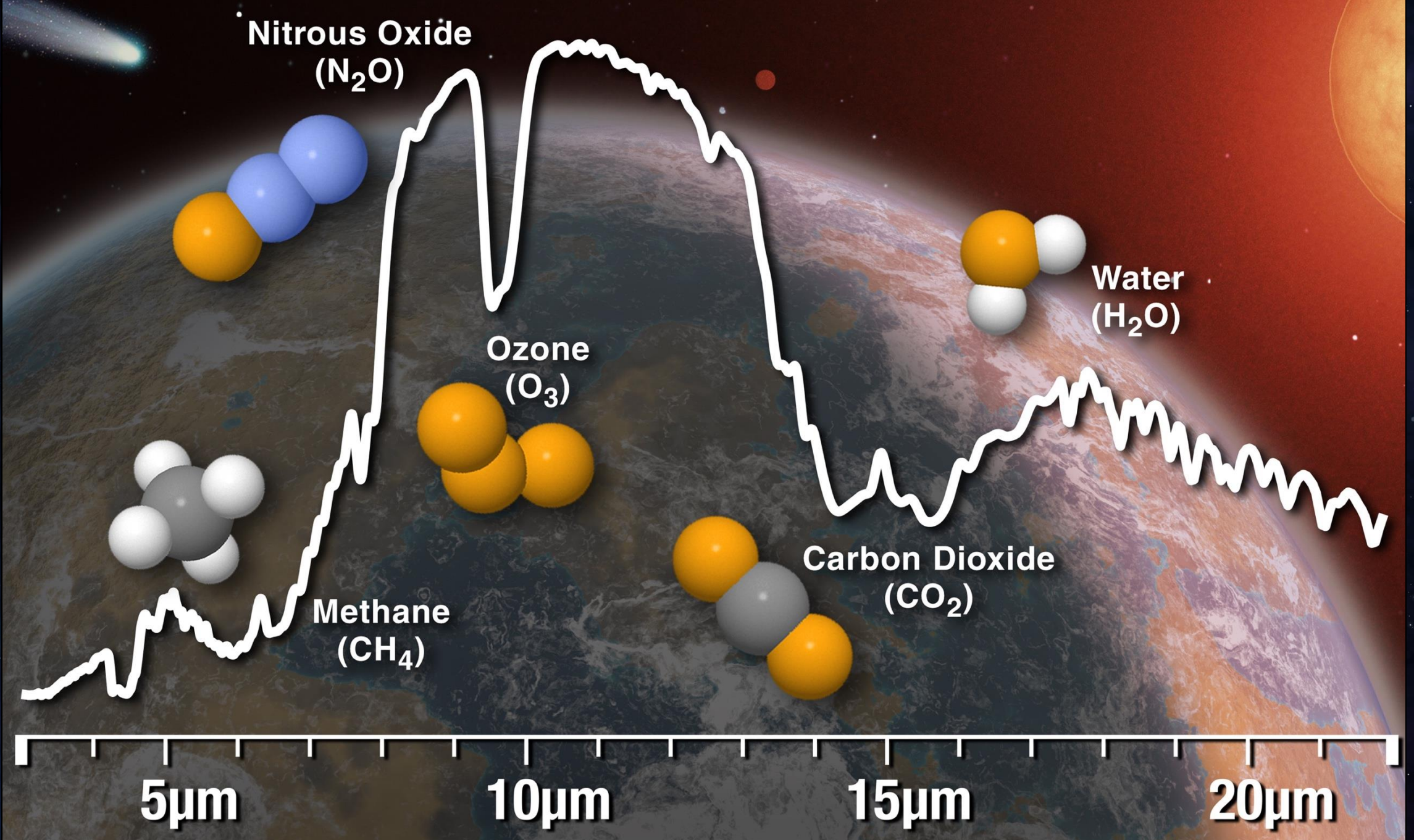


Detect H₂O & CO₂ on Dayside (No Reference Point)



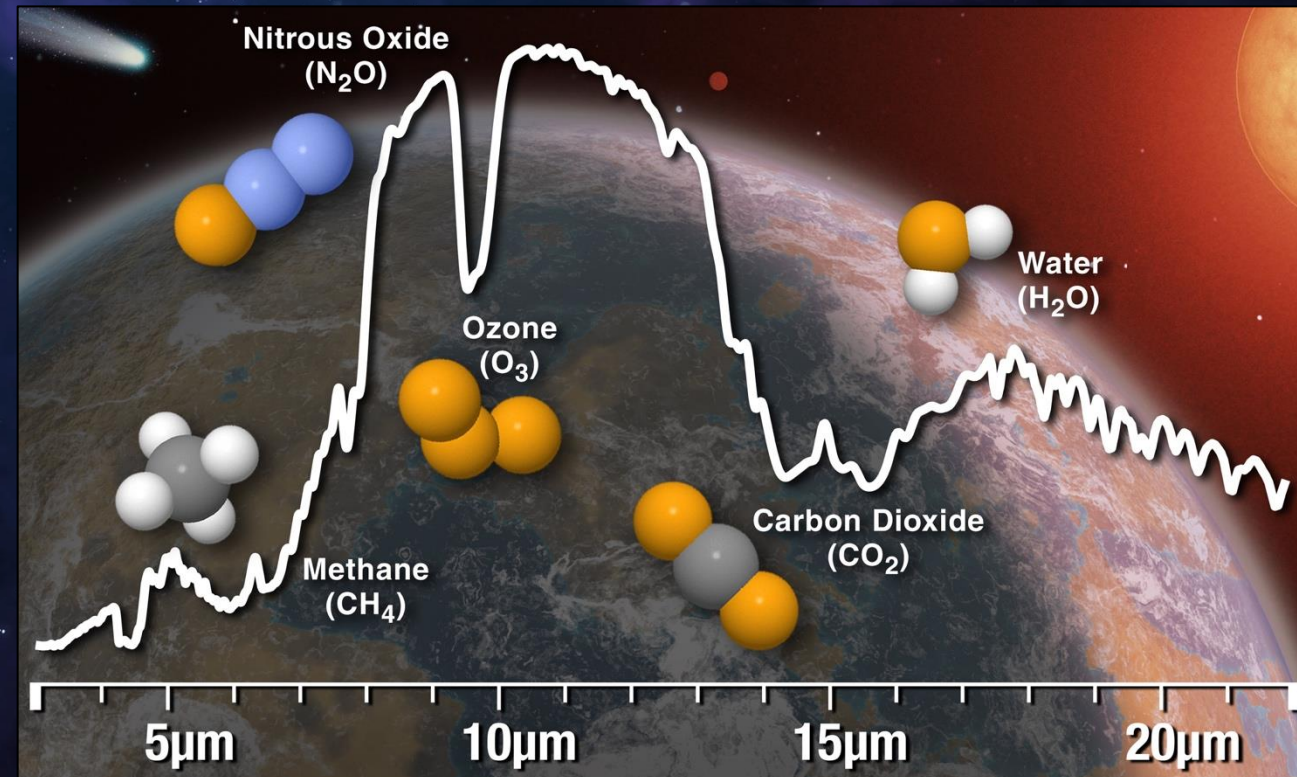
Detect H₂O & CO₂ on Dayside (Nightside Reference)





Measurement Capability Needs

- Mid-IR Instrument
 - Ultra-stable spectrometer ($\lesssim 10$ ppm noise floor)
 - Simultaneous, broad wavelength coverage (3 – 18+ μm)
 - Large dynamic range ($K_{\text{mag}} = 4 - 8$)
- Telescope
 - Large primary mirror (~ 2 m)
 - Cooled to < 40 K
 - Sub-pixel pointing stability
 - Long-duration, uninterrupted stares (~ 4 weeks)



Summary

- We accurately classify spectra as being star-only or star+planet using machine learning techniques
- We detect the first JWST nightside emission spectrum of WASP-17b, revealing a ~ 1000 K atmosphere and transport-driven chemistry.
- We detect molecular features on LTT 9779b without using transits or eclipses



Image
generated
from AI



JOHNS HOPKINS

APPLIED PHYSICS LABORATORY

Rocky Planet Emission Spectra

- Signal is strongest at mid-IR wavelengths (5 – 20 μm)
- Deepest absorption feature is CO_2 at 15 μm
- CH_4 , N_2O , and O_3 also have prominent mid-IR features

Planet-Star Flux (F_p/F_s)

