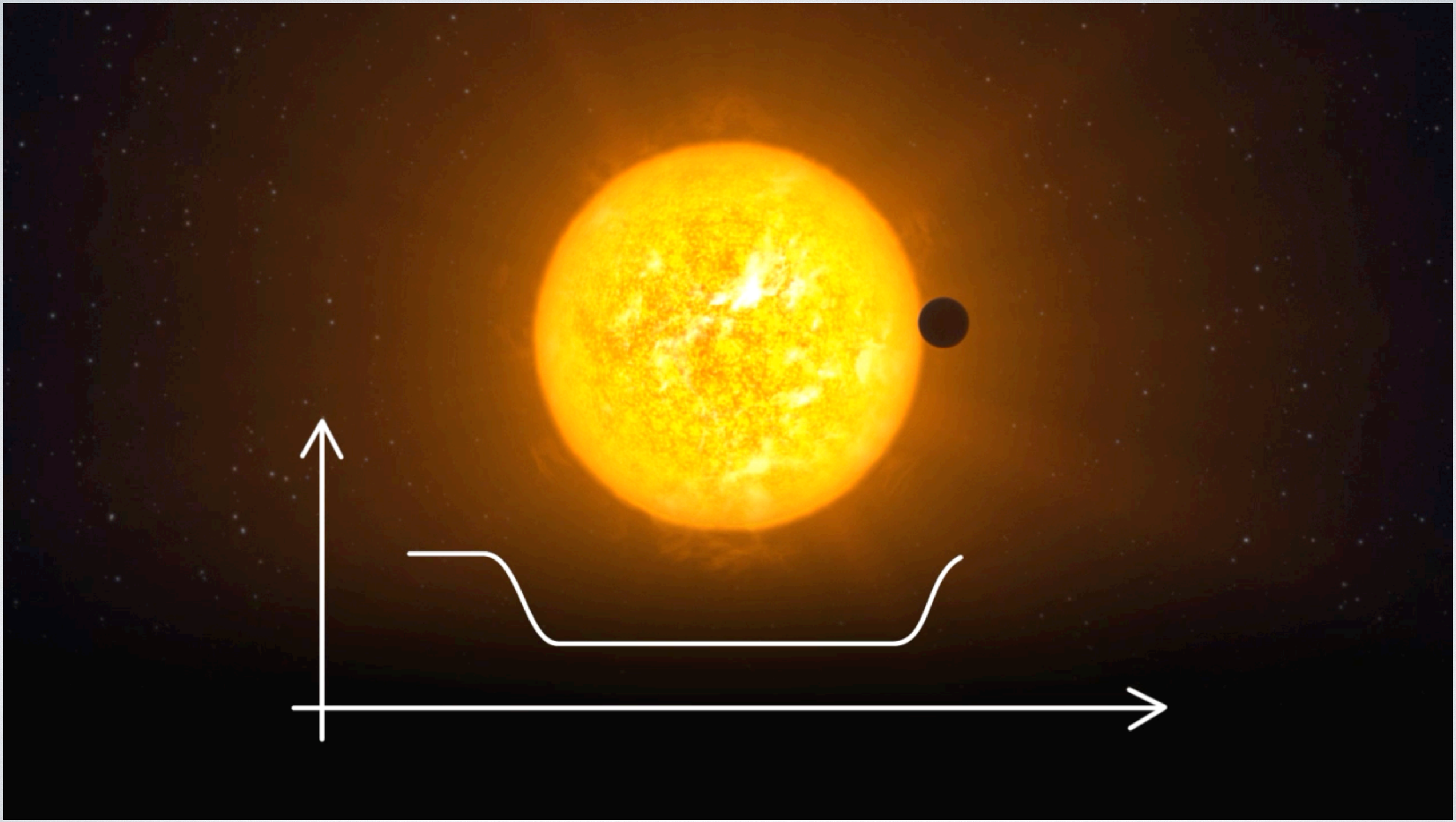
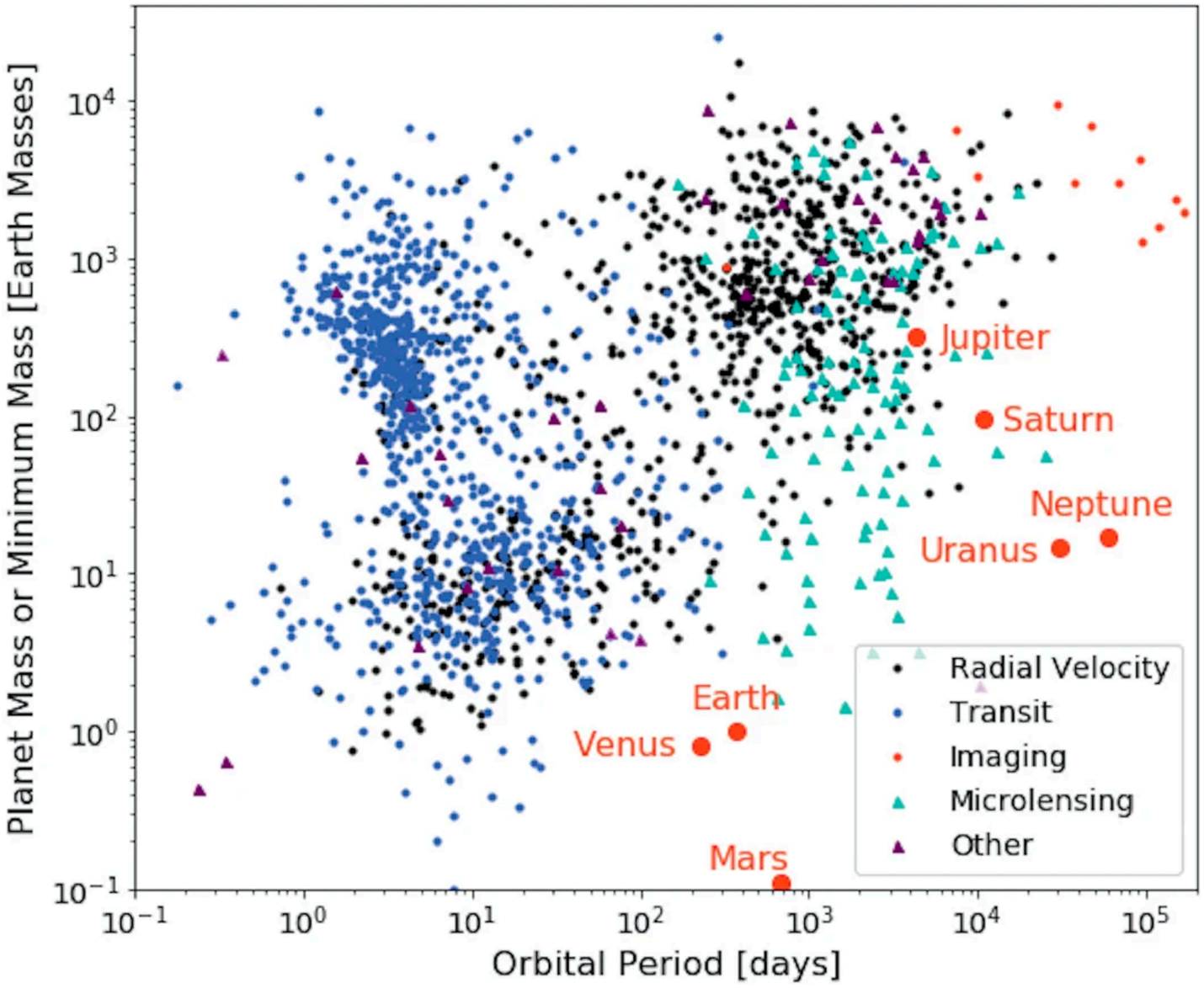
Characterisations of atmospheres in Exoplanet

And the particular case of LTT 9779 b.

R. Ramírez Reyes

1- Departamento de Astronomía, Universidad de Chile, Las Condes, Santiago, Chile





Source: The Demographics of Wide-Separation Planets, B.Scott Gaudi

Exoplanet Populations

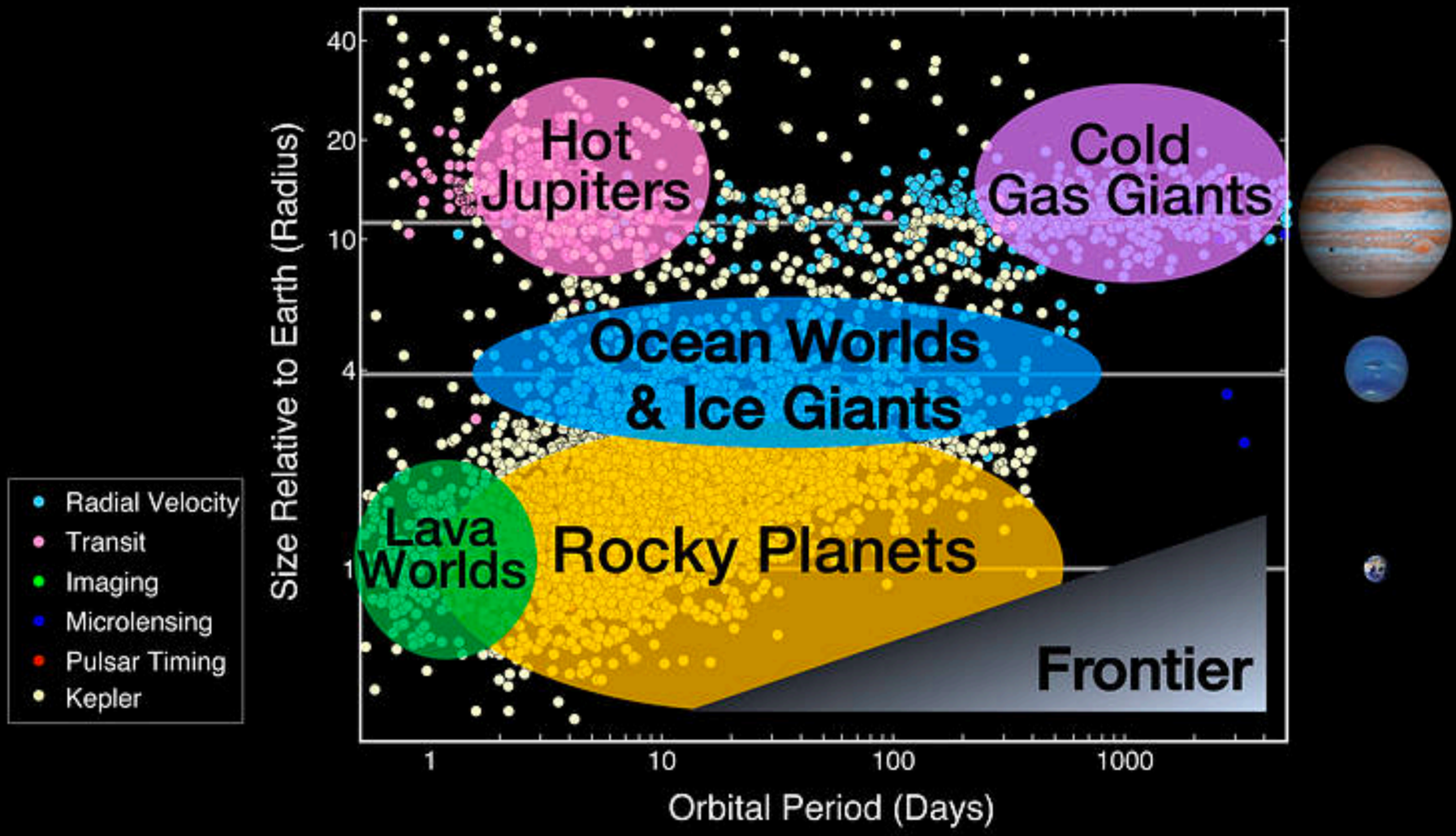
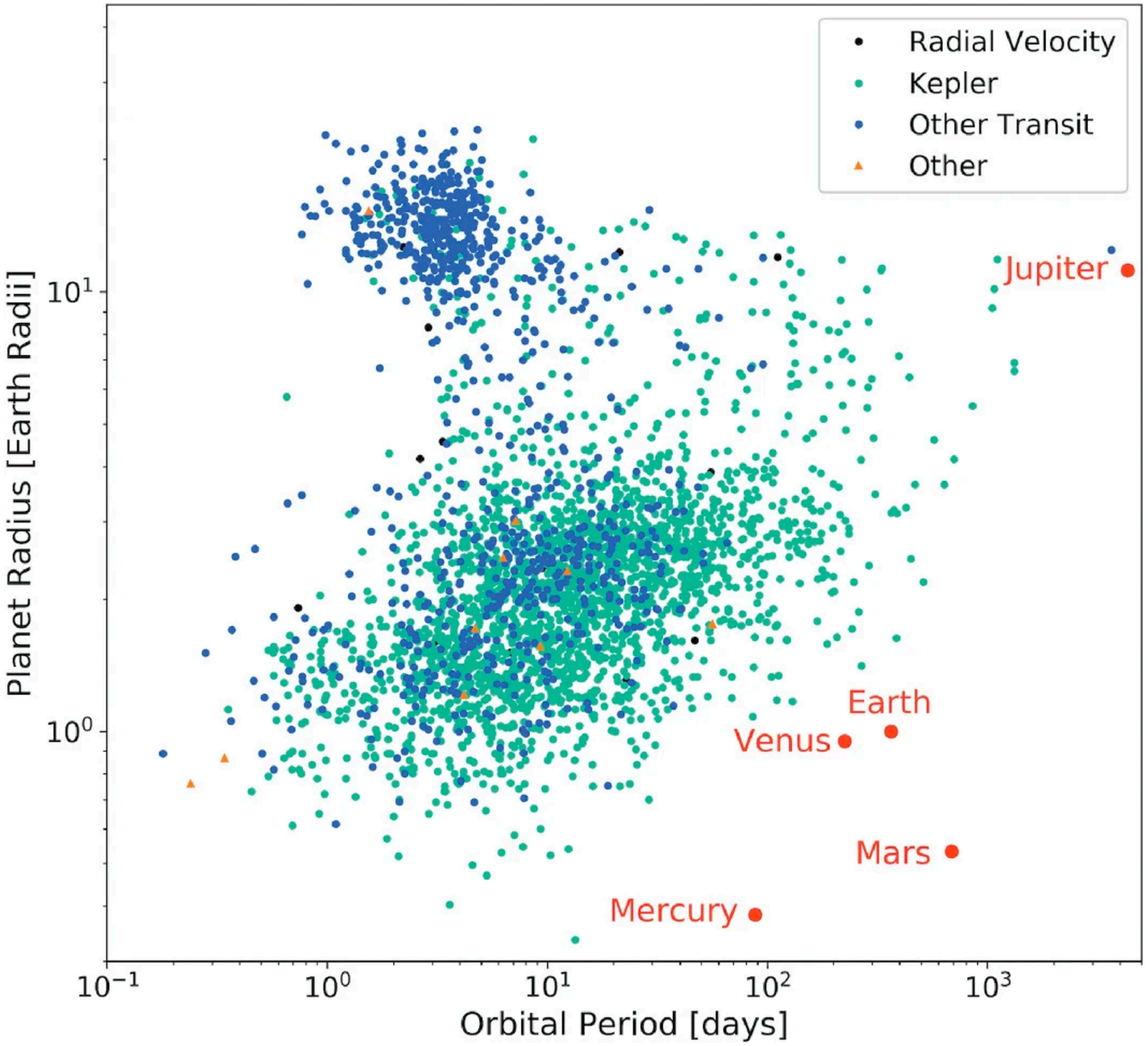
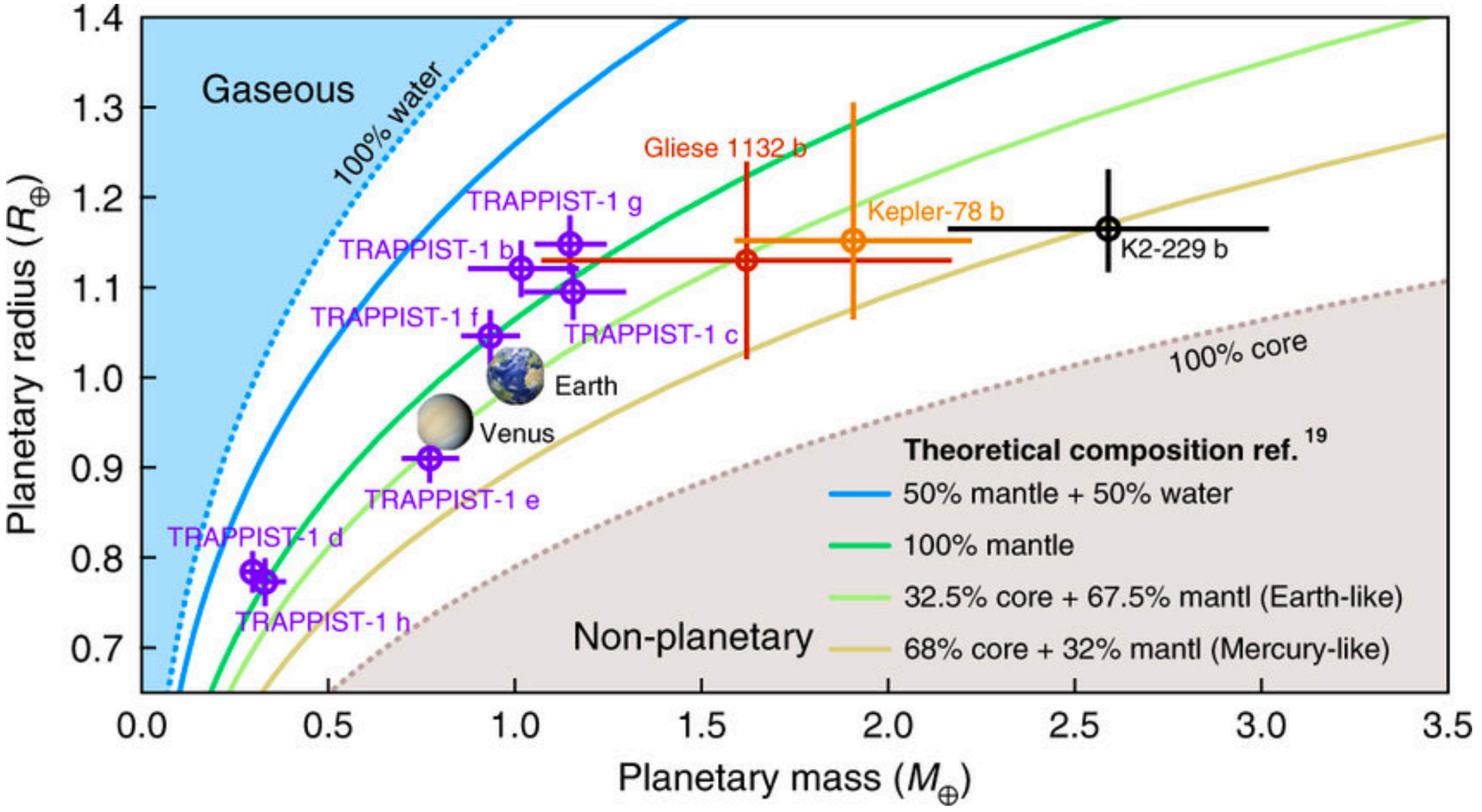


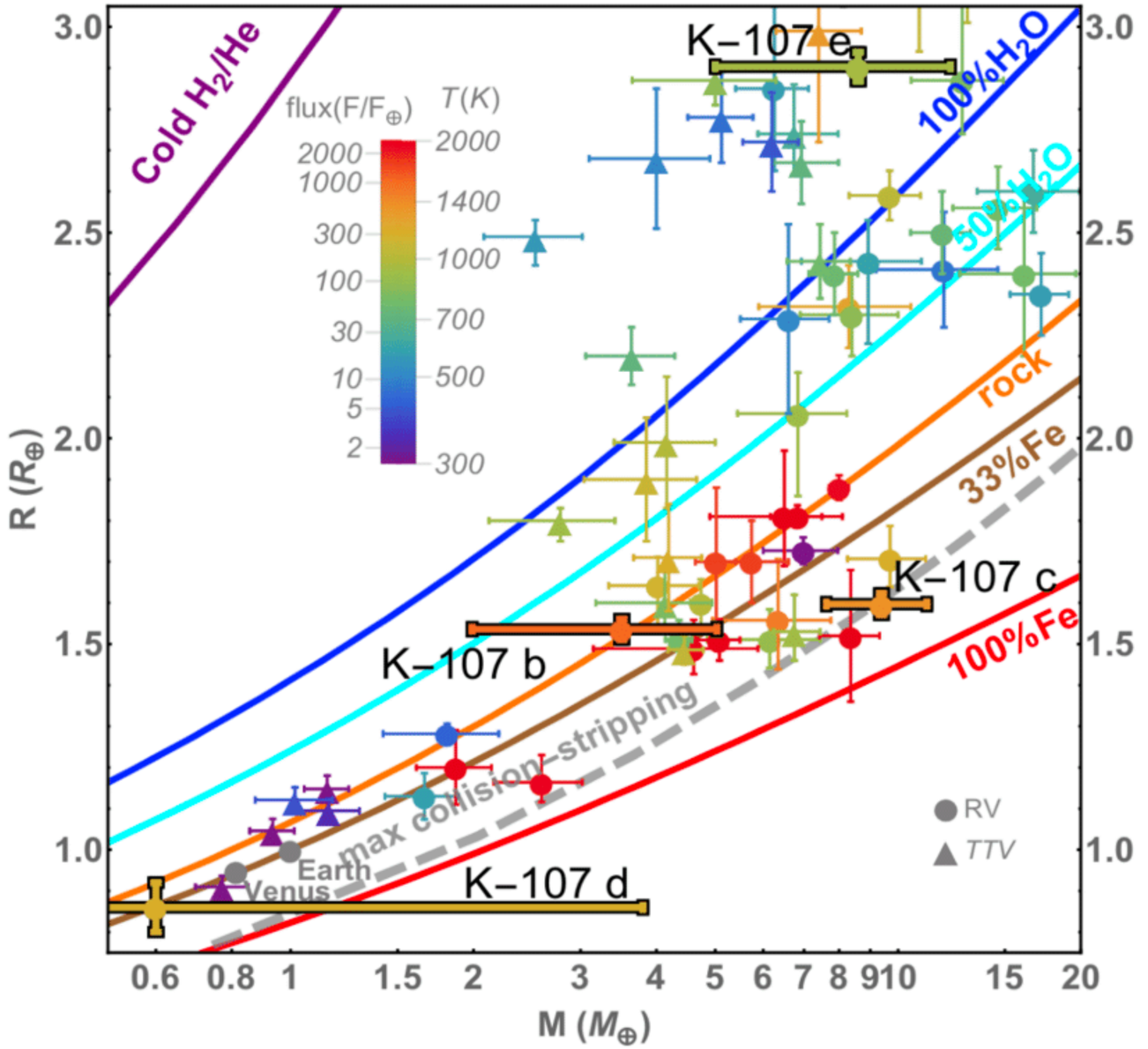
Image credit: NASA/Ames Research Center/Natalie Batalha/Wendy Stenzel



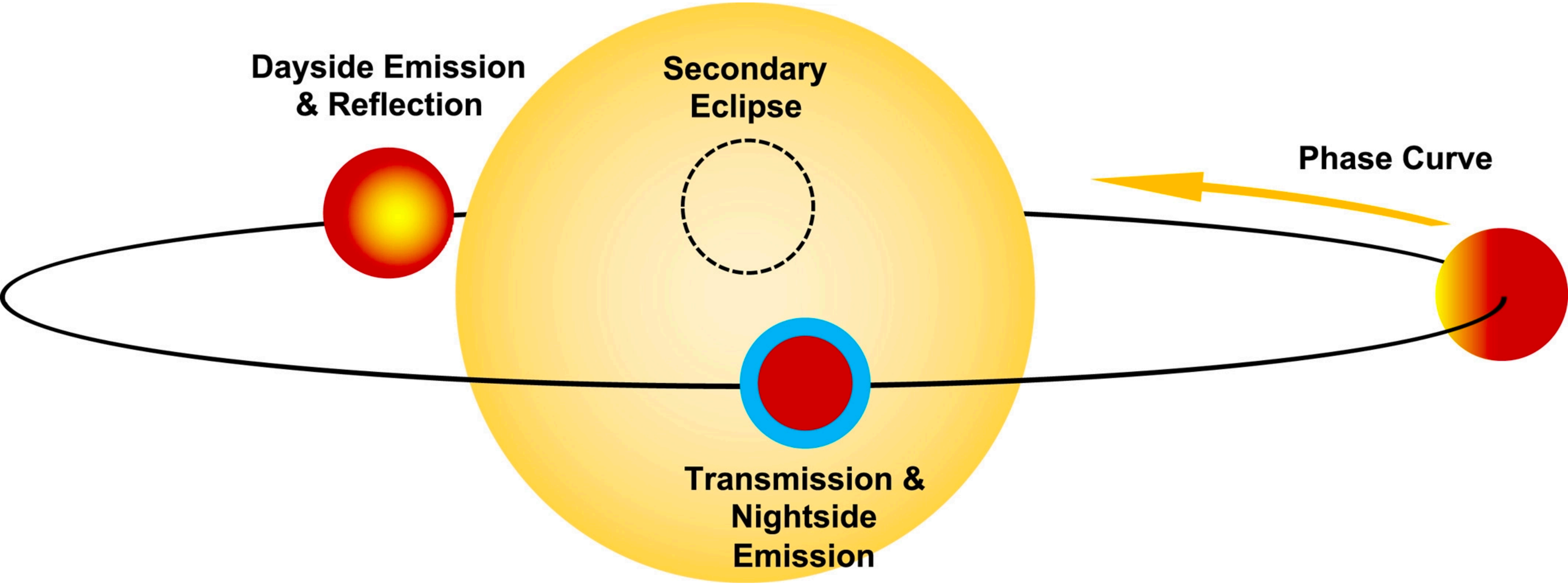
Source: The Demographics of Wide-Separation Planets, B.Scott Gaudi



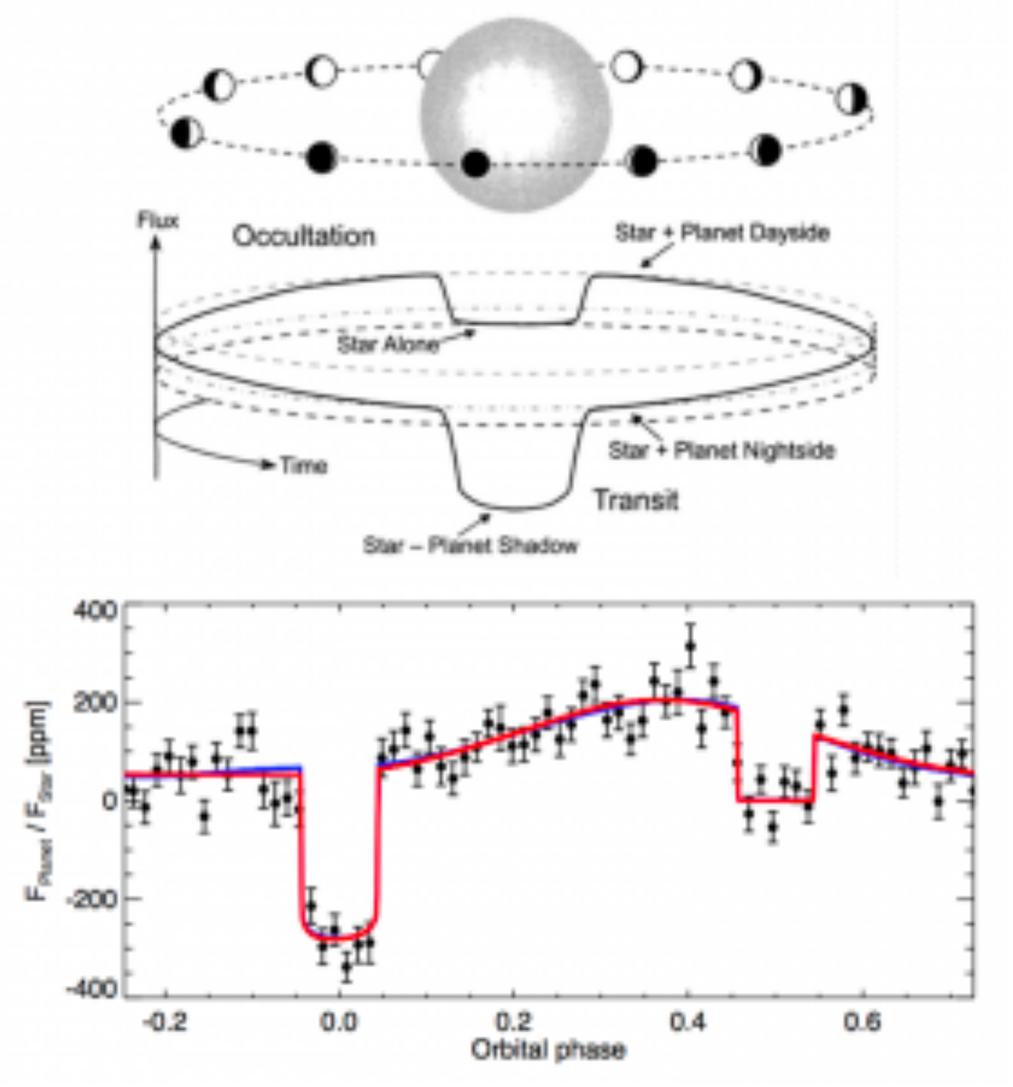
Source: An Earth-sized exoplanet with a Mercury-like composition, A. Santerne et al. 2018



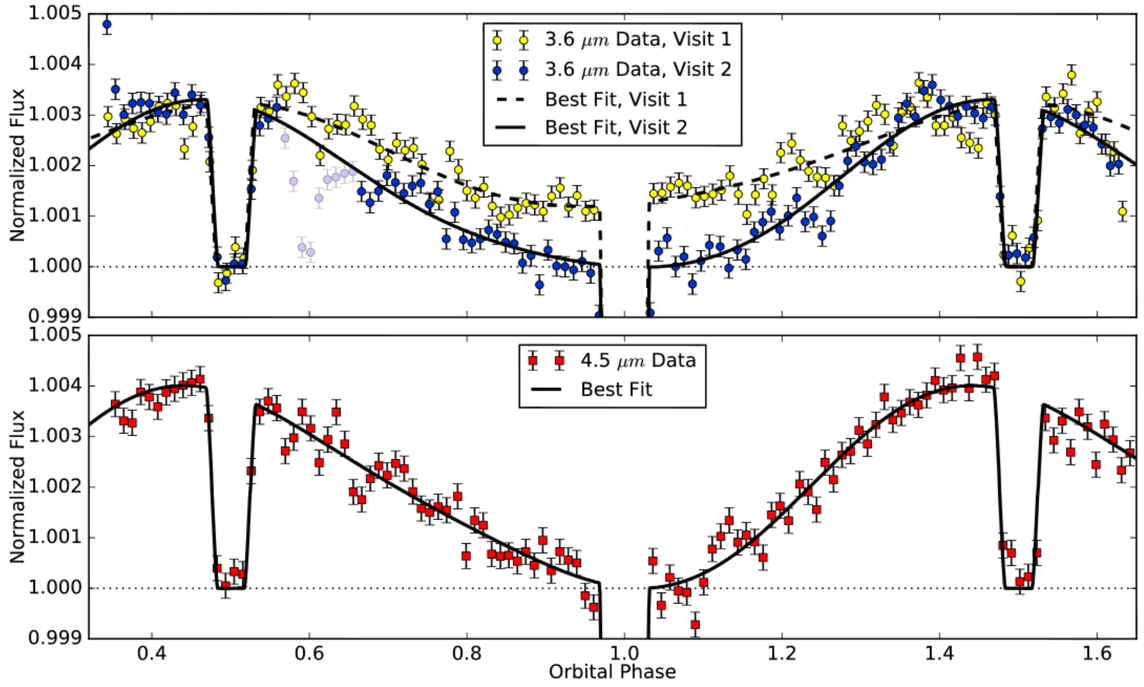
Source: A giant impact as the likely origin of different twins in the Kepler-107 exoplanet system, Aldo S. Bonomo et al. 2019



Source: JGR Planets, Aerosols in Exoplanet Atmospheres



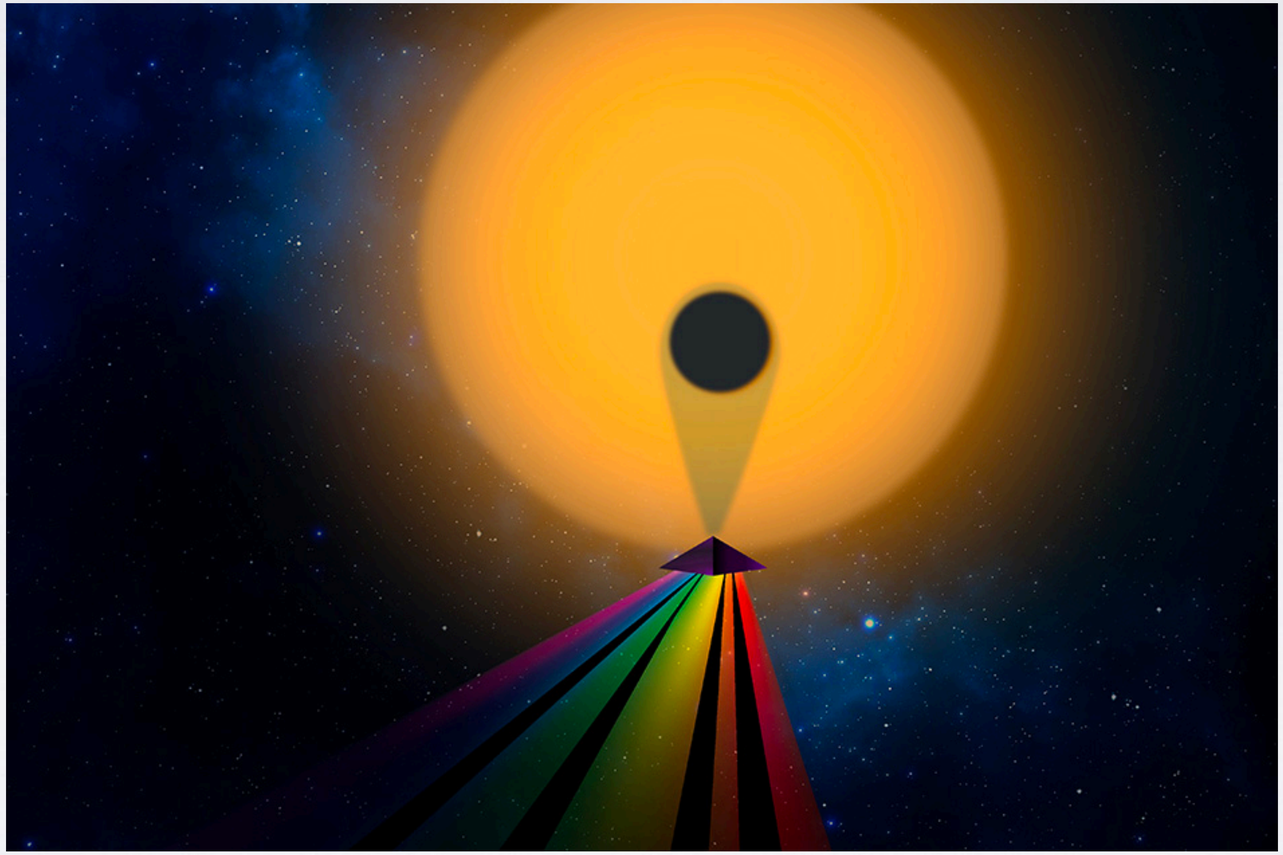
Brice-Oliver Demory et al. 2016



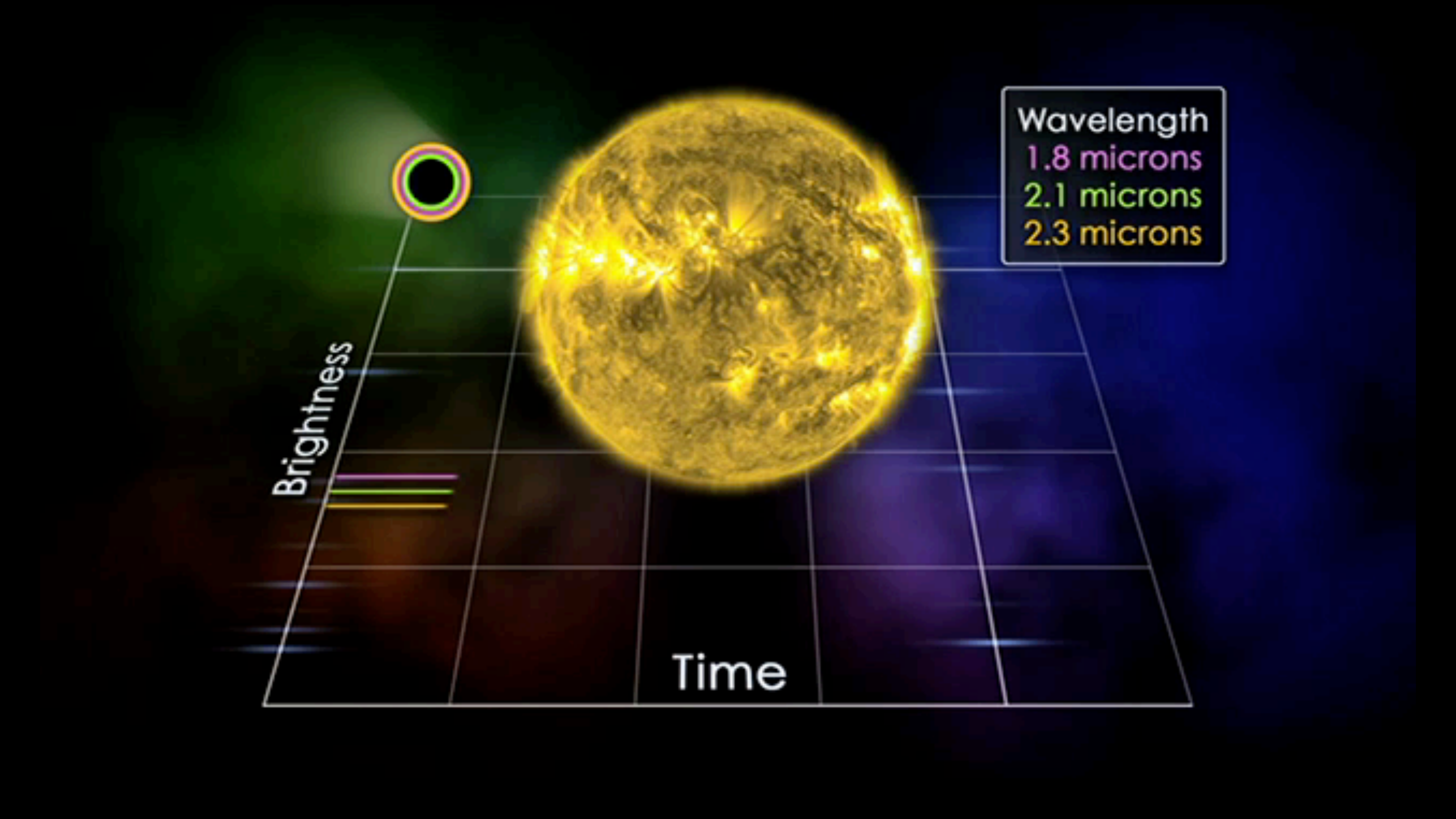
Kevin B. Stevenson et al. 2016

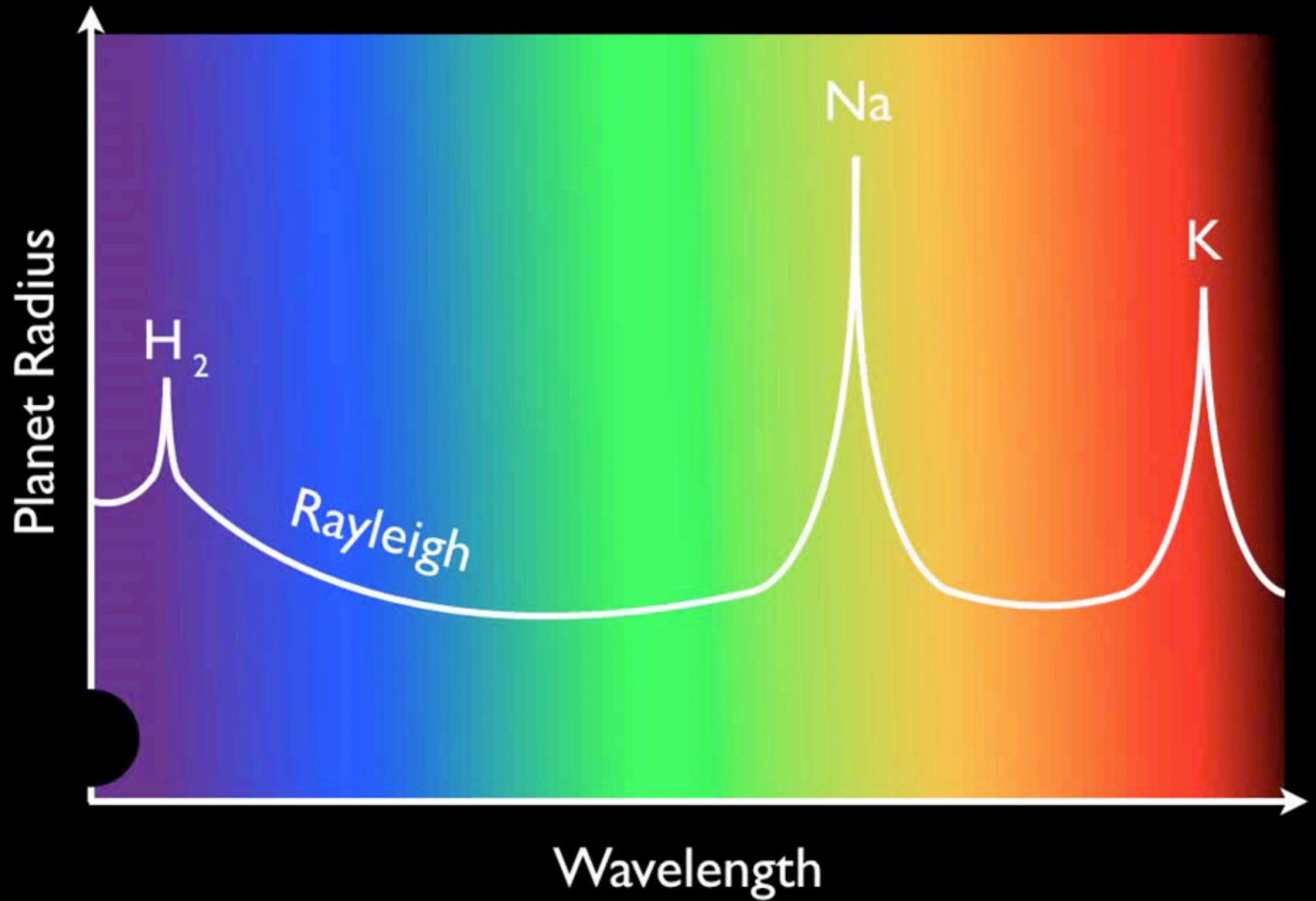
Transmission Spectroscopy

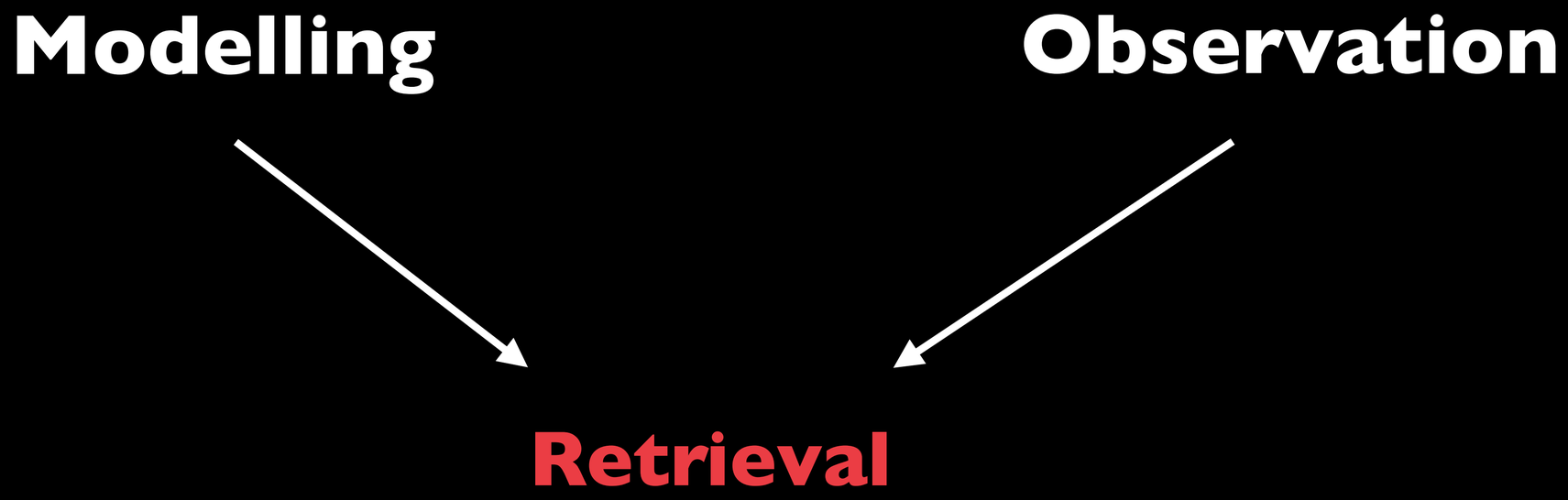
- A technique used to gather details about the chemical composition and the extent of the atmosphere of a transiting exoplanet.

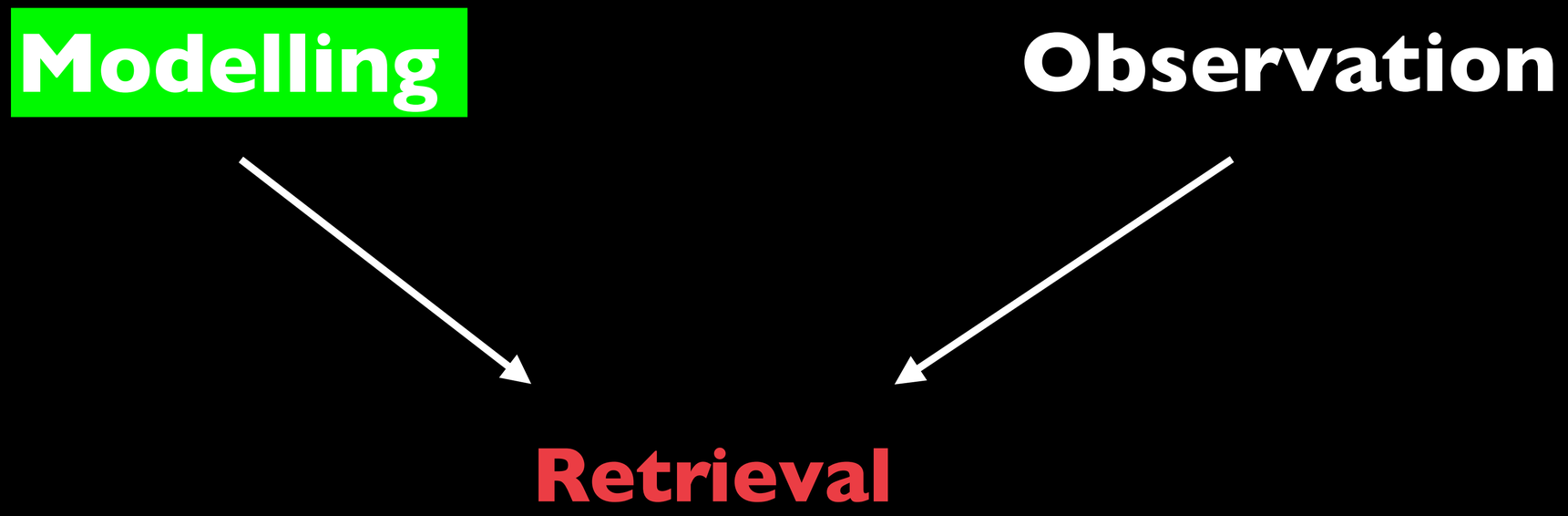


Credit: Christine Daniloff/MIT, Julien de Wit

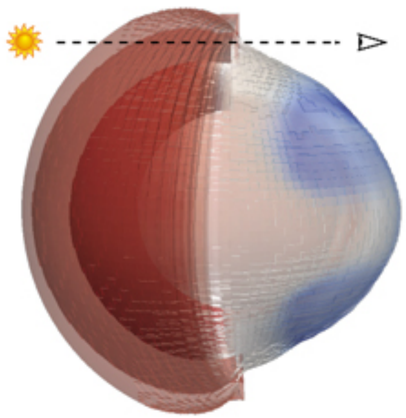

Wavelength
1.8 microns
2.1 microns
2.3 microns
Brightness
Time


Planet Radius
Na
K
H2
Rayleigh
Wavelength

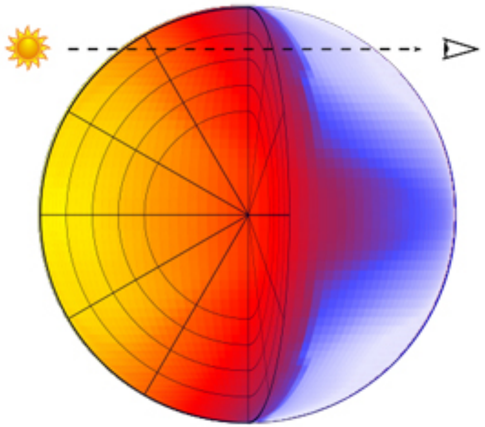

Modelling
Observation
Retrieval


Modelling
Observation
Retrieval

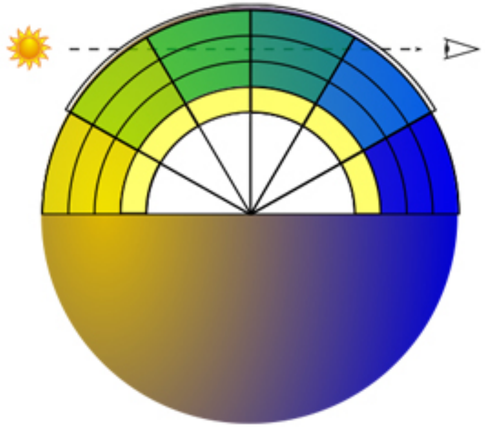
Modelling



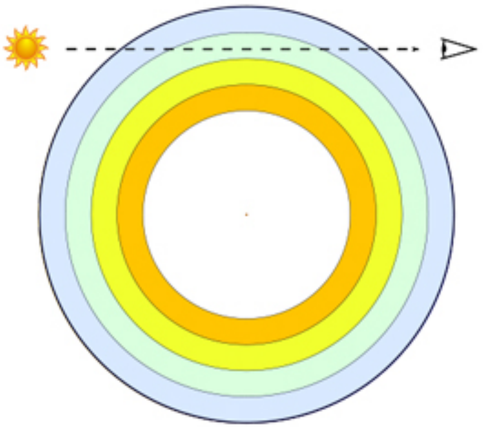
(a) WASP-121b (GCM)



(b) 3D

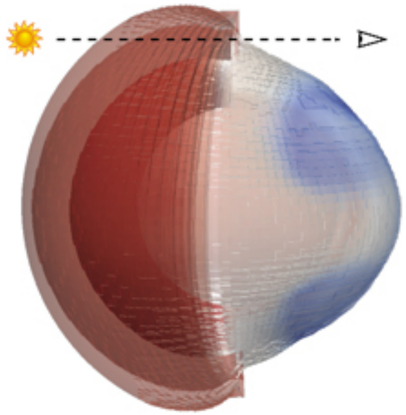


(c) 2D

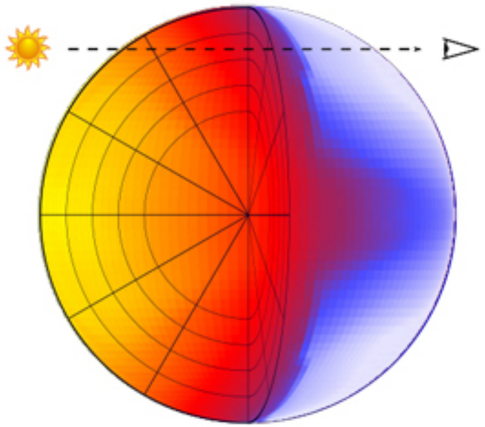


(d) 1D

Modelling



(a) WASP-121b (GCM)



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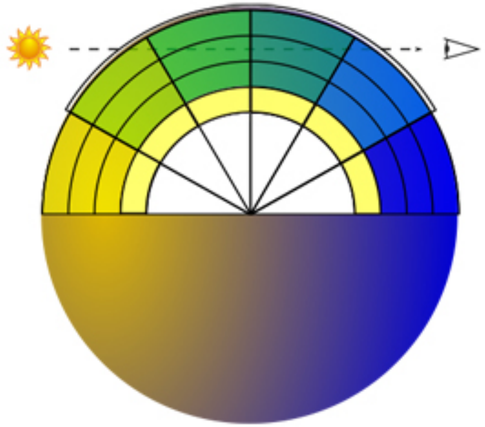

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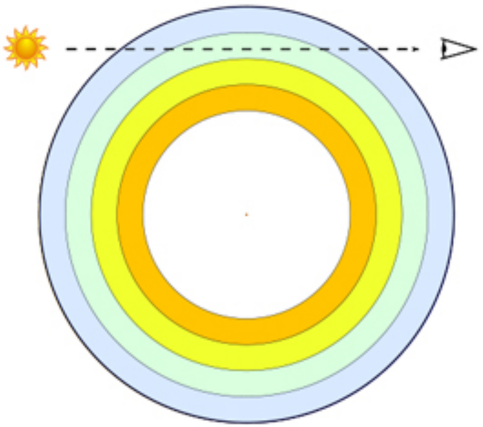
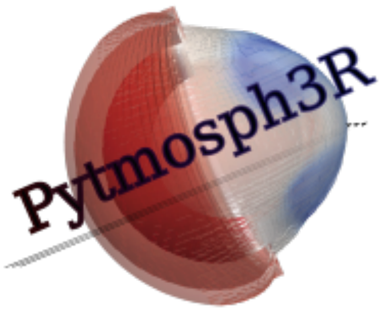


(d) 1D

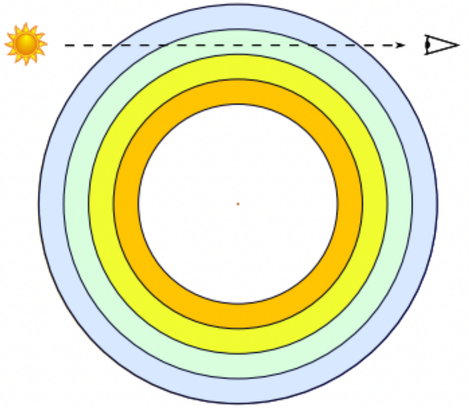


ExoRT

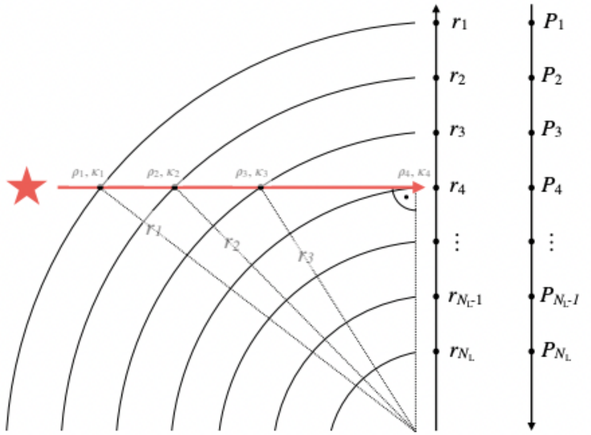
ERC-ATMO

E-R

PetitRADATRANS



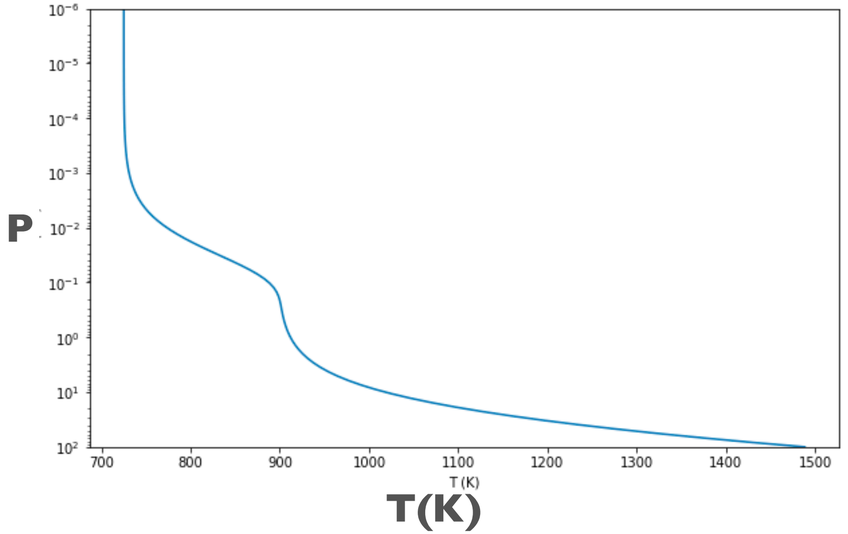
(d) 1D

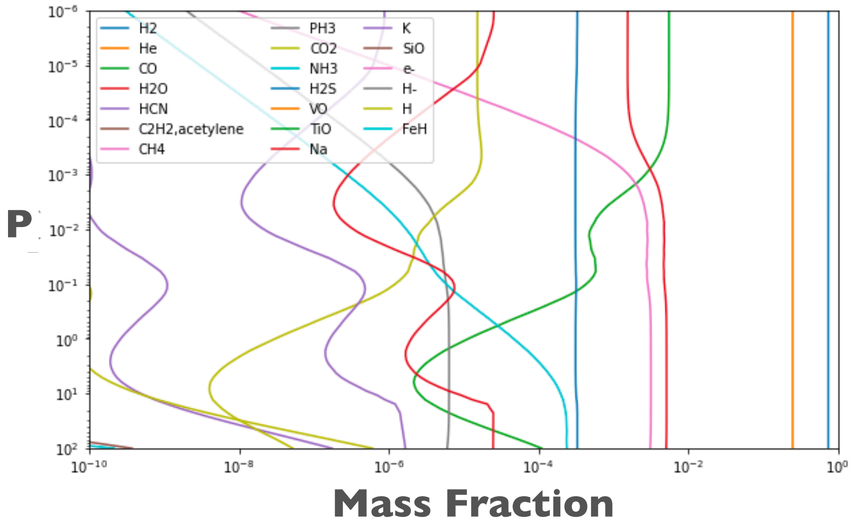


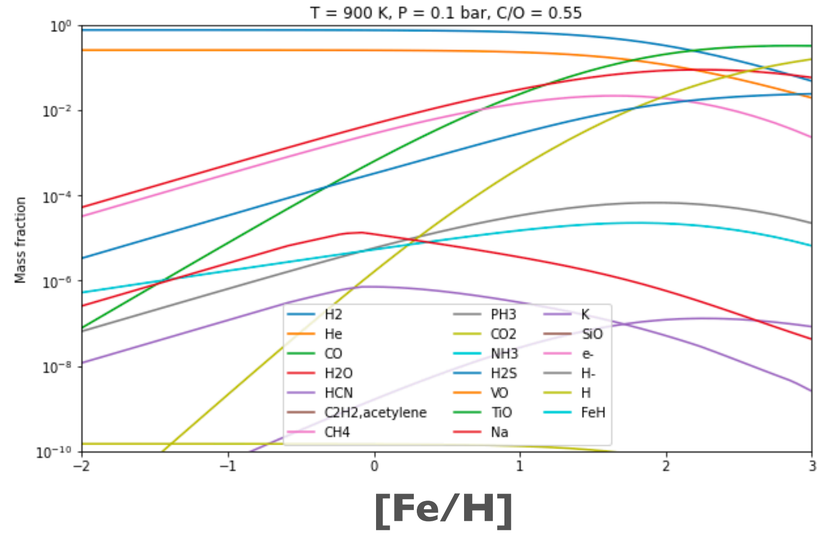
- Line Species
- Rayleigh Species
- Continuum Opacities
- Planet Gravity
- Pressure Layer
- Temperature
- Mass Fraction
- Planet Size

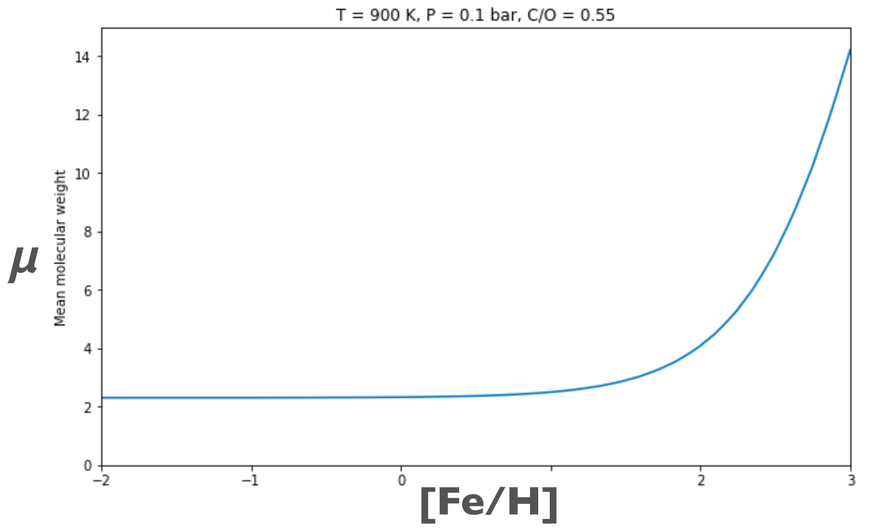
PetitRADATRANS

Interpolating chemical equilibrium abundances



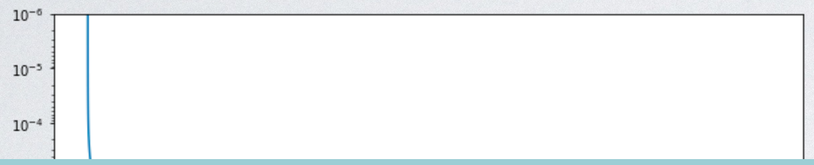


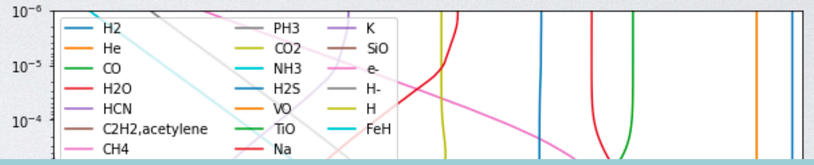




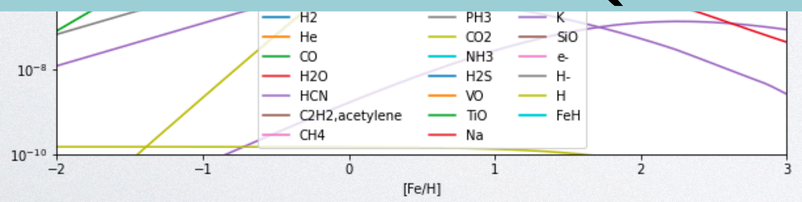
PetitRADATRANS

Interpolating chemical equilibrium abundances

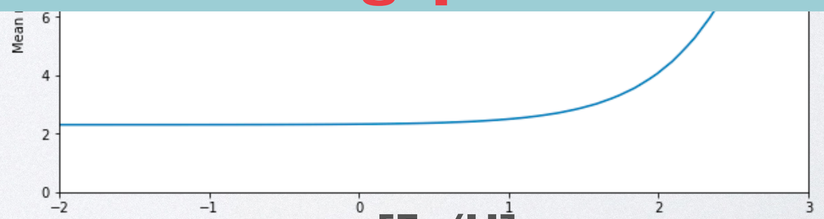




- **The chemical abundances inferred from spectra are not necessarily representative of the pressures and temperatures probed locally by the observation.**
- **In addition, the radiation field of the host star may influence the abundance and opacity structure of the atmosphere by dissociating or ionising chemical species or forming photochemical hazes. (No advection/mixing/photochemistry)**

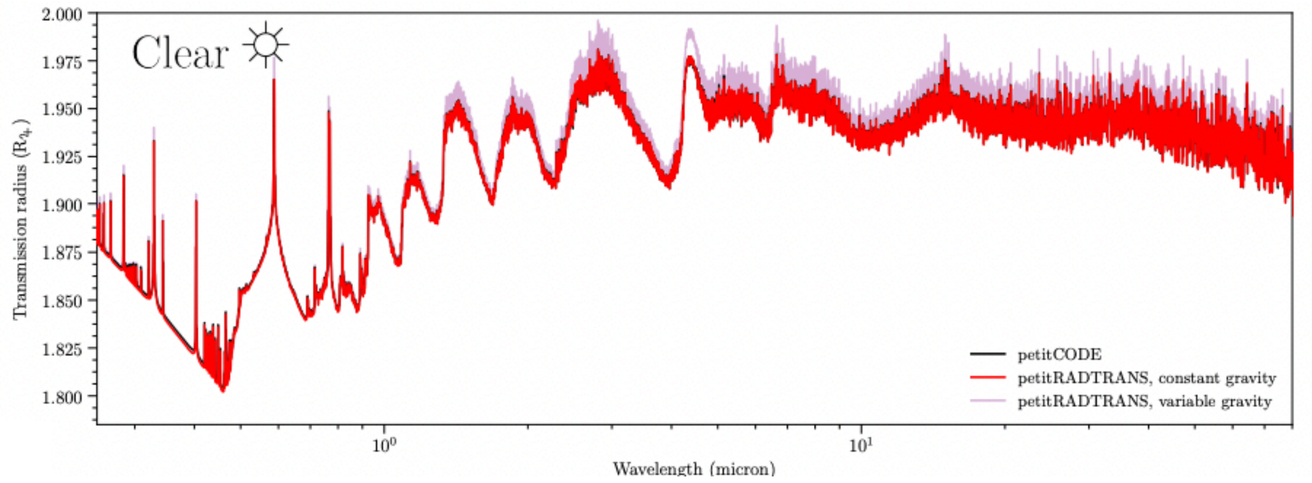


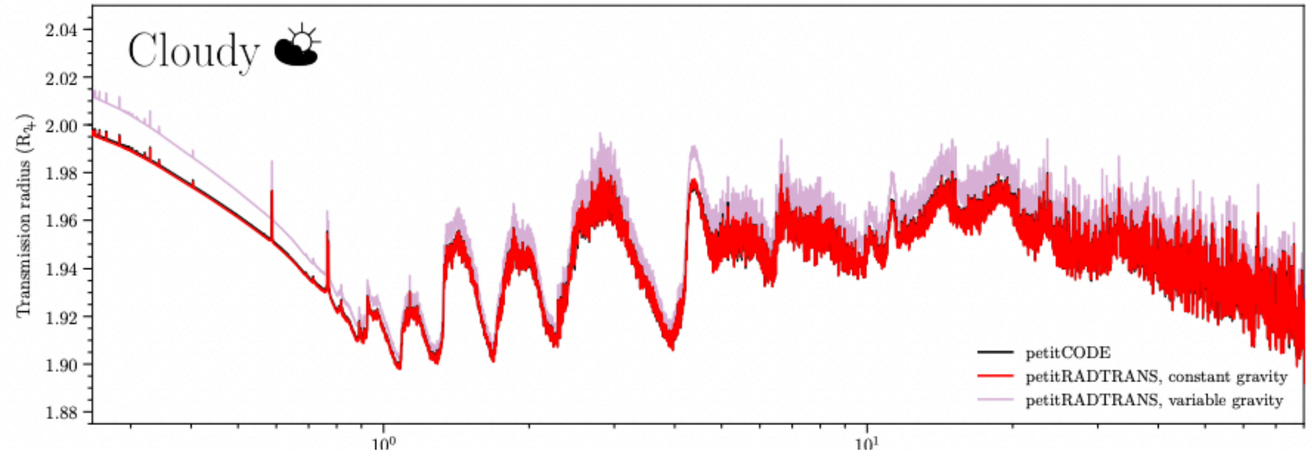
[Fe/H]



[Fe/H]

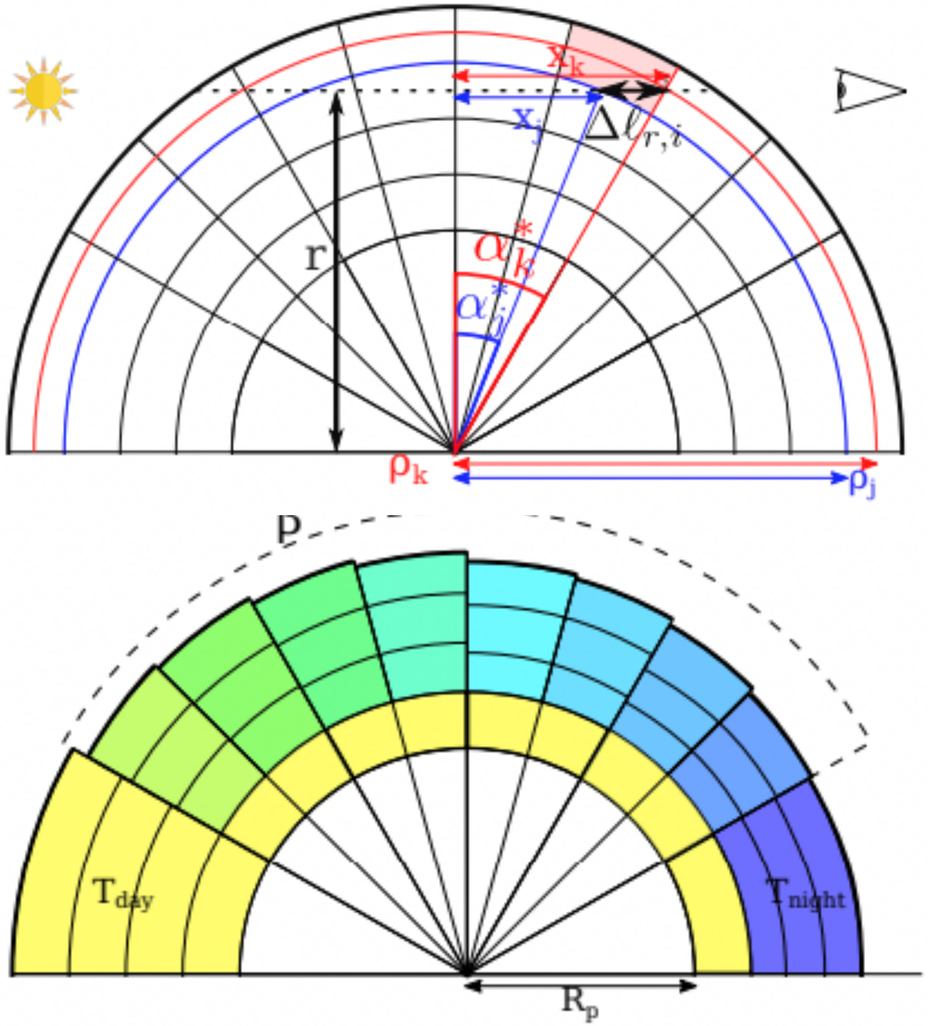
PetitRADATRANS

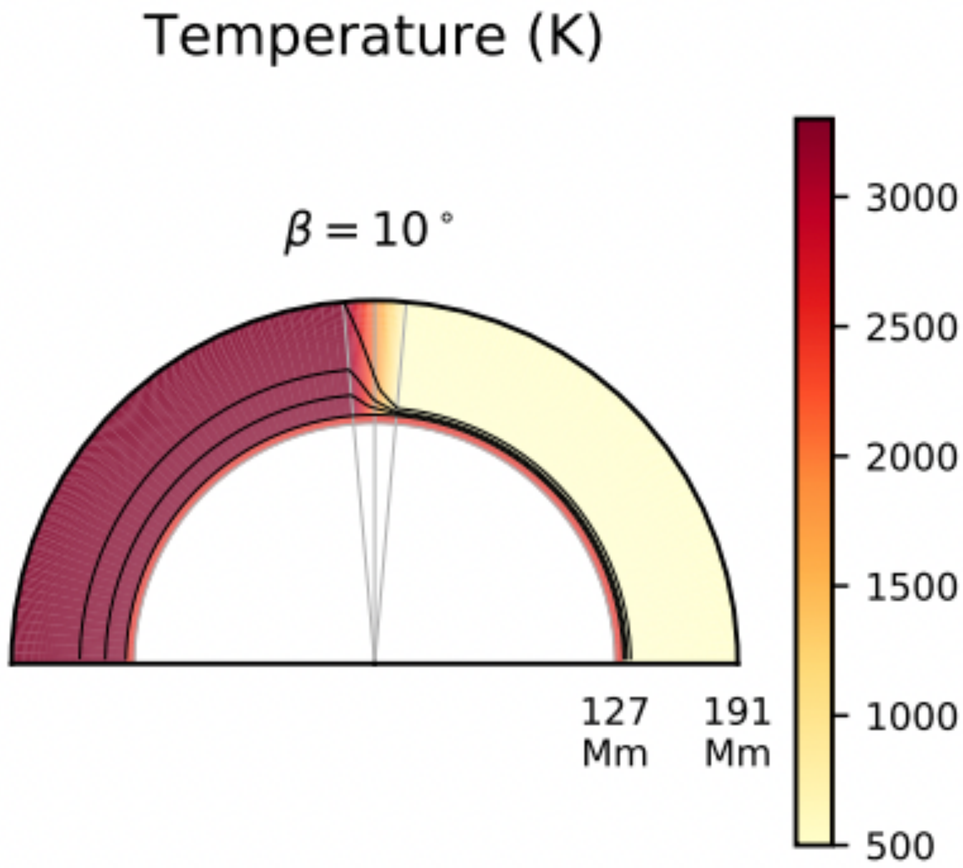




Pytmosph3R

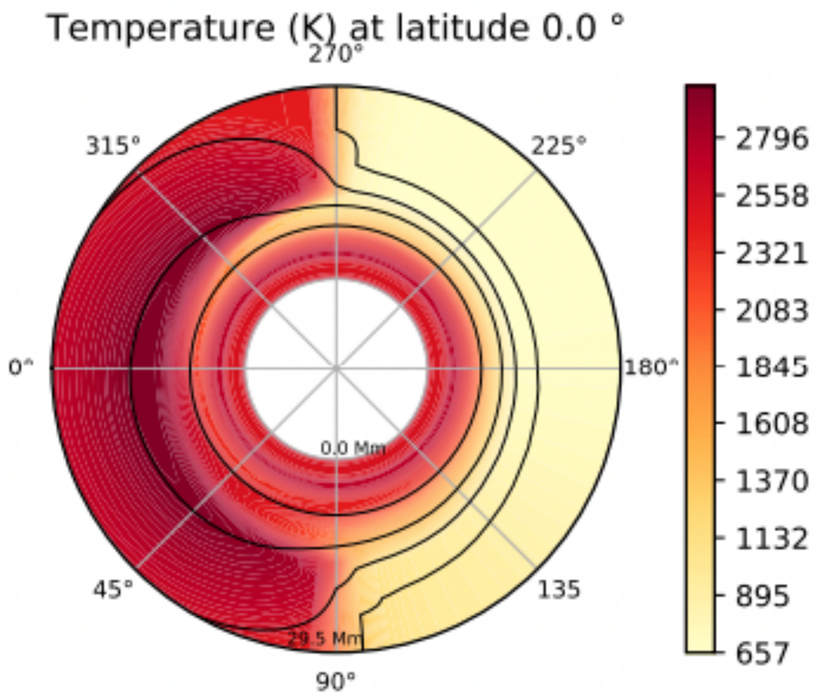
2D Modelling

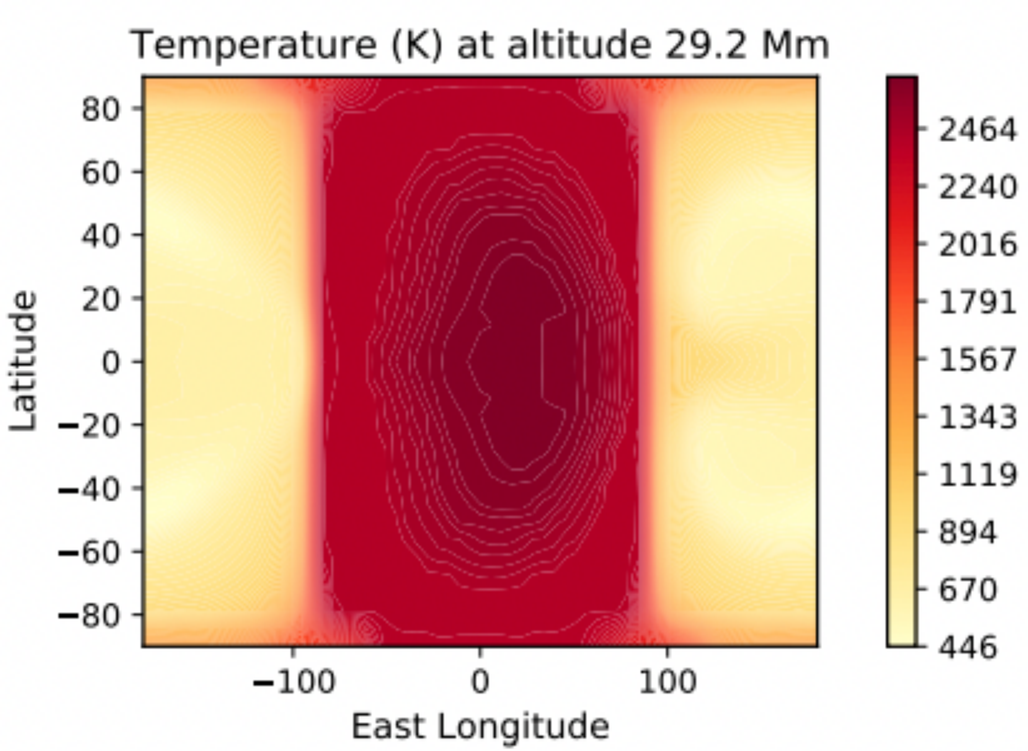


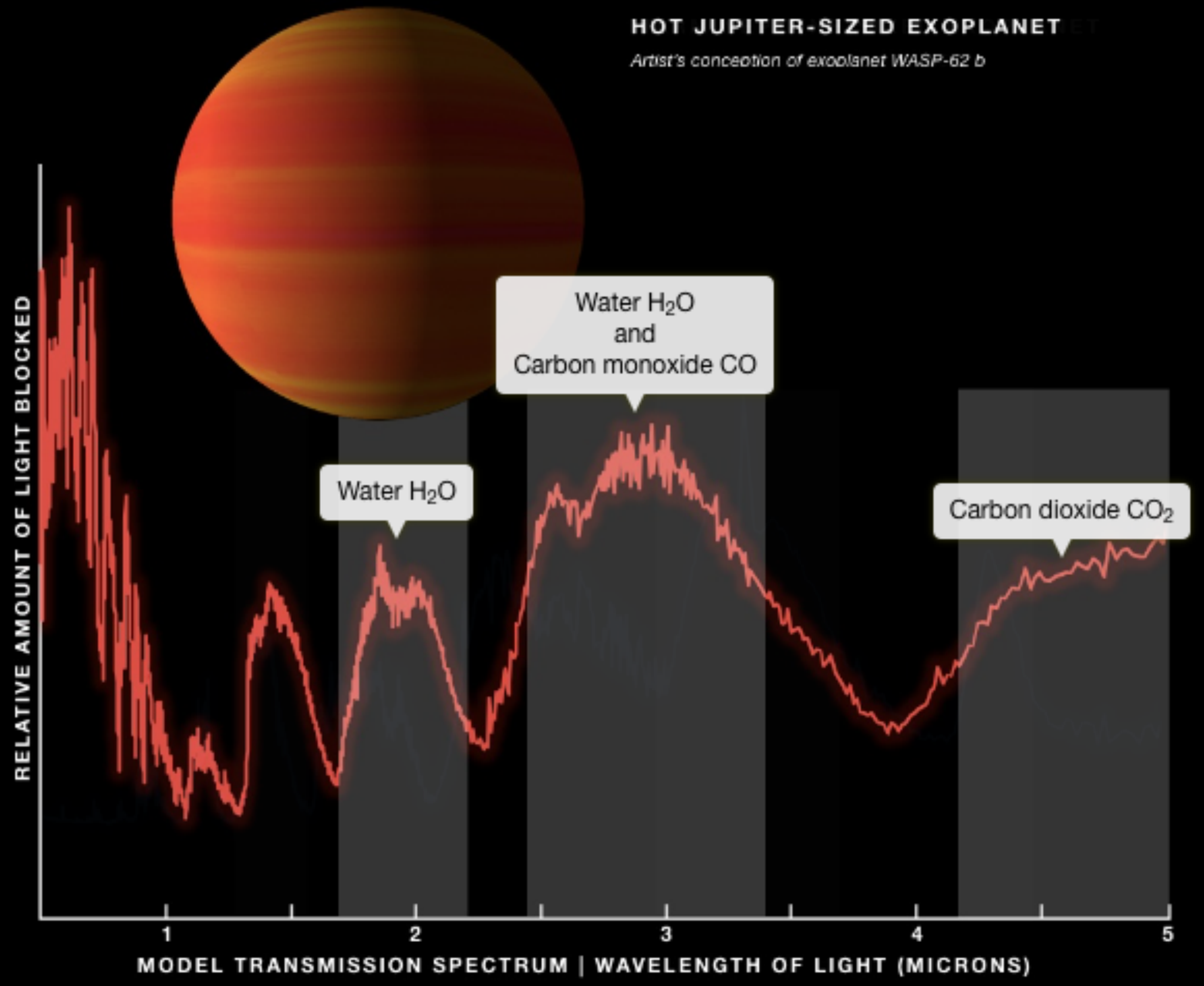


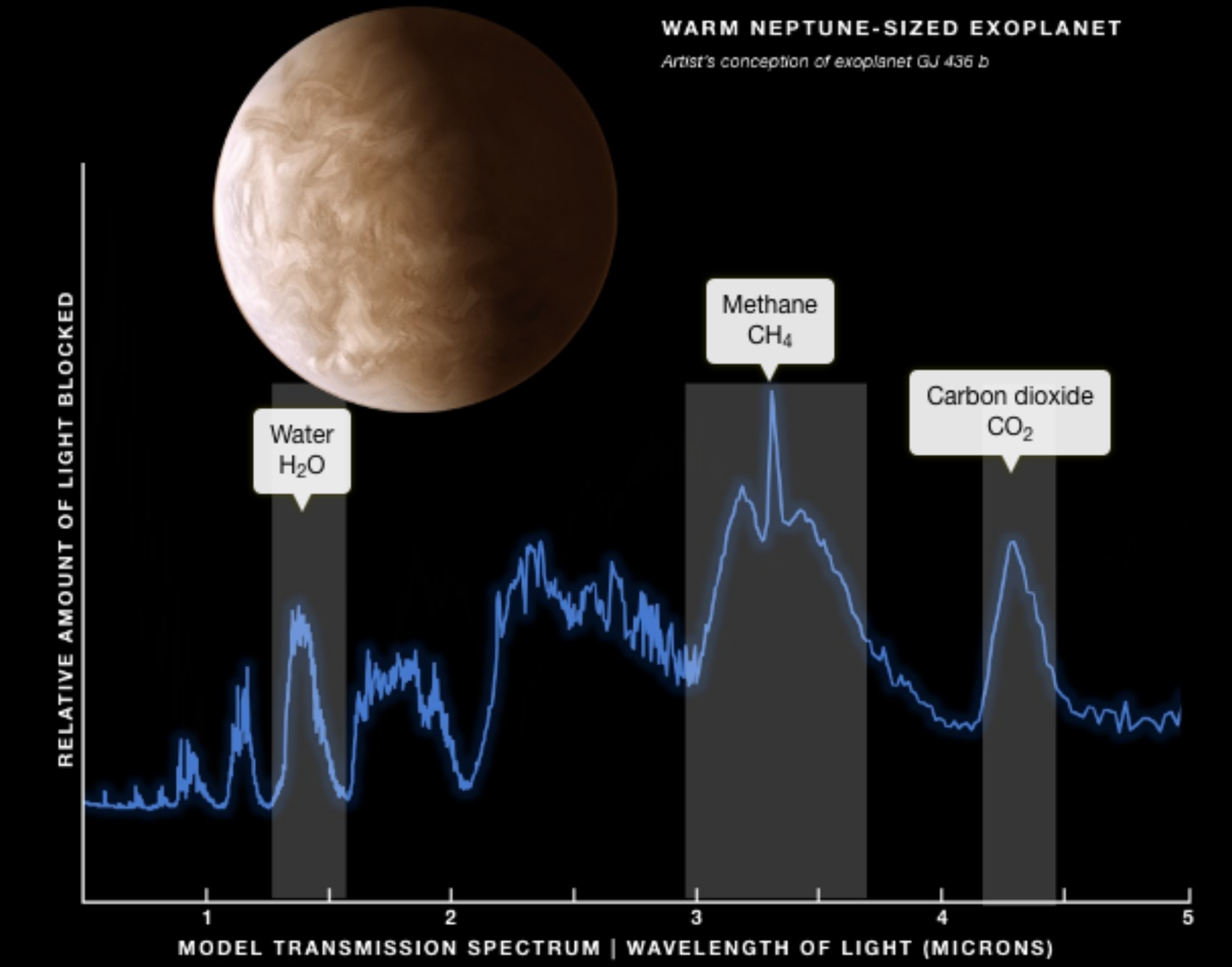
Pytmosph3R

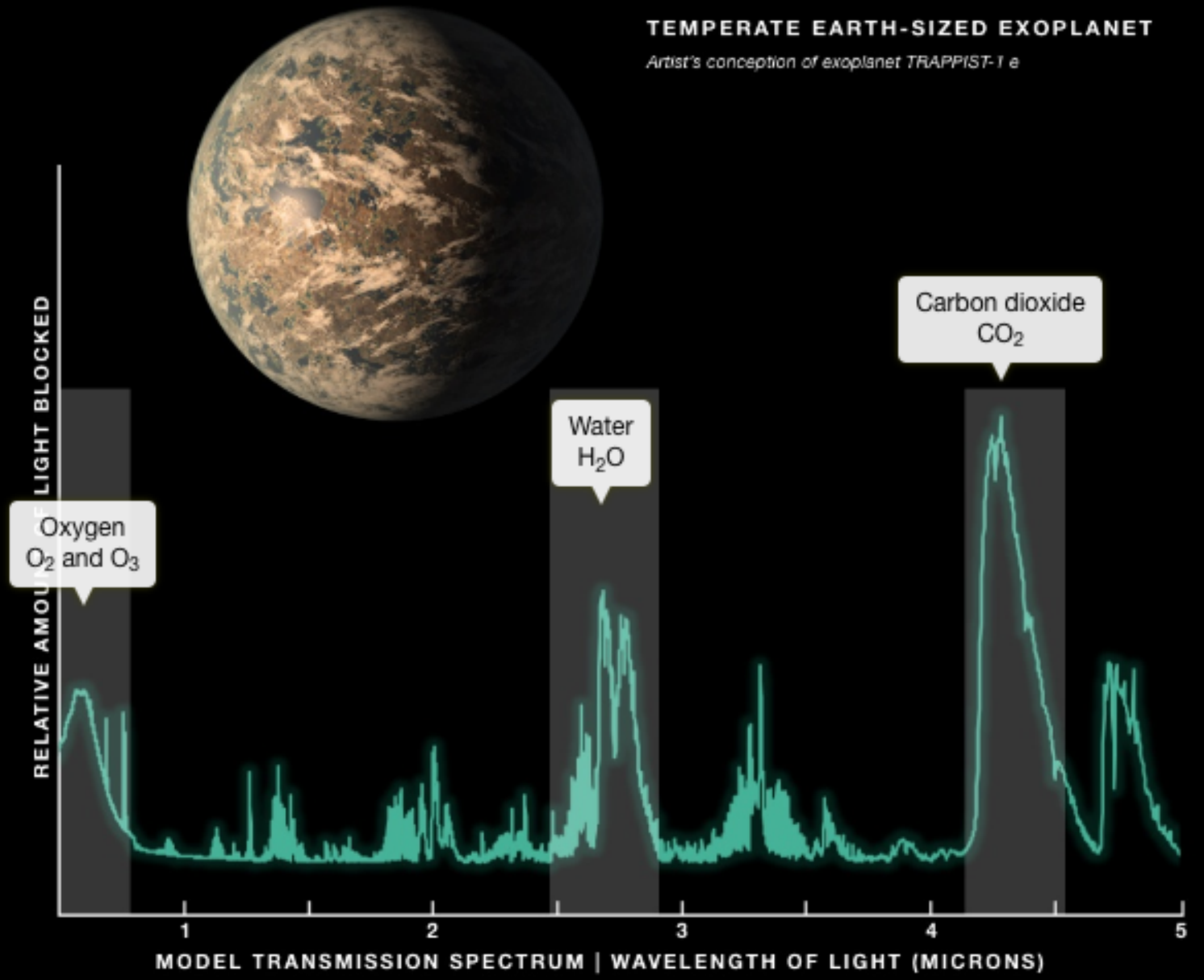
3D Modelling

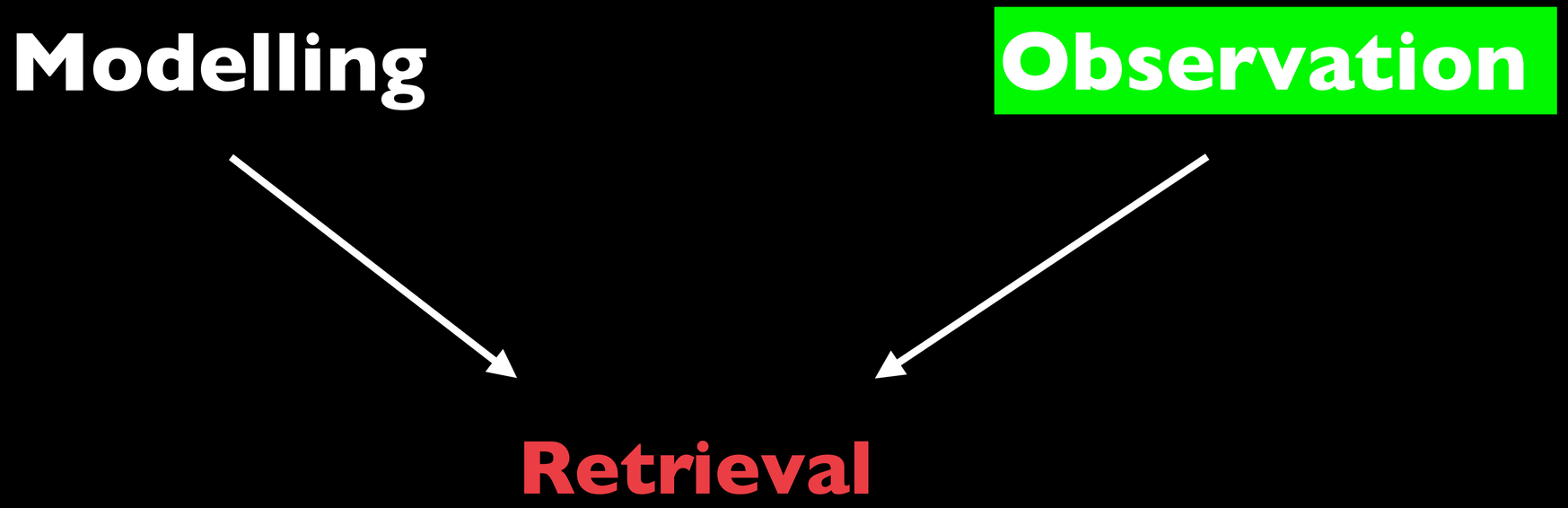





HOT JUPITER-SIZED EXOPLANET
Artist's conception of exoplanet WASP-62 b
Water H_2O and Carbon monoxide CO
Water H_2O
Carbon dioxide CO_2
RELATIVE AMOUNT OF LIGHT BLOCKED
1
2
3
4
5
MODEL TRANSMISSION SPECTRUM | WAVELENGTH OF LIGHT (MICRONS)


WARM NEPTUNE-SIZED EXOPLANET
Artist's conception of exoplanet GJ 436 b
Water
H_2O
Methane
CH_4
Carbon dioxide
CO_2
RELATIVE AMOUNT OF LIGHT BLOCKED
1
2
3
4
5
MODEL TRANSMISSION SPECTRUM | WAVELENGTH OF LIGHT (MICRONS)

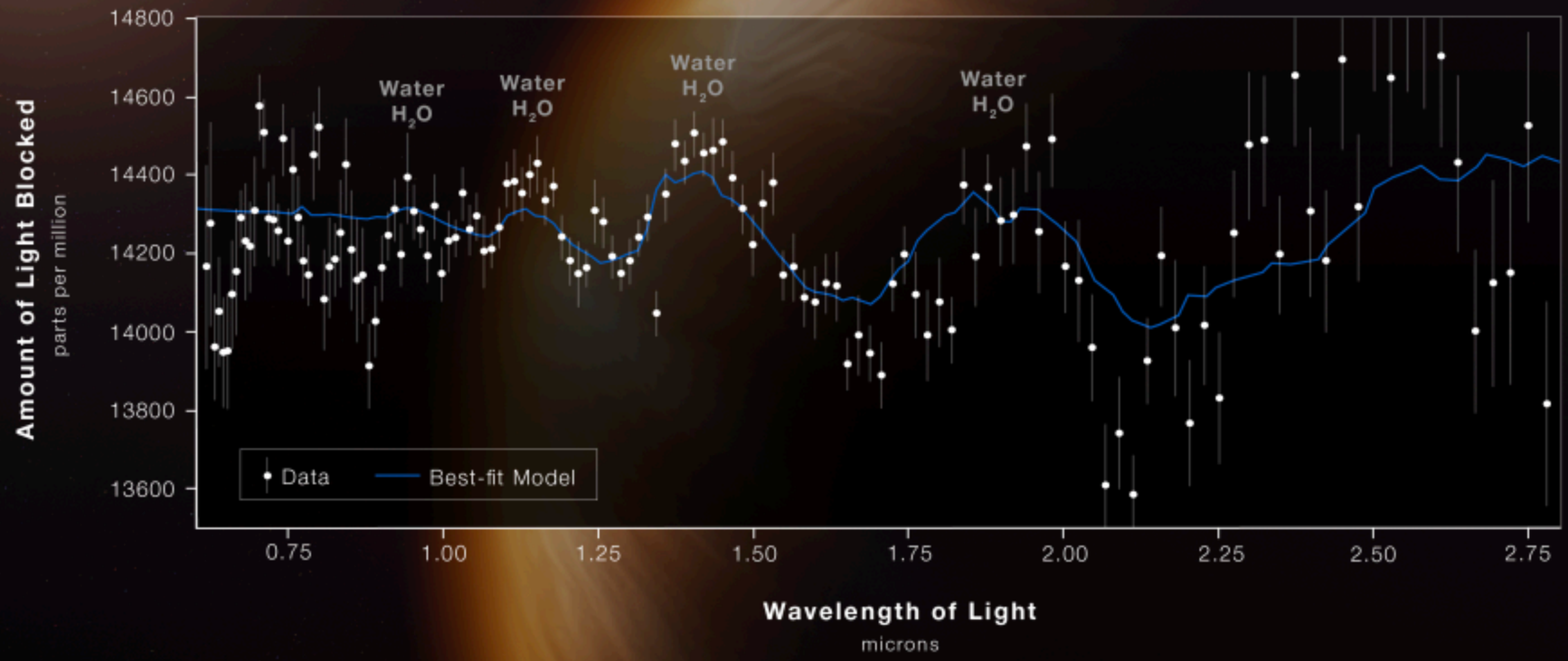

TEMPERATE EARTH-SIZED EXOPLANET
Artist's conception of exoplanet TRAPPIST-1 e
RELATIVE AMOUNT OF LIGHT BLOCKED
Oxygen
O_2 and O_3
Water
H_2O
Carbon dioxide
CO_2
1
2
3
4
5
MODEL TRANSMISSION SPECTRUM | WAVELENGTH OF LIGHT (MICRONS)


Modelling
Observation
Retrieval

HOT GAS GIANT EXOPLANET WASP-96 b

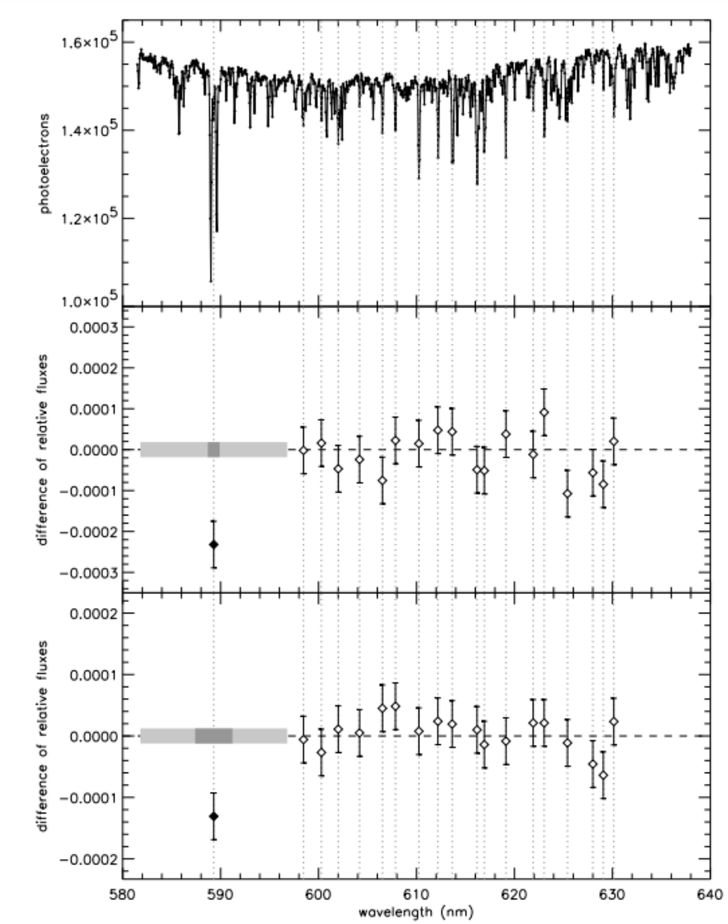
ATMOSPHERE COMPOSITION

NIRISS | Single-Object Slitless Spectroscopy



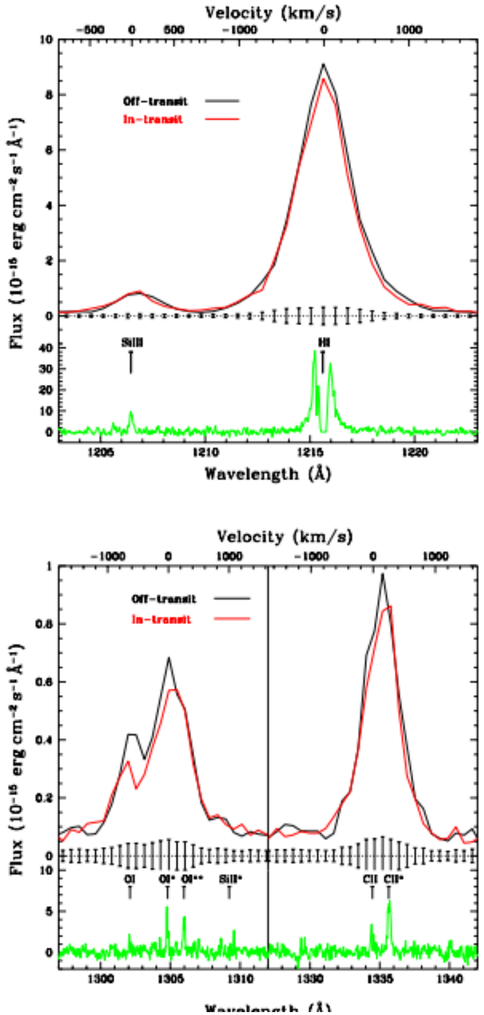
WEBB
SPACE TELESCOPE

Transmission Spectroscopy



Fist detection of Na

Charbonneau et al. (2002)

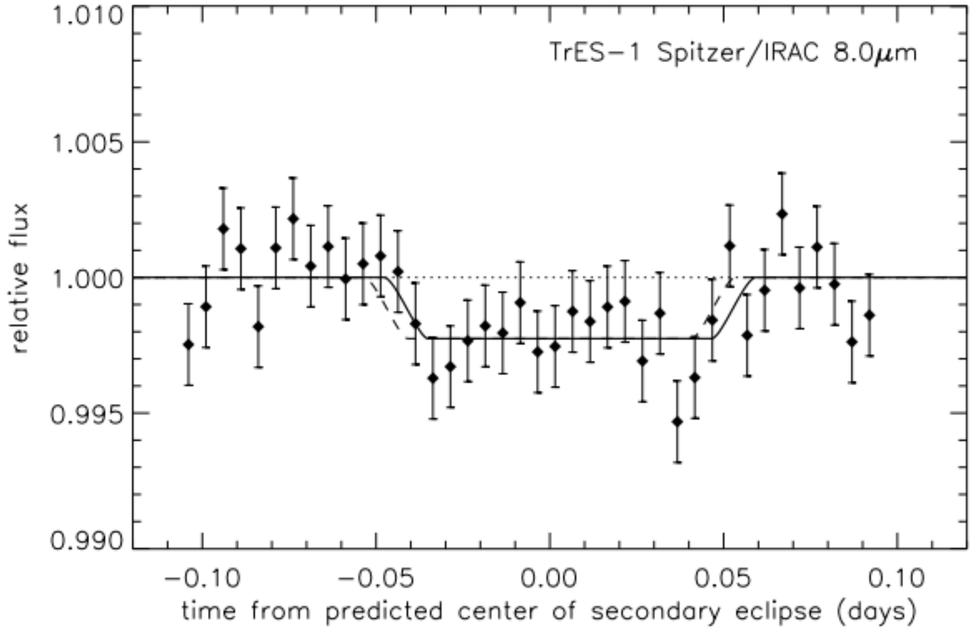


Fist detection C an H

Brown et al. (2002)

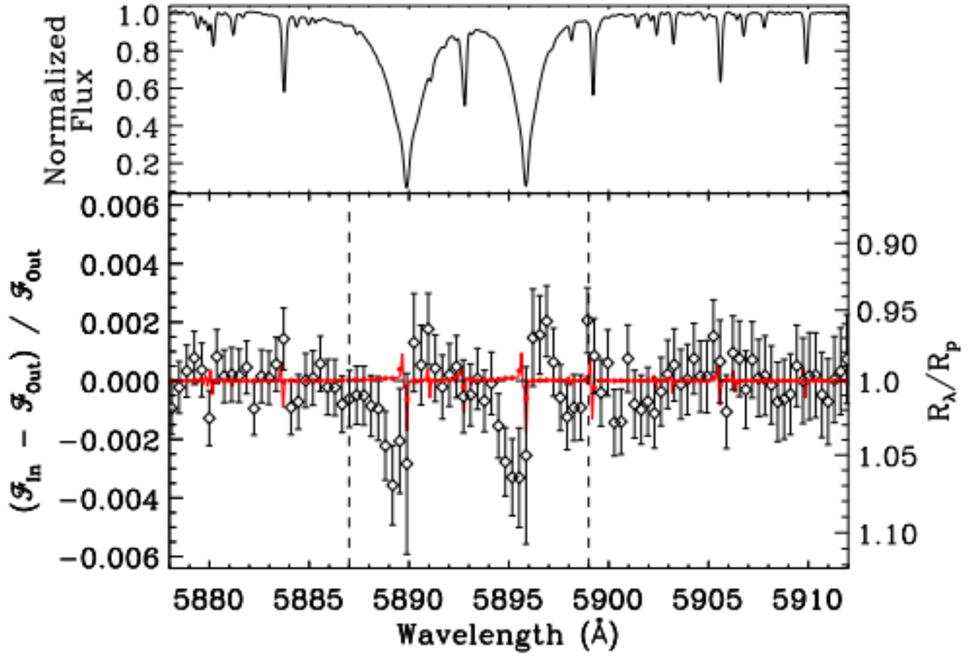
Transmission Spectroscopy

First Thermal Emission



Charbonneau et al. (2005)

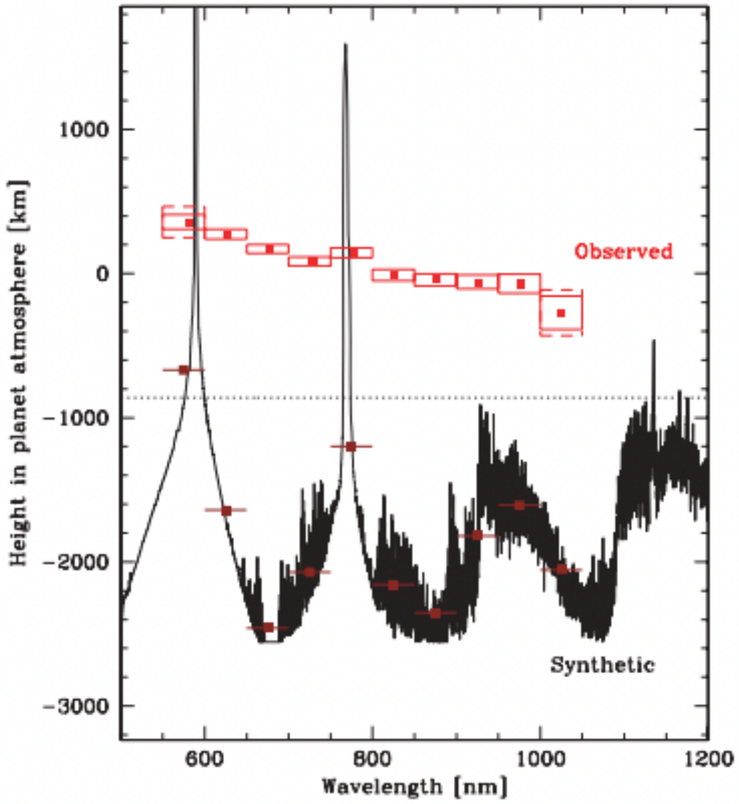
Fist Ground detection of Na



Seth Redfield et al. (2007)

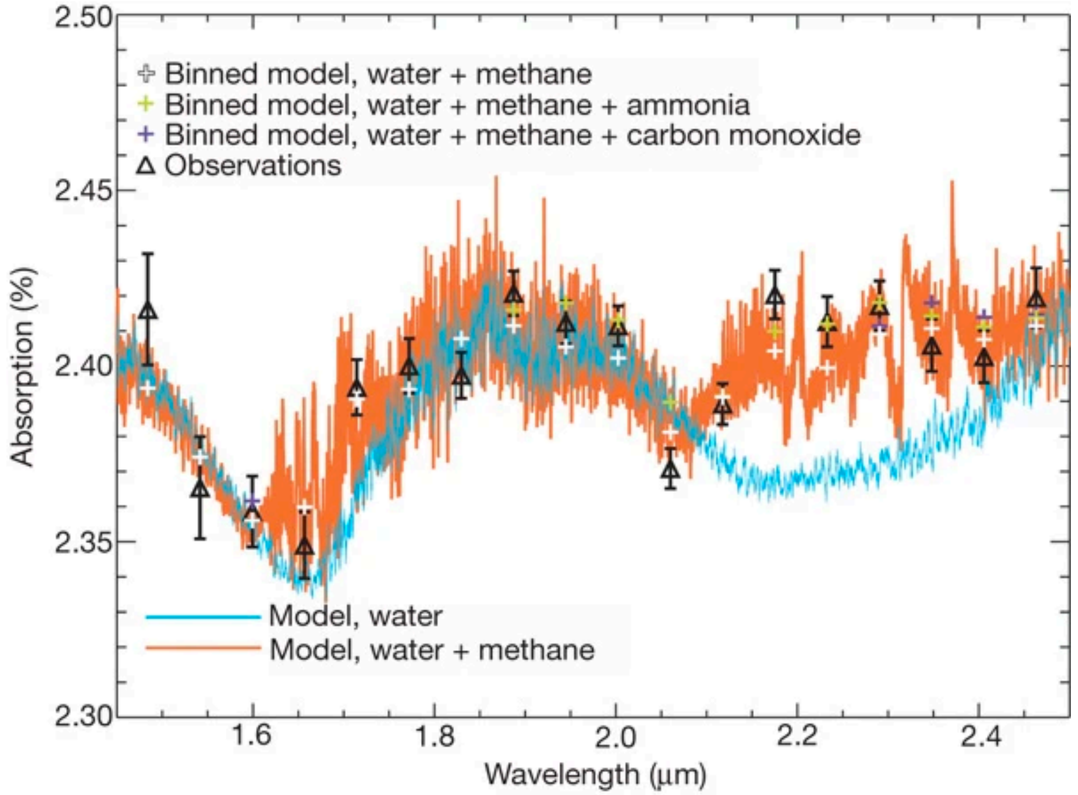
Transmission Spectroscopy

Atmospheric Haze



F. Pont et al. (2007)

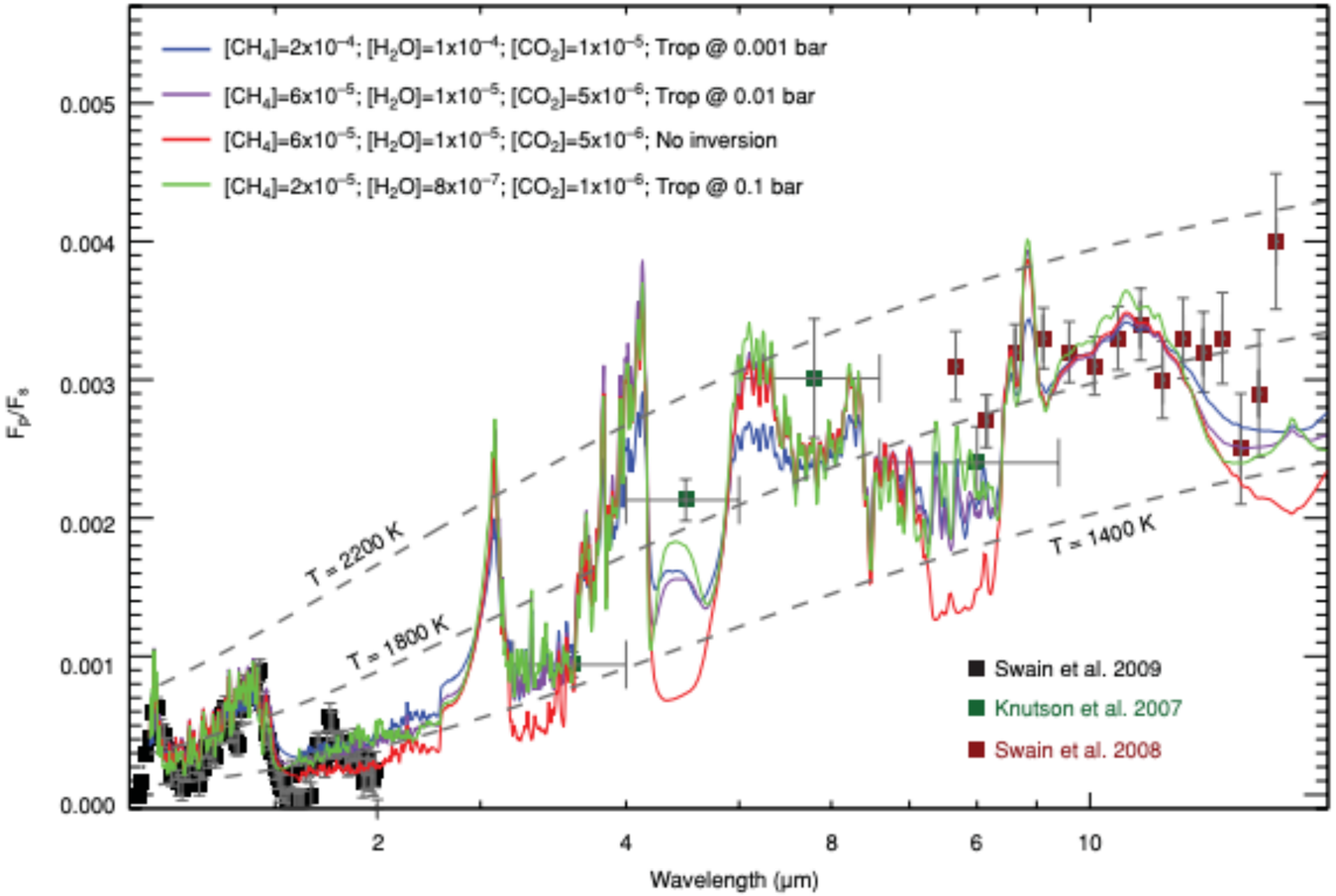
The presence of methane



F. Pont et al. (2008)

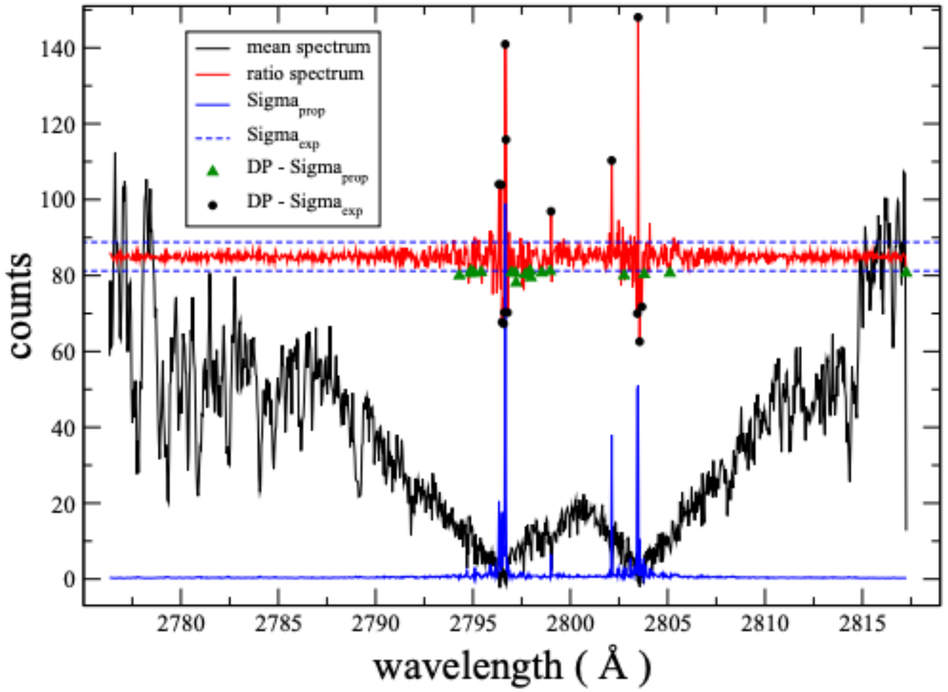
Transmission Spectroscopy

H2O, CH4, CO2



M. R. Swain (2009)

Metals in the exosphere

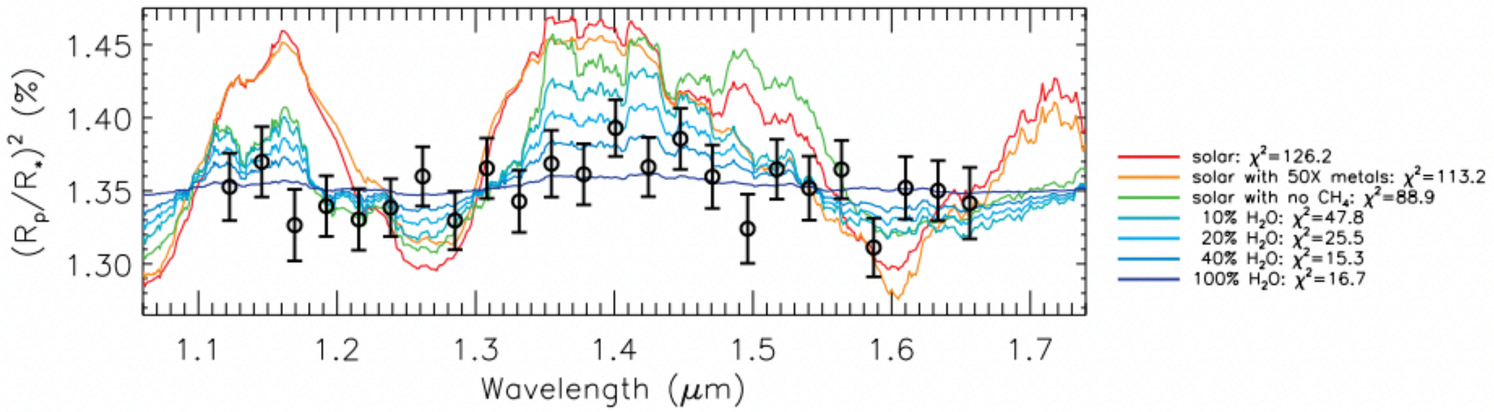


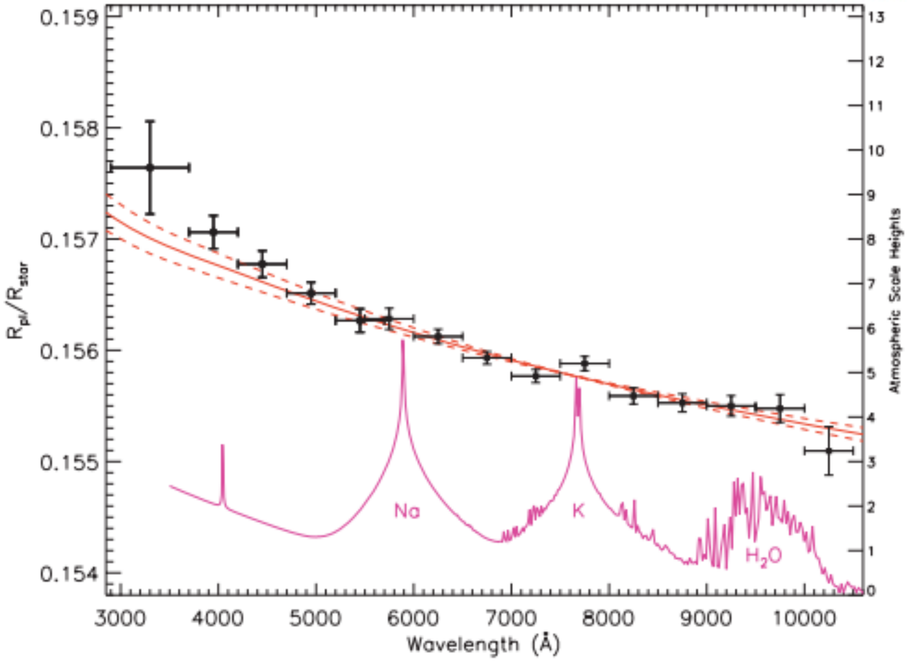
L. Fossati and C.A. Haswell (2010)

Transmission Spectroscopy

FLAT TRANSMISSION SPECTRUM

Berta et al (2012)

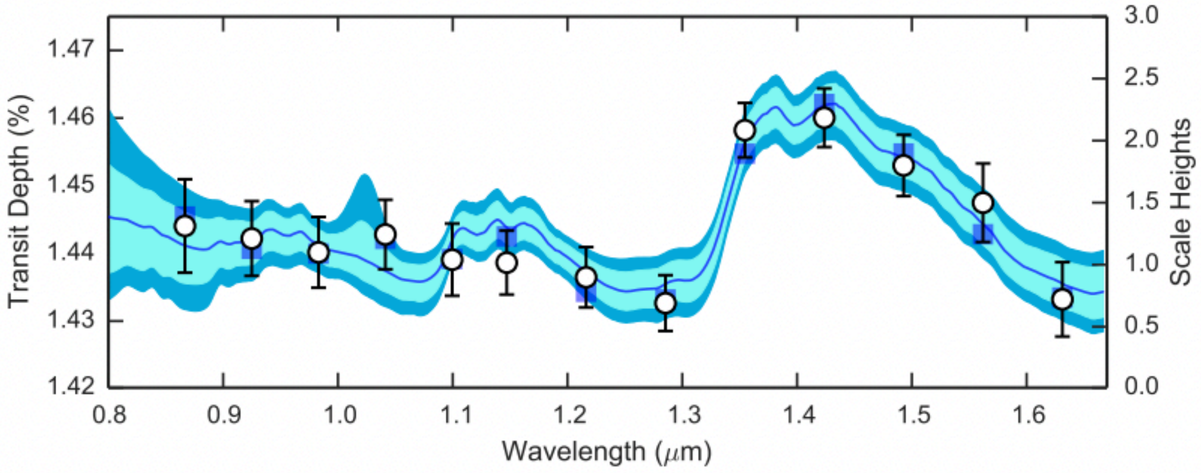




D. K. Sing, F. Pont, et al. (2011)

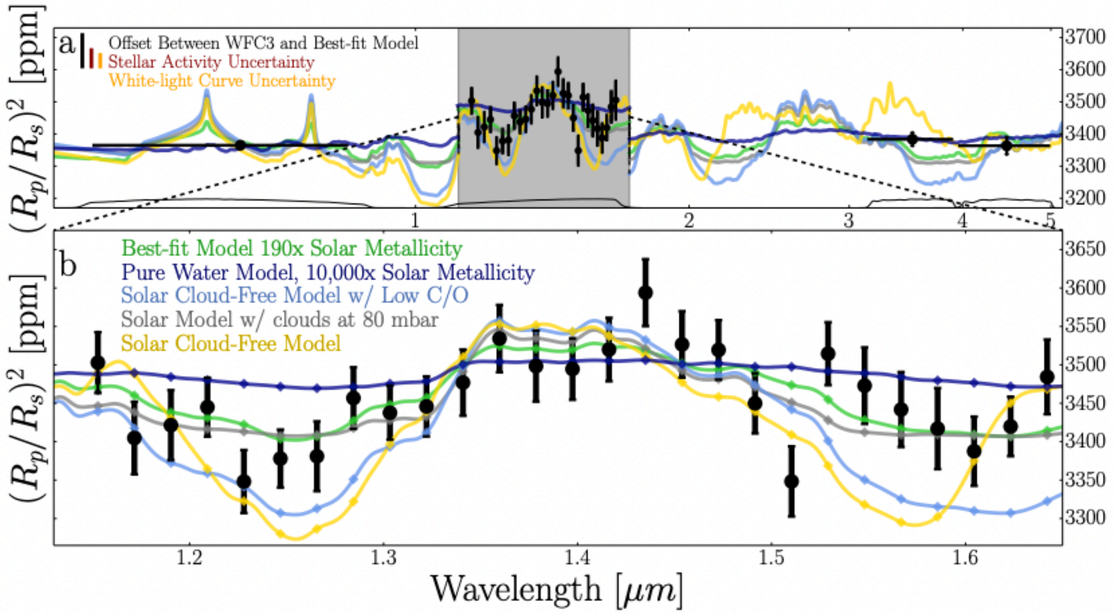
Transmission Spectroscopy

Clear Detection of Water



Kreidberg et al. (2014)

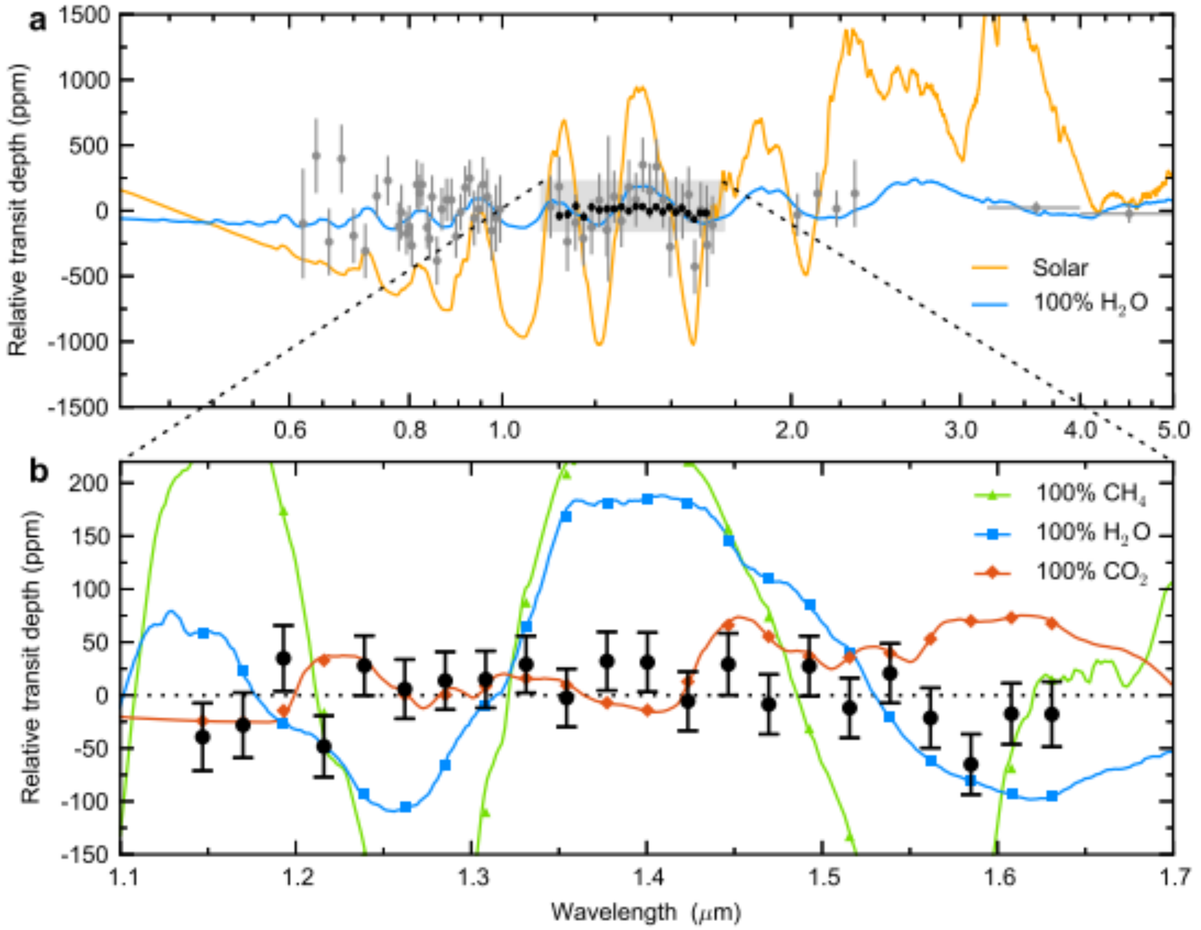
Water in Exo-Neptune



Jonathan Fraine et al. (2014)

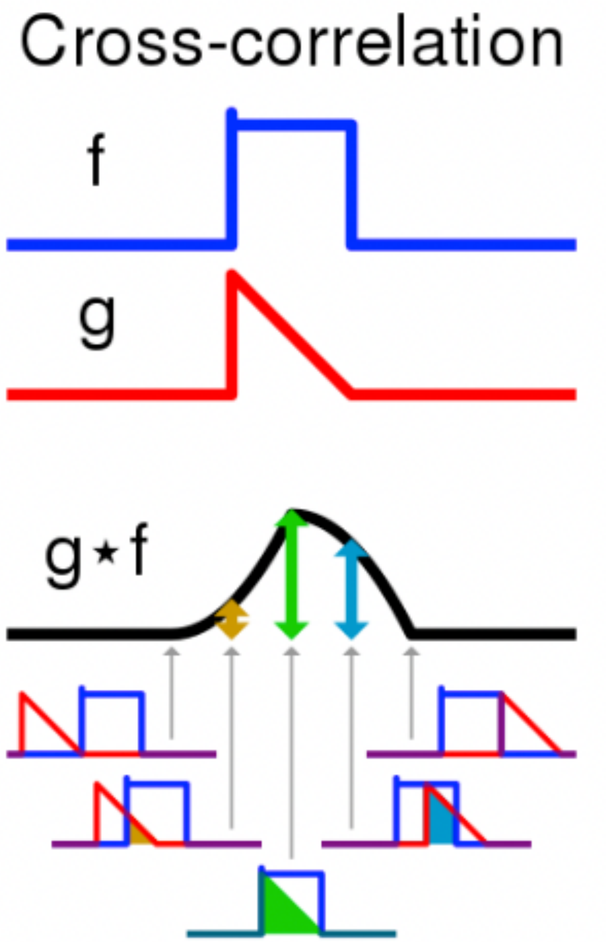
Transmission Spectroscopy

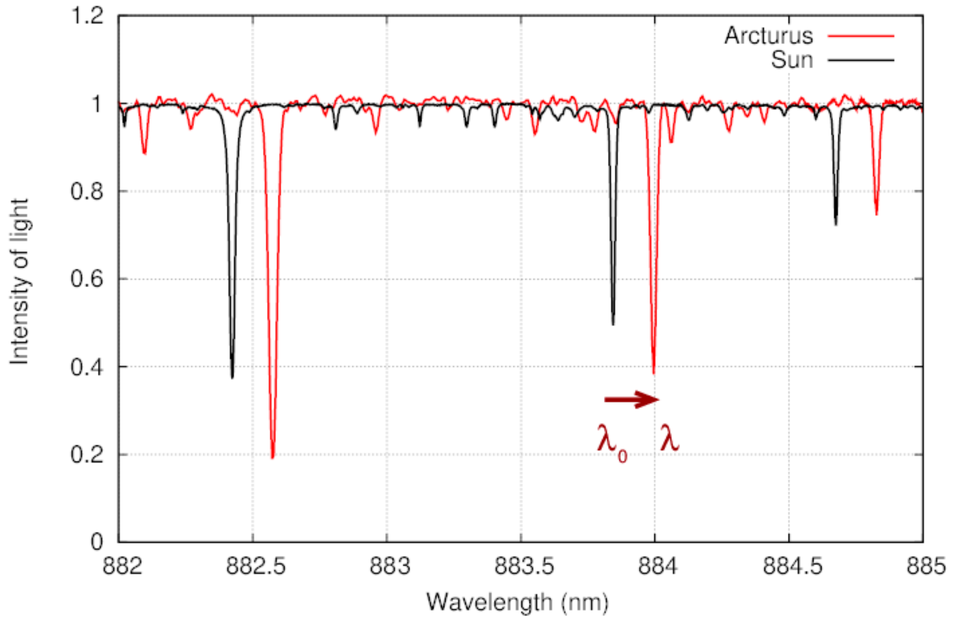
Clouds in the atmosphere of the super-Earth exoplanet GJ 1214b



Kreidberg et al. (2013)

Cross-Correlation Function

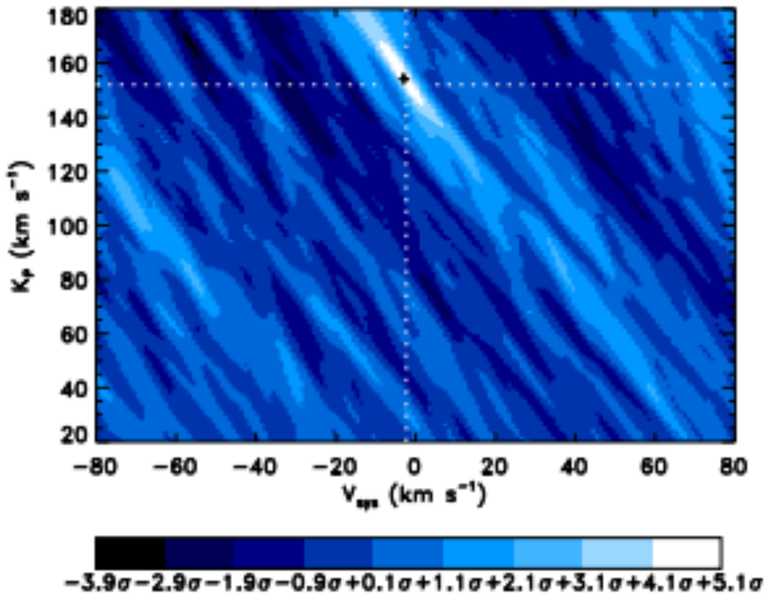




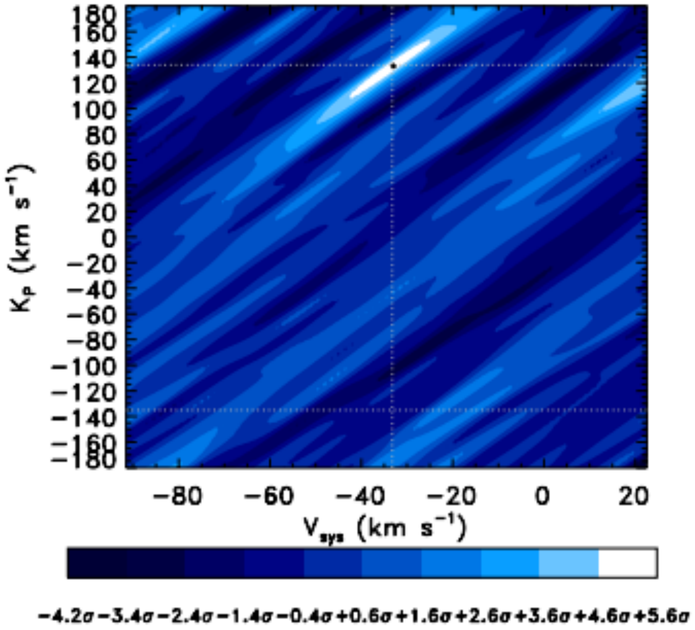
$$\mathrm{CCF}(\lambda, t) = \frac{\sum_i m_i(\lambda) w_i(\lambda, t) R_i(\lambda, t)}{\sum_i m_i(\lambda) w_i(\lambda, t)}$$

Cross-Correlation Function

Detection of water absorption

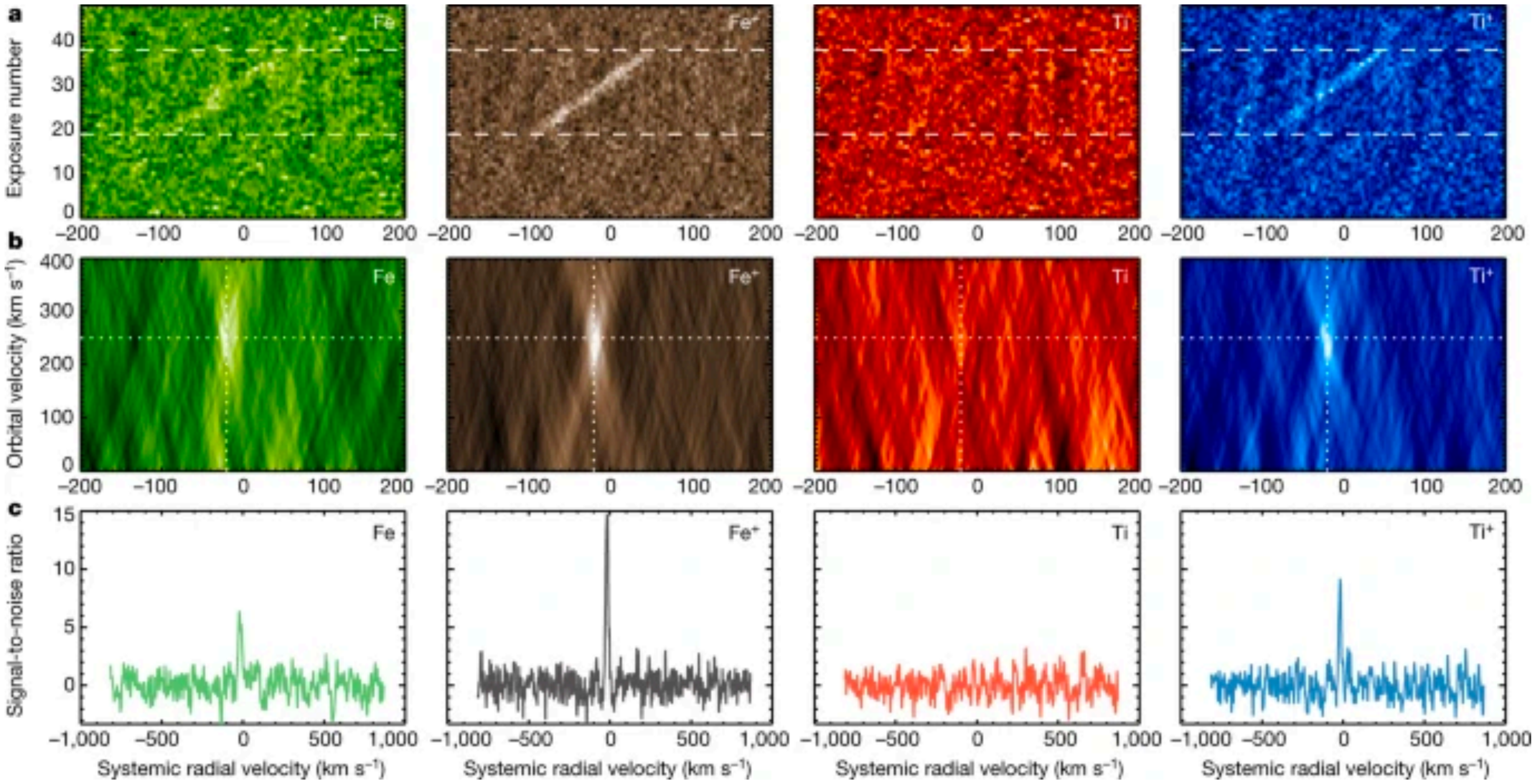


J. L. Birkby et al. (2013)



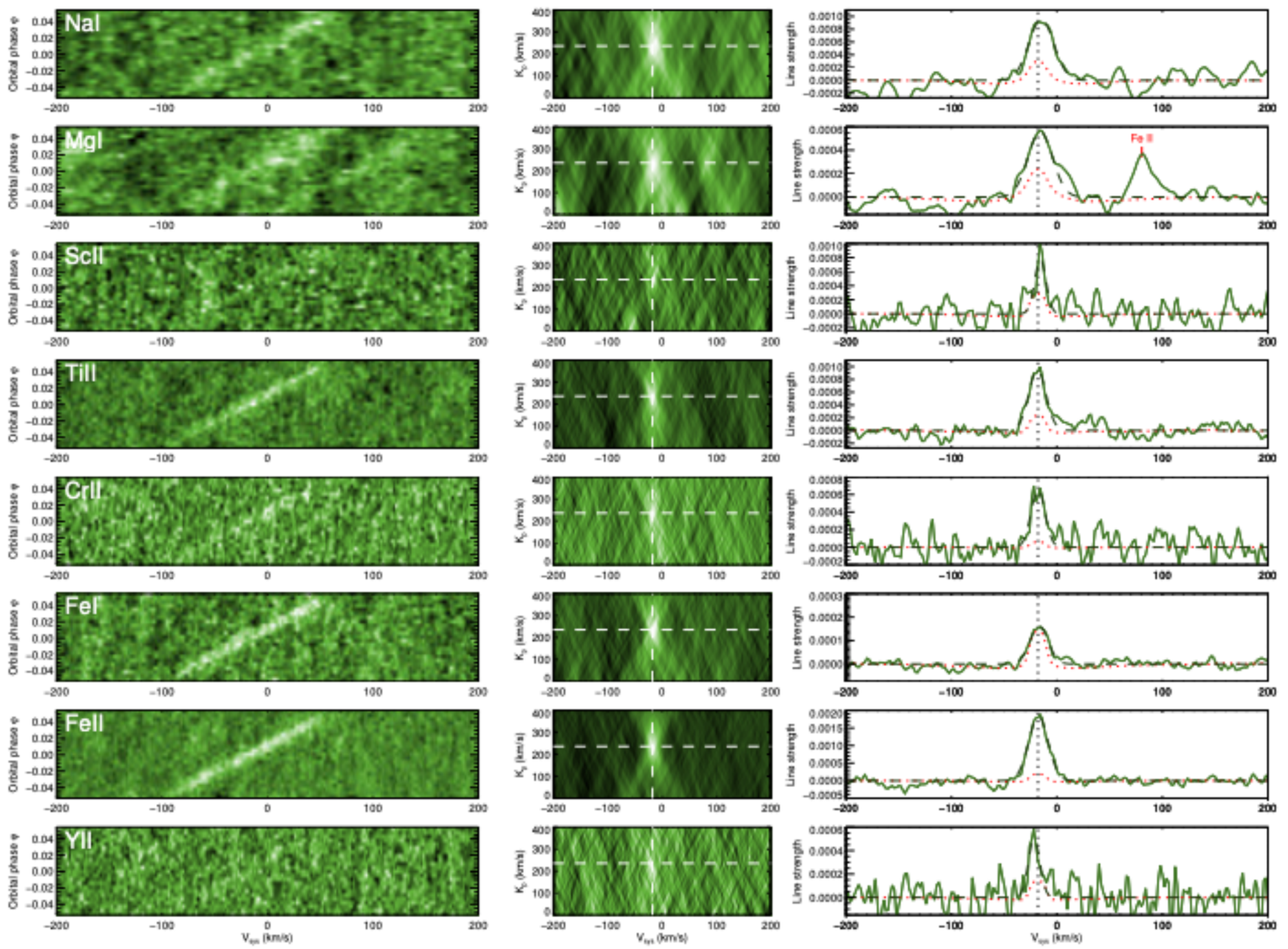
J. L. Birkby et al. (2017)

Cross-Correlation Function



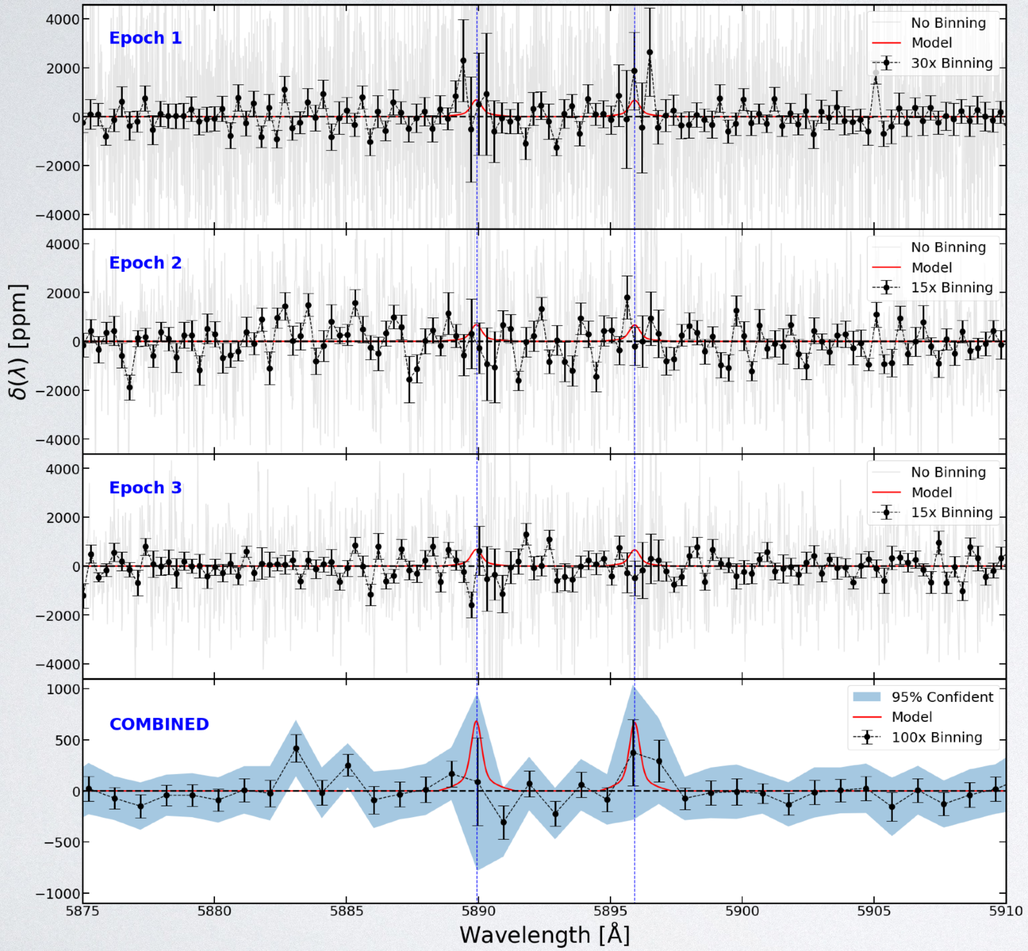
H. Jens Hoeijmakers, et al. (2018)

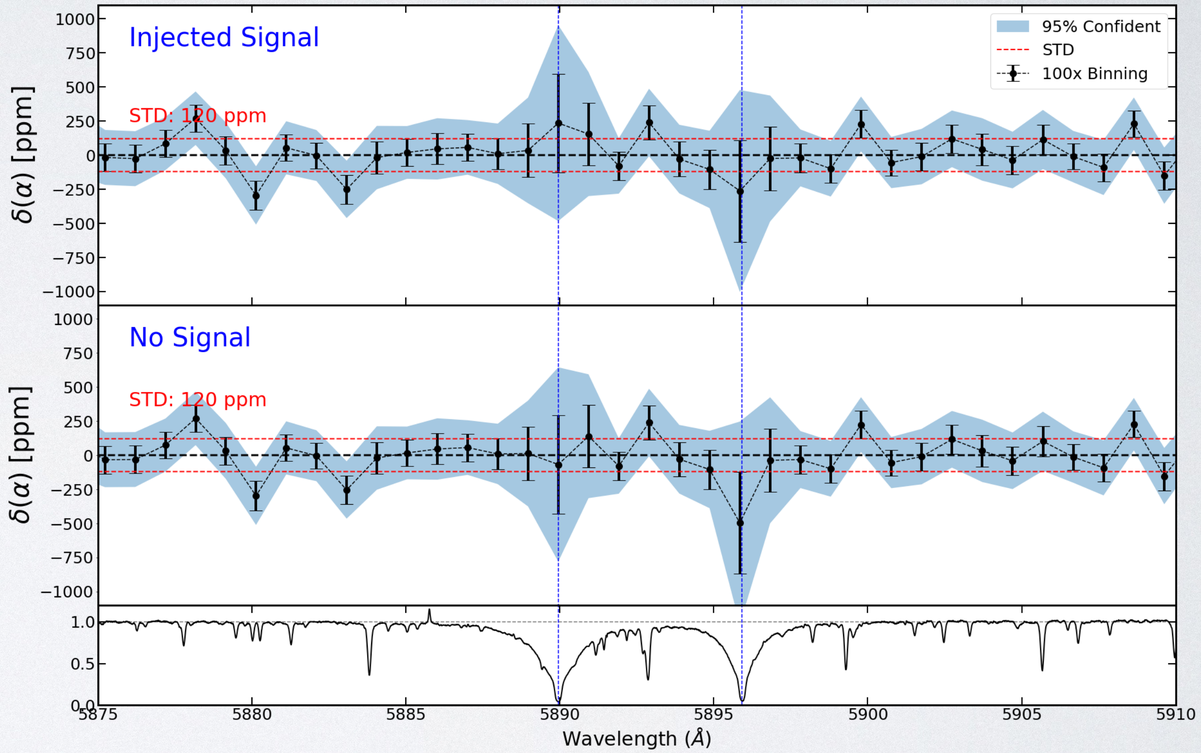
Cross-Correlation Function



H. Jens Hoeijmakers, et al. (2019)

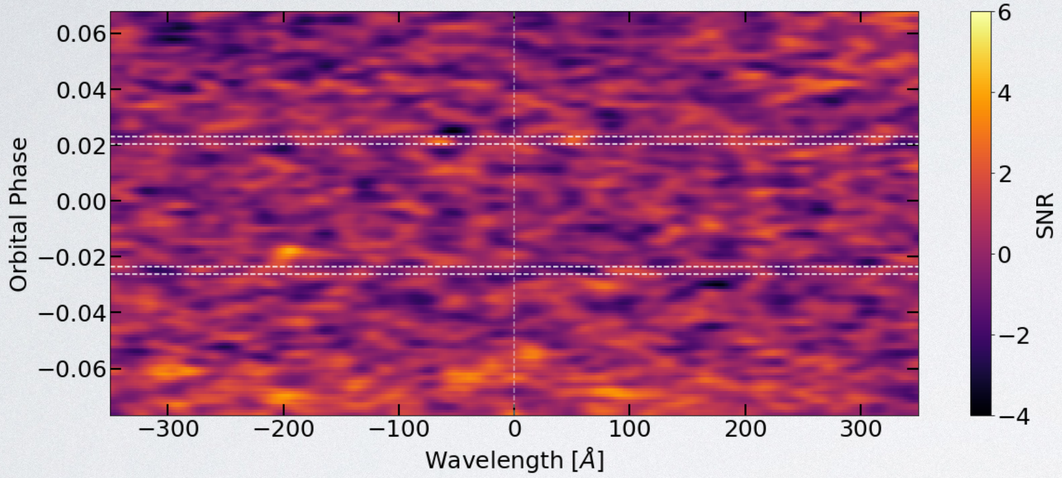
Transmission Spectroscopy
LTT 9779b

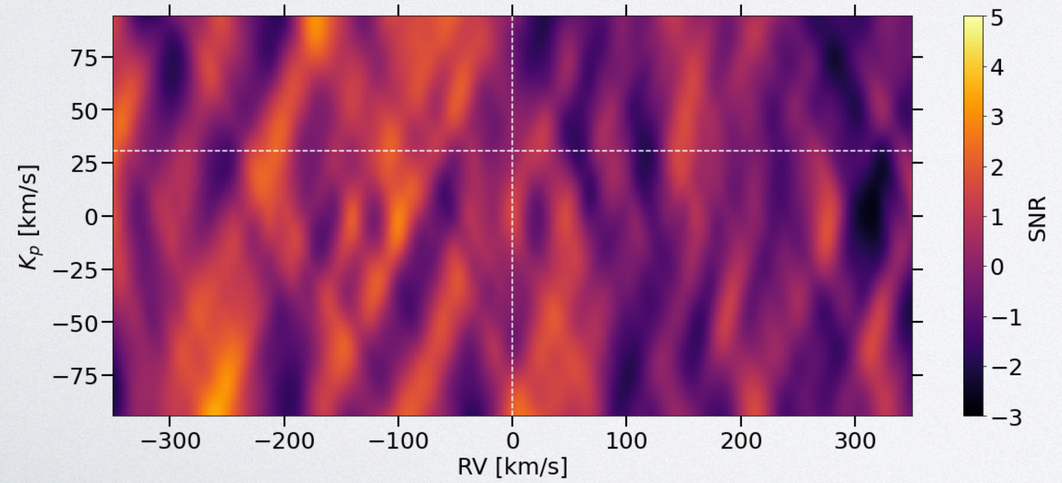




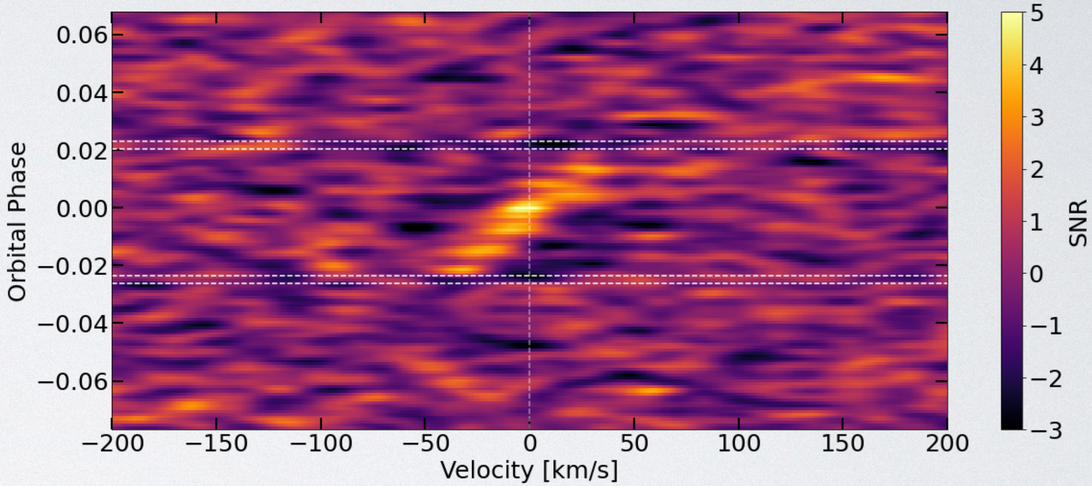
Transmission Spectroscopy
LTT 9779b

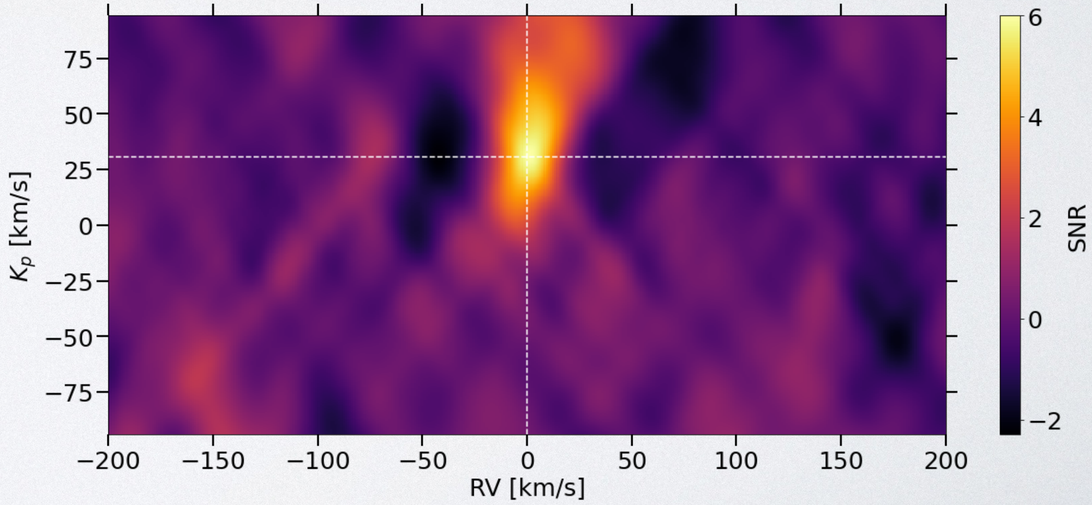
Data





Model

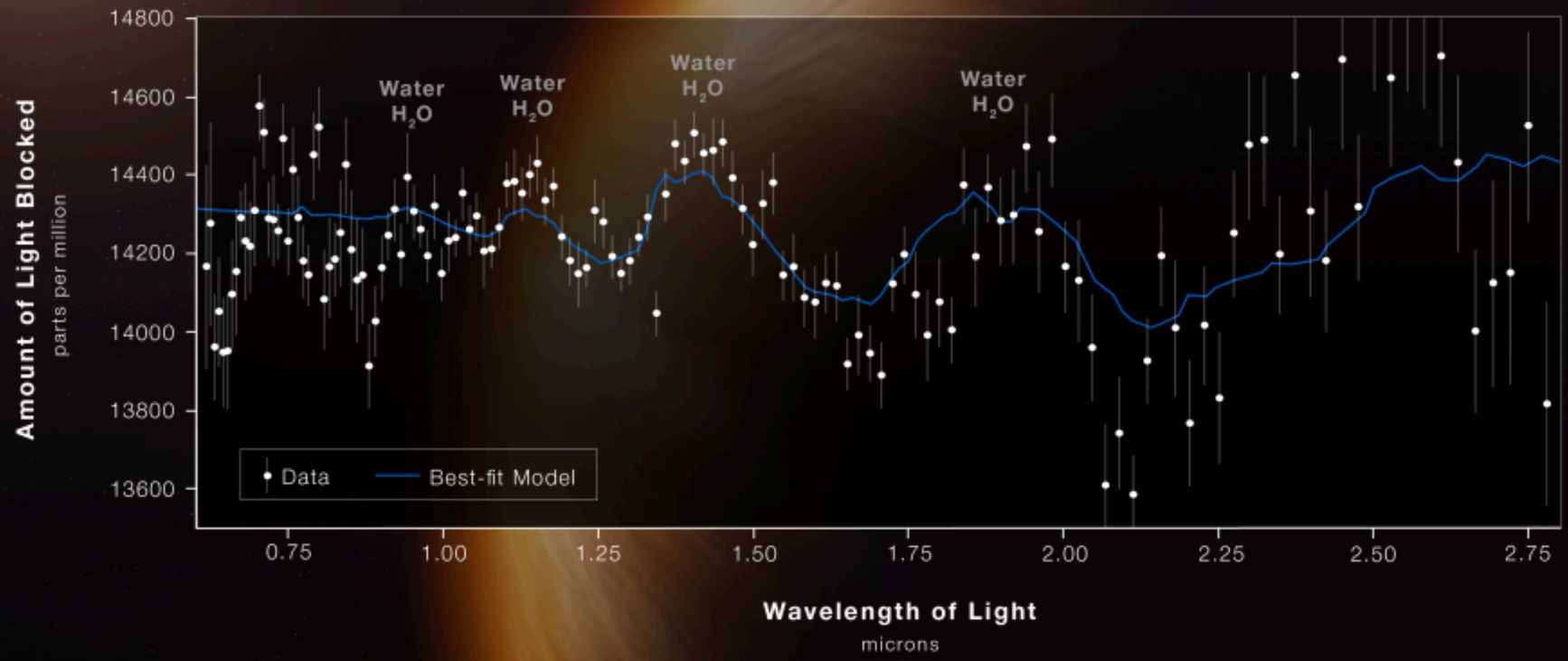




HOT GAS GIANT EXOPLANET WASP-96 b

ATMOSPHERE COMPOSITION

NIRISS | Single-Object Slitless Spectroscopy

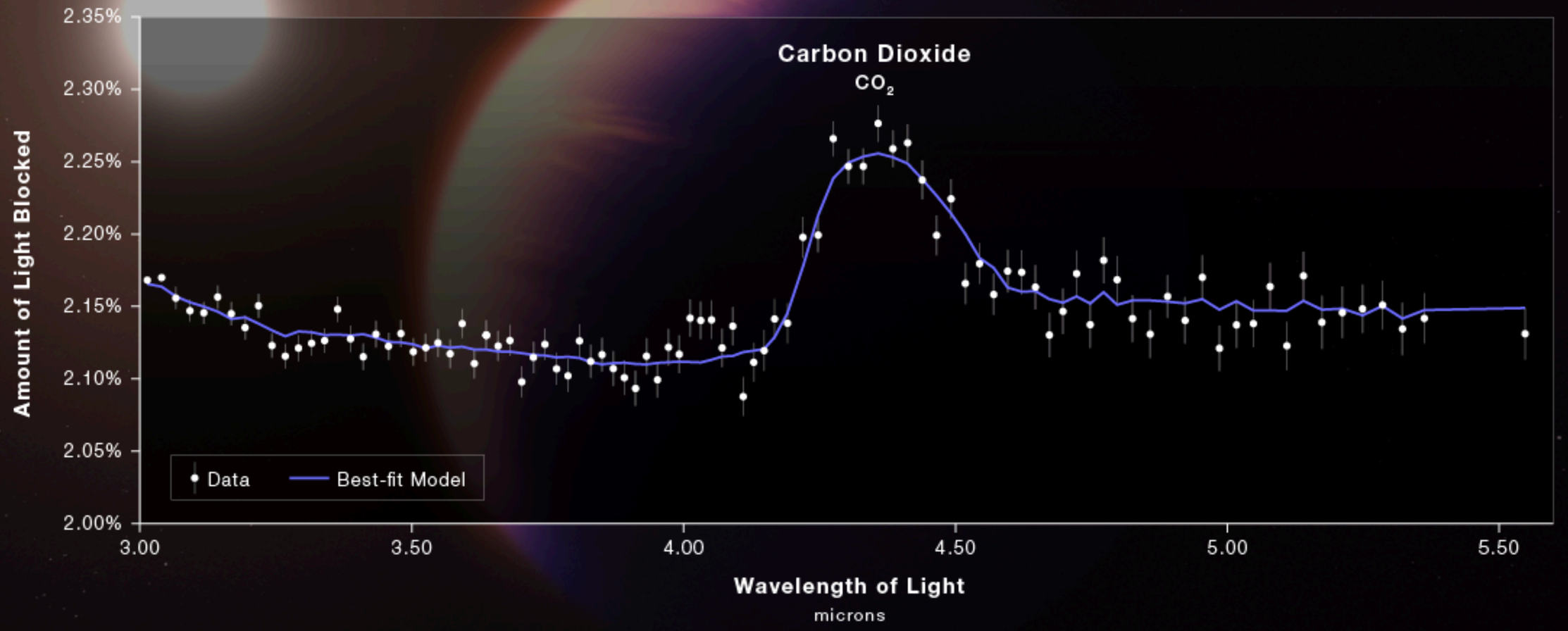


WEBB
SPACE TELESCOPE

HOT GAS GIANT EXOPLANET WASP-39 b

ATMOSPHERE COMPOSITION

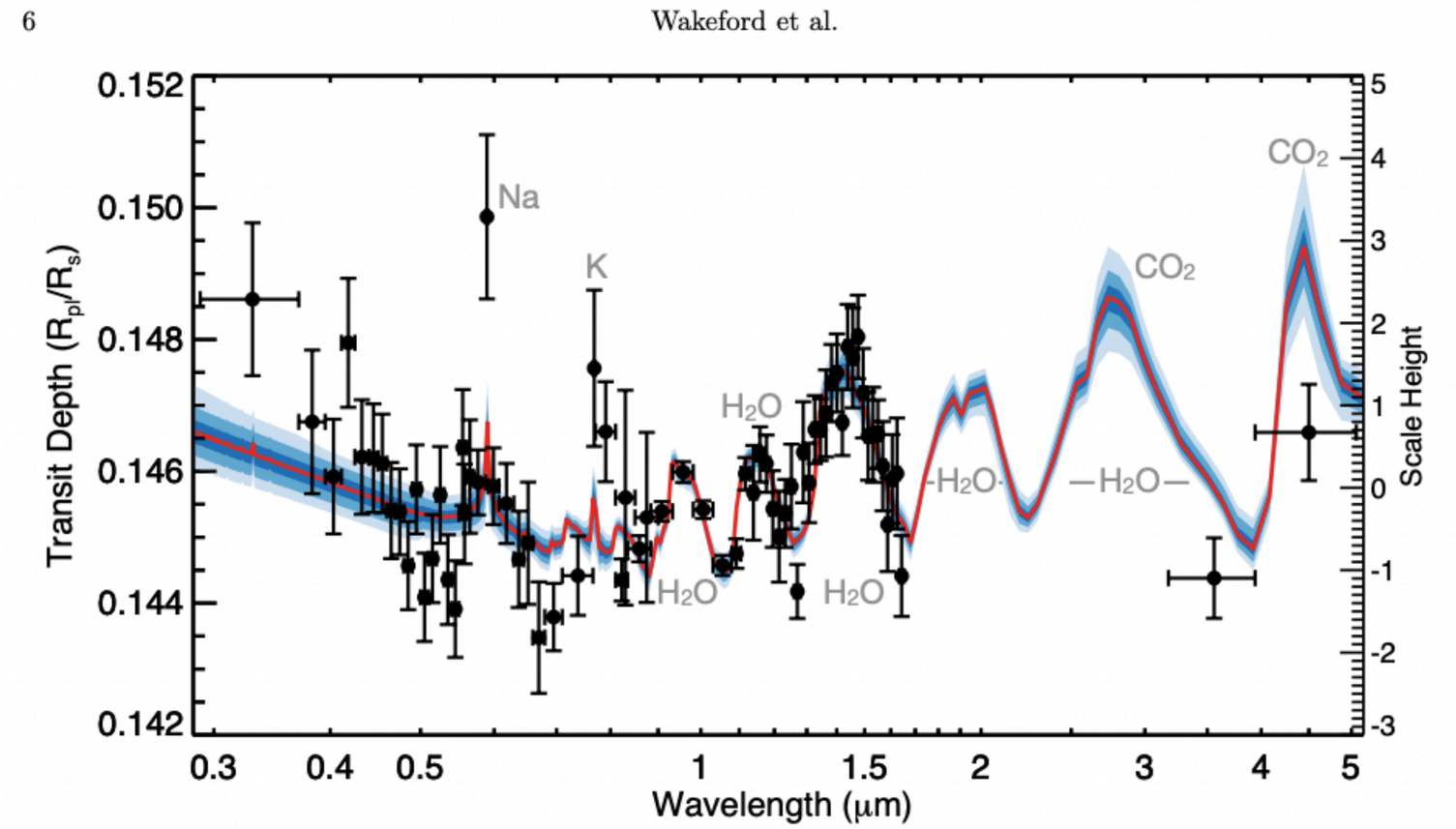
NIRSpec | Bright Object Time-Series Spectroscopy



WEBB
SPACE TELESCOPE

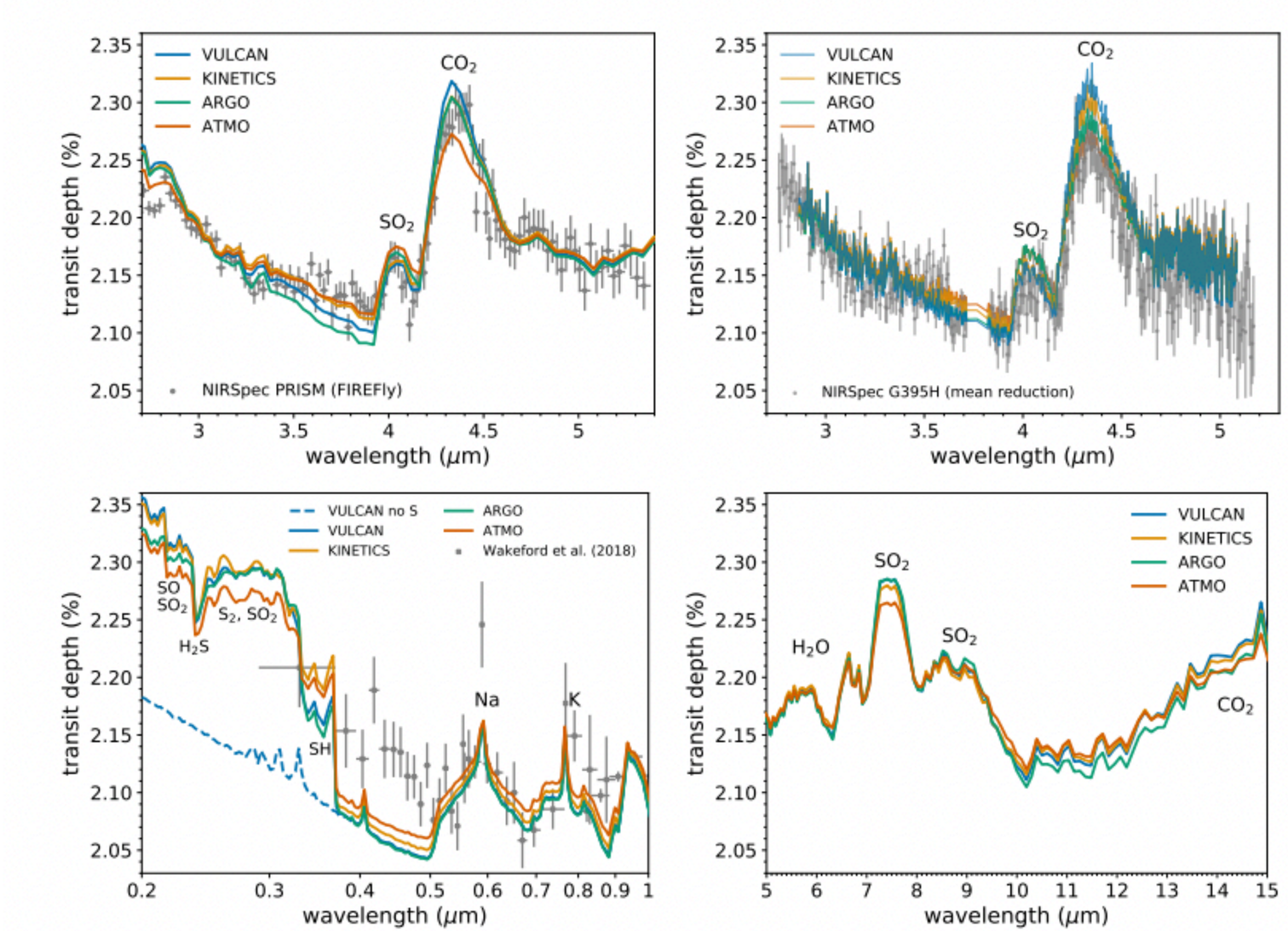
Transmission Spectroscopy

COMPLETE TRANSMISSION SPECTRUM OF WASP-39b



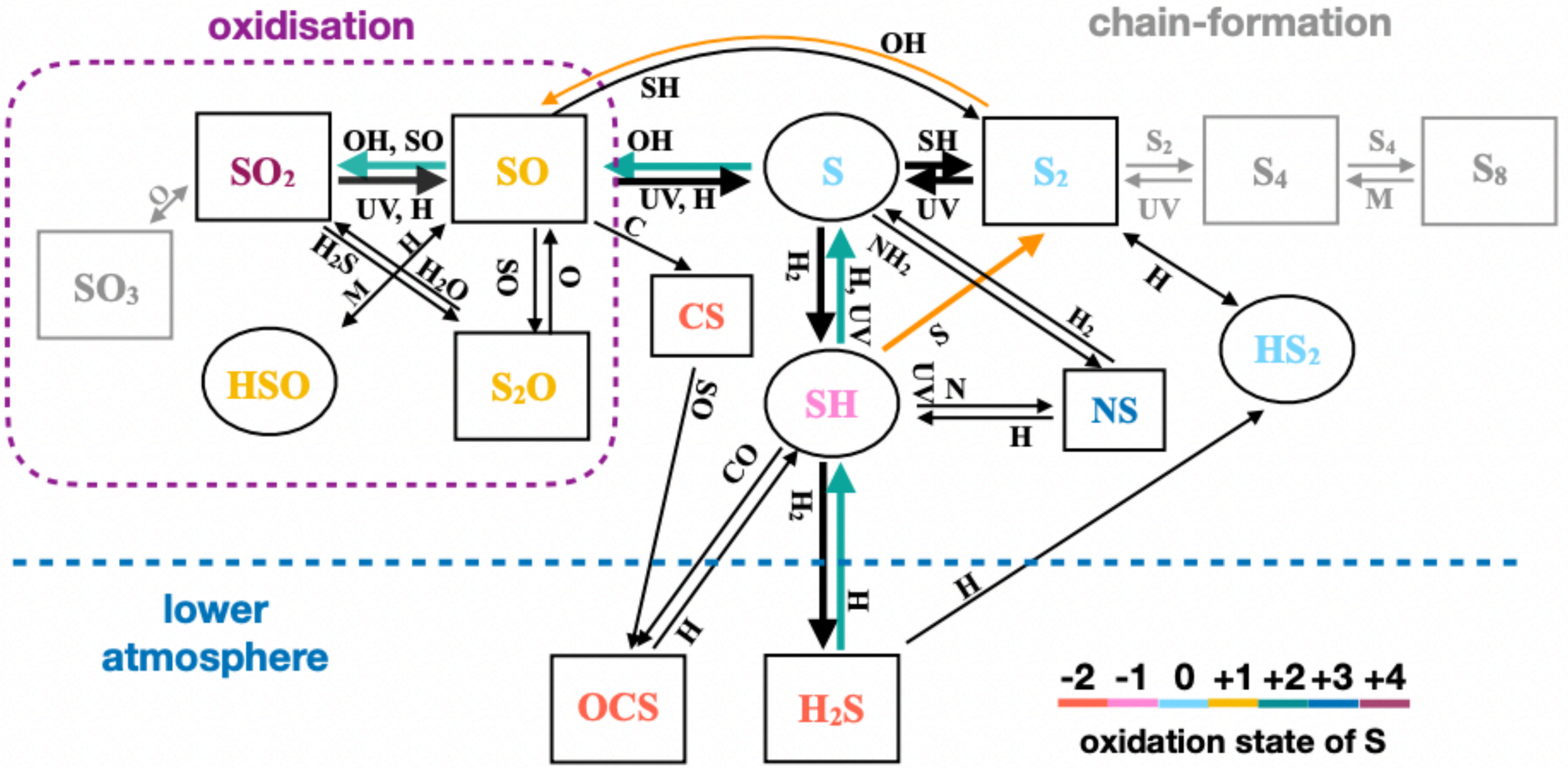
Wakeford et al. (2017)

Direct Evidence of Photochemistry in an Exoplanet Atmosphere



Shang-Min Tsai et al. (2022)

Direct Evidence of Photochemistry in an Exoplanet Atmosphere



Shang-Min Tsai et al. (2022)

Conclusion

- A planet’s atmospheric characterisation requires several techniques, like transmission spectroscopy and CCF.
- Observations from space on hot exoplanets are the most feasible.
- A 2D modelling of the transmission is preferable for current observation. 3D models are still expensive in time.
- Chemical interactions such as photochemistry are needed with the new sensitivity of the new telescopes.