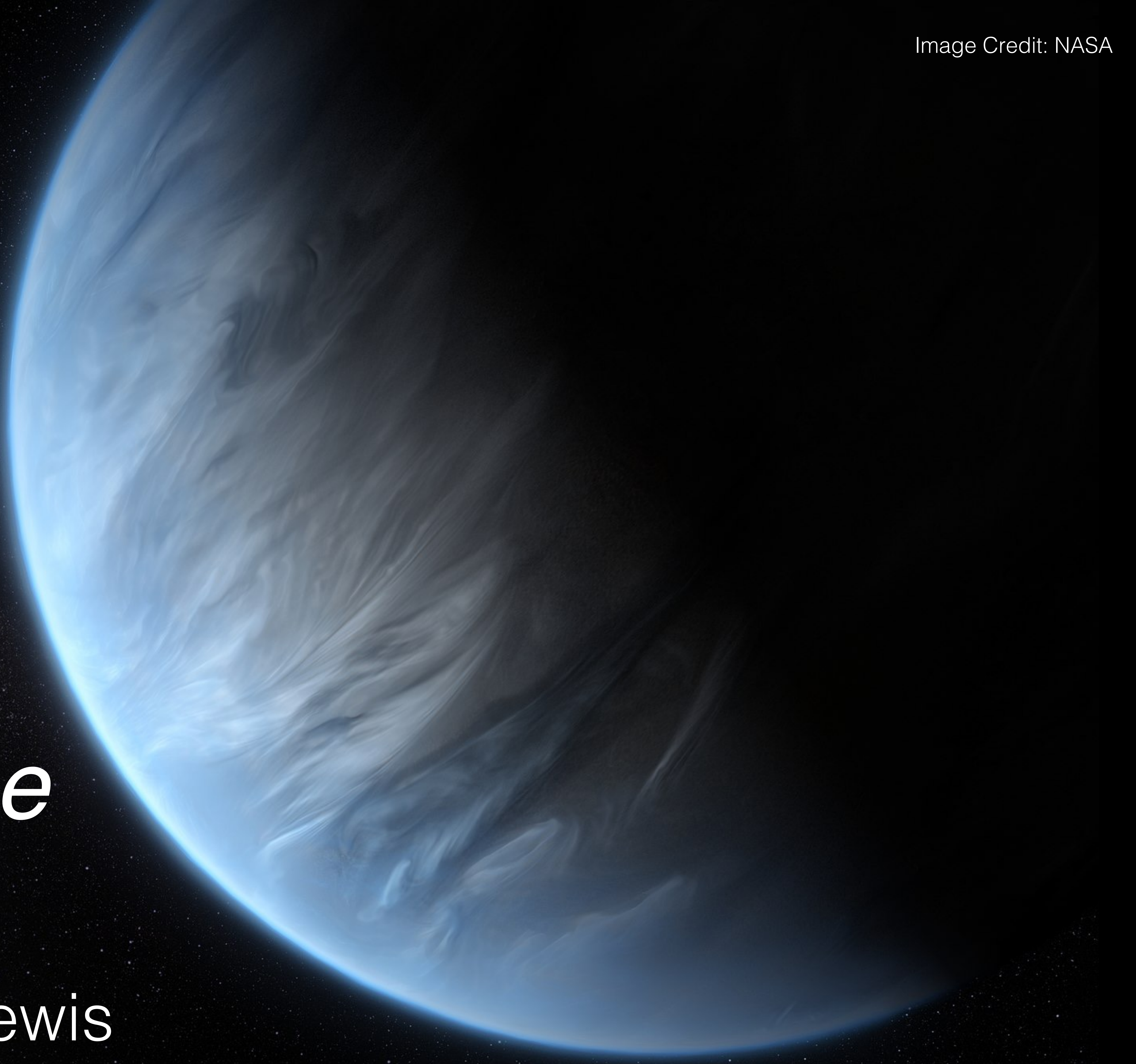
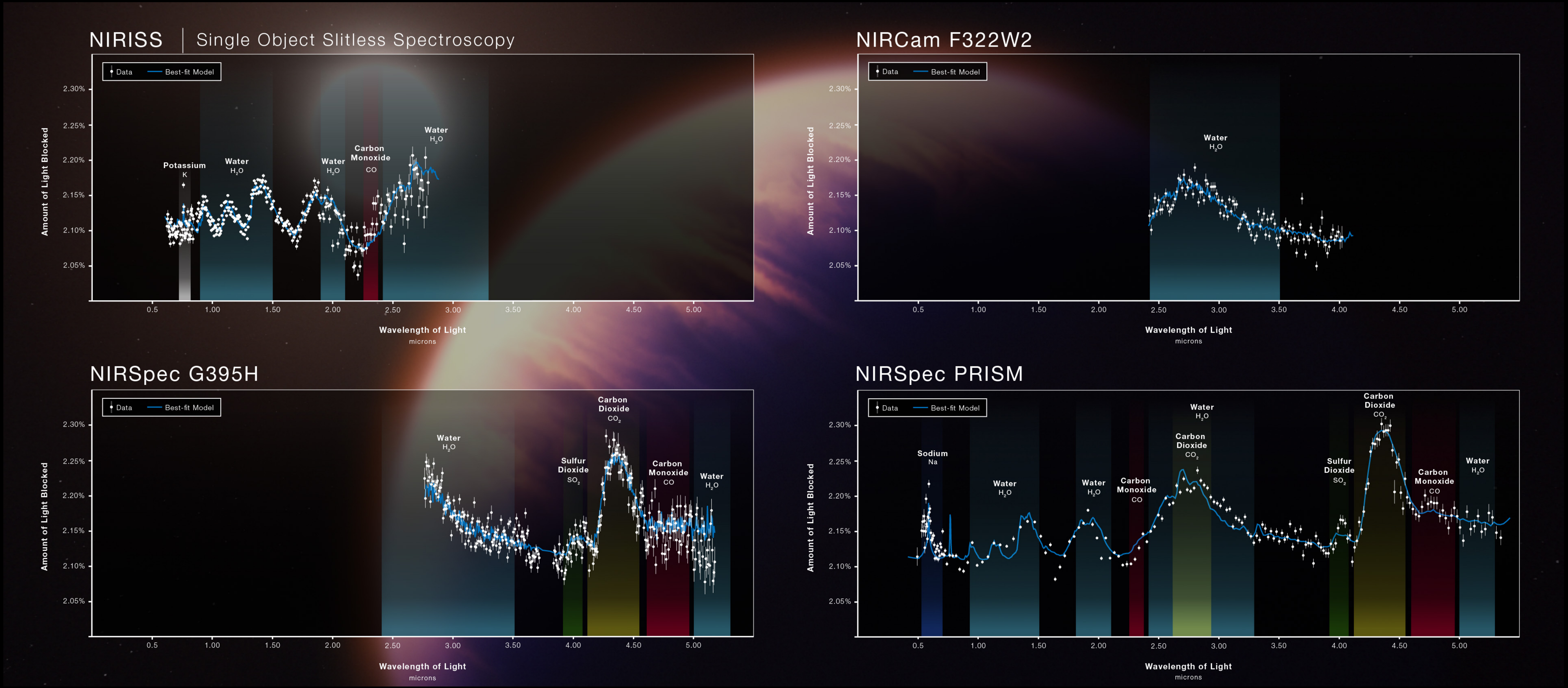
Sagan Summer Workshop 2023



Next Steps in Characterizing Exoplanet Atmospheres with JWST: Transit Science

Nikole K. Lewis
Cornell University

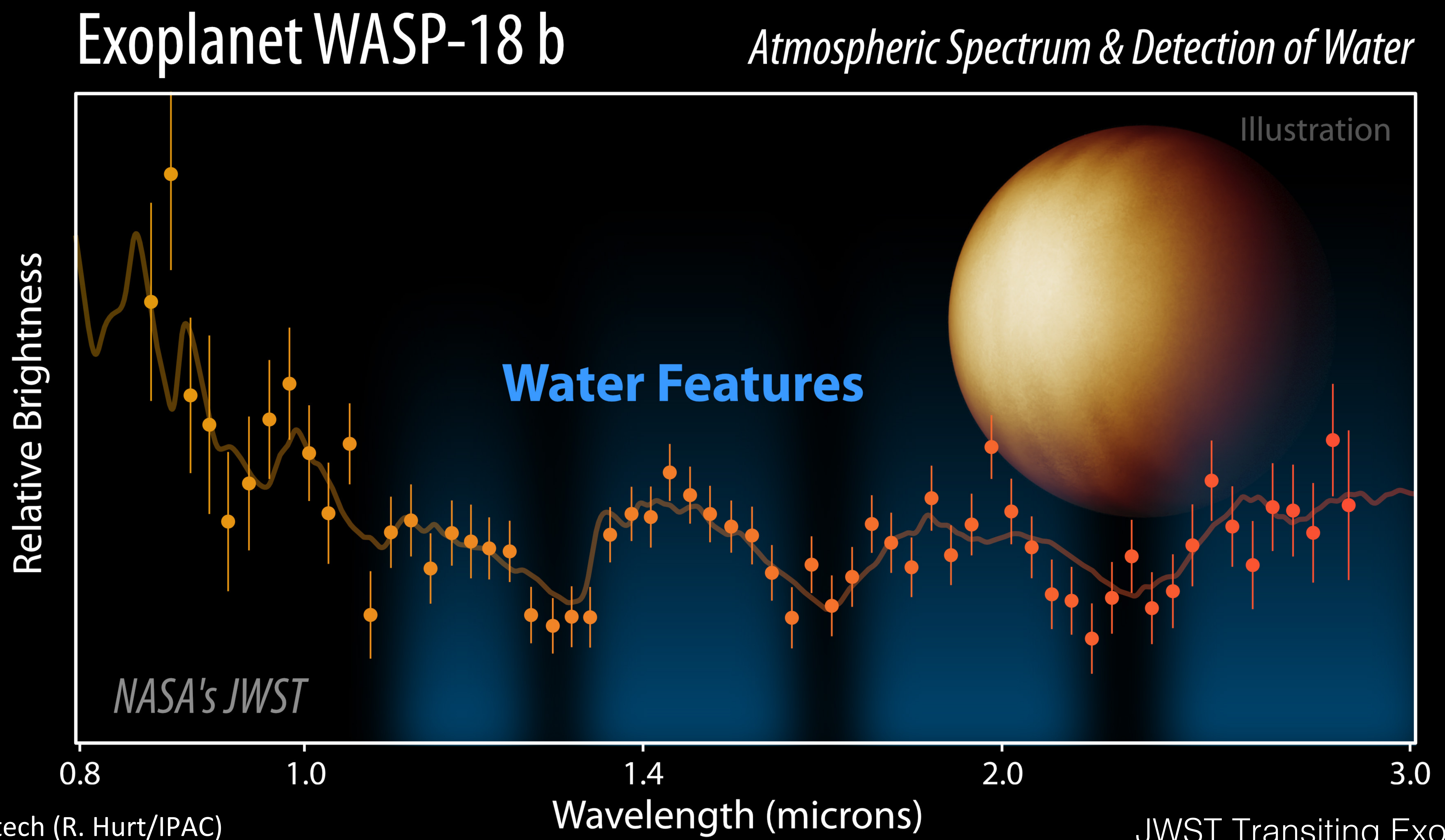
You've already seen some of the awesome JWST Cycle 1 transiting exoplanet science this week…



Credit: NASA, ESA, CSA, J. Olmsted (STScI)

JWST Transiting Exoplanet ERS Team

You've already seen some of the awesome JWST Cycle 1 transiting exoplanet science this week…



Credit: NASA, JPL-Caltech (R. Hurt/IPAC)

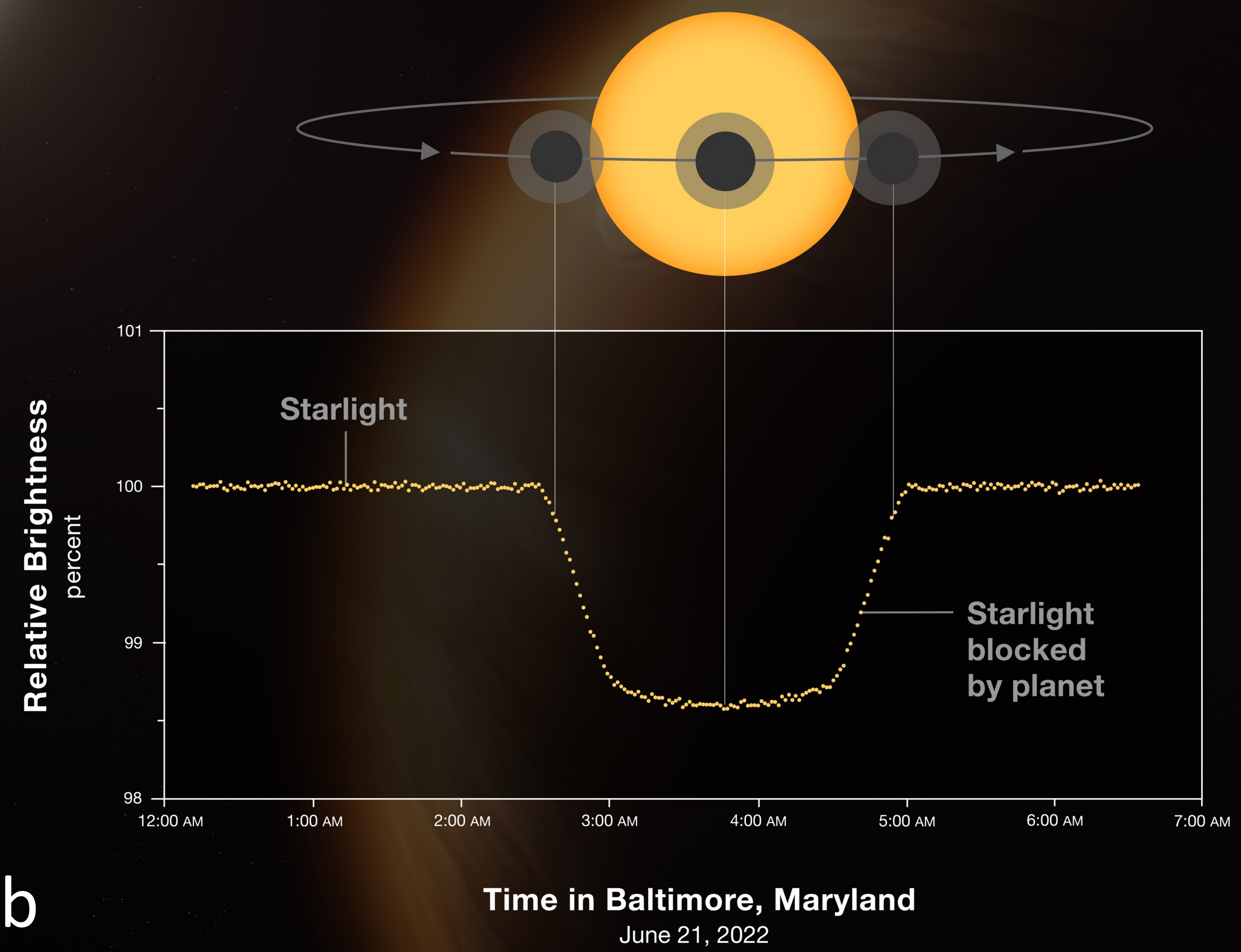
JWST Transiting Exoplanet ERS Team

You've already seen some of the awesome JWST Cycle 1 transiting exoplanet science this week…

Credit: NASA, ESA, CSA, J. Olmsted (STScI)

Zieba et al. (2023)

JWST time-series observations are AMAZING!



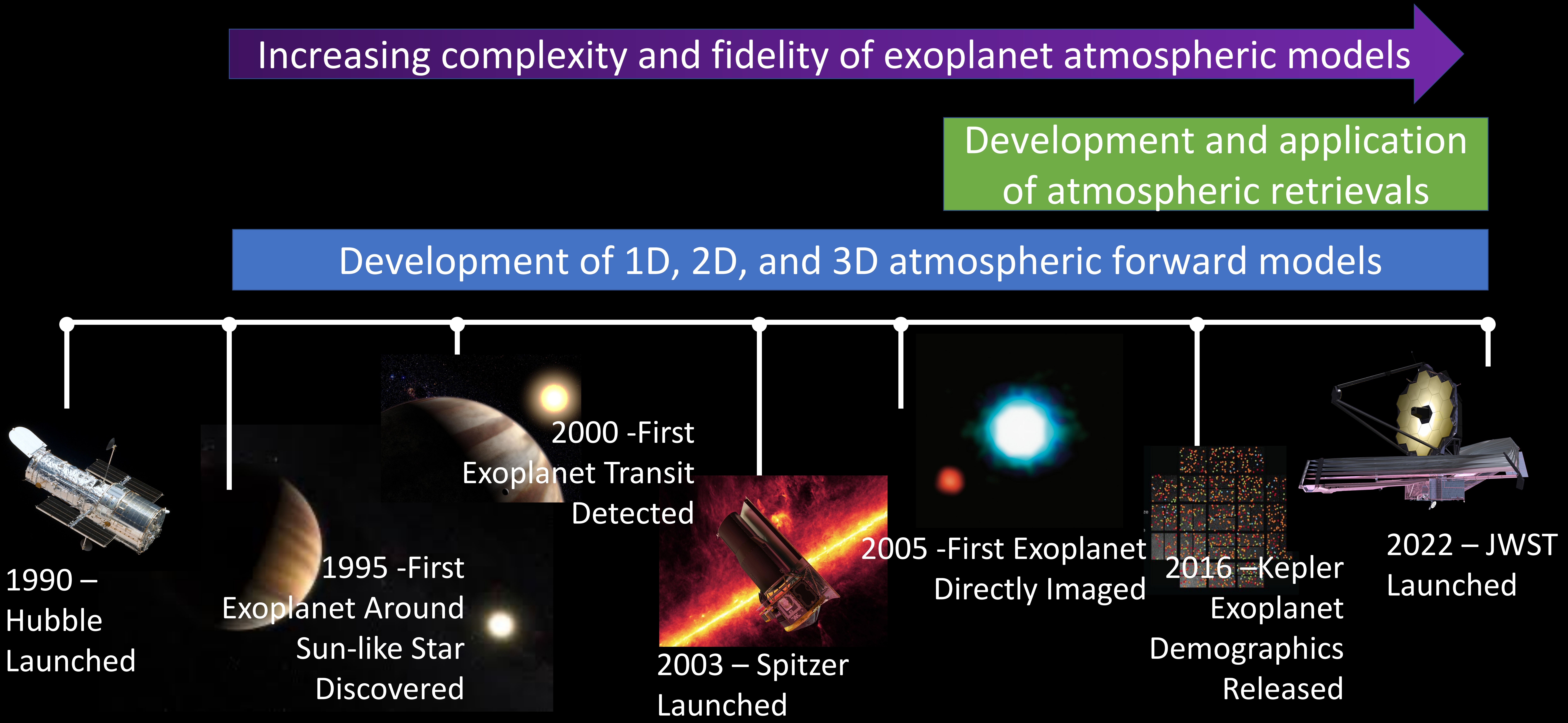
Actual Data!

WASP-96b

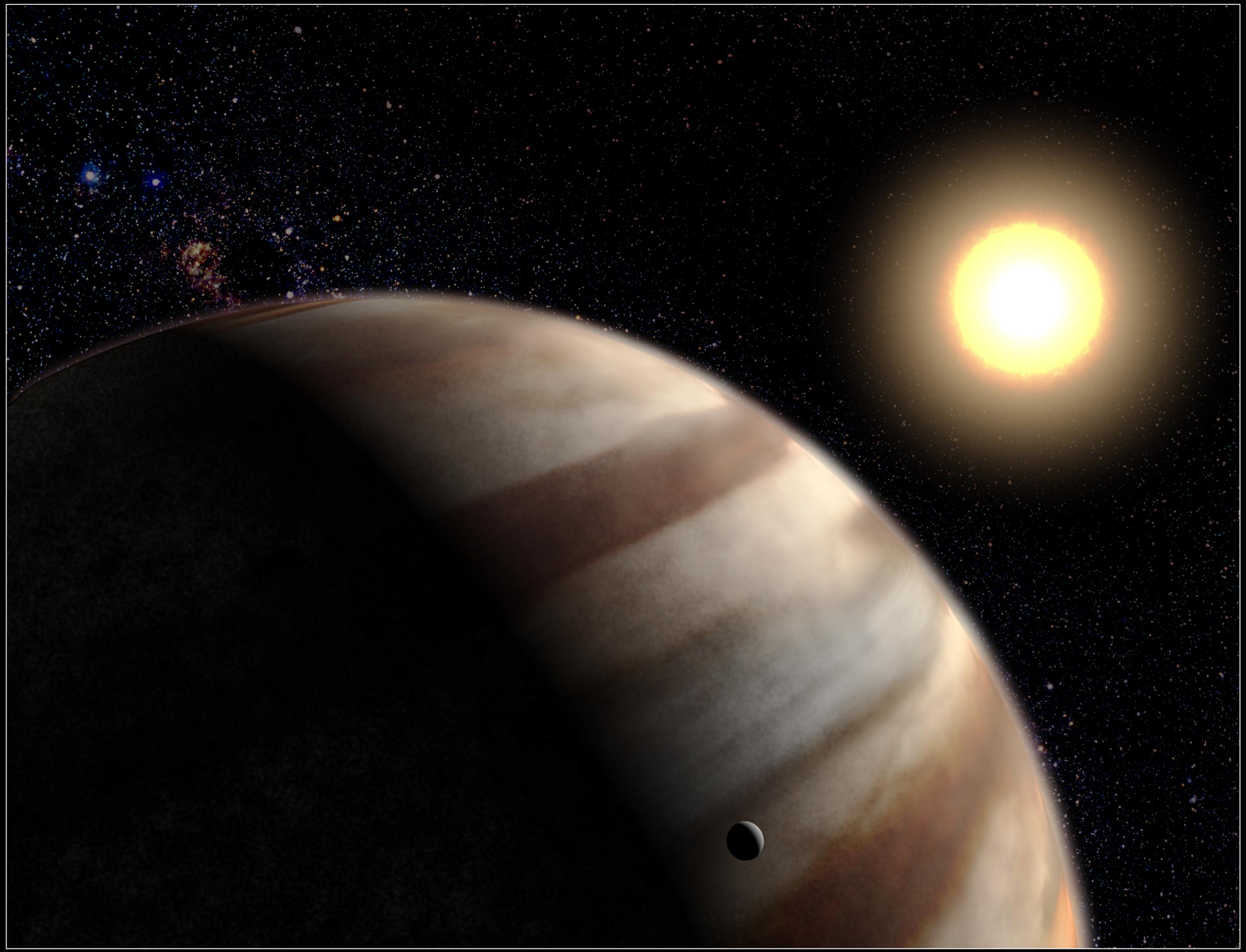
Image Credit: NASA/STScI


Image Credit: NASA
“You can’t really know where you are going until you know where you have been”
-Maya Angelou

A solid foundation was laid for exoplanet atmospheric characterization in the era of JWST

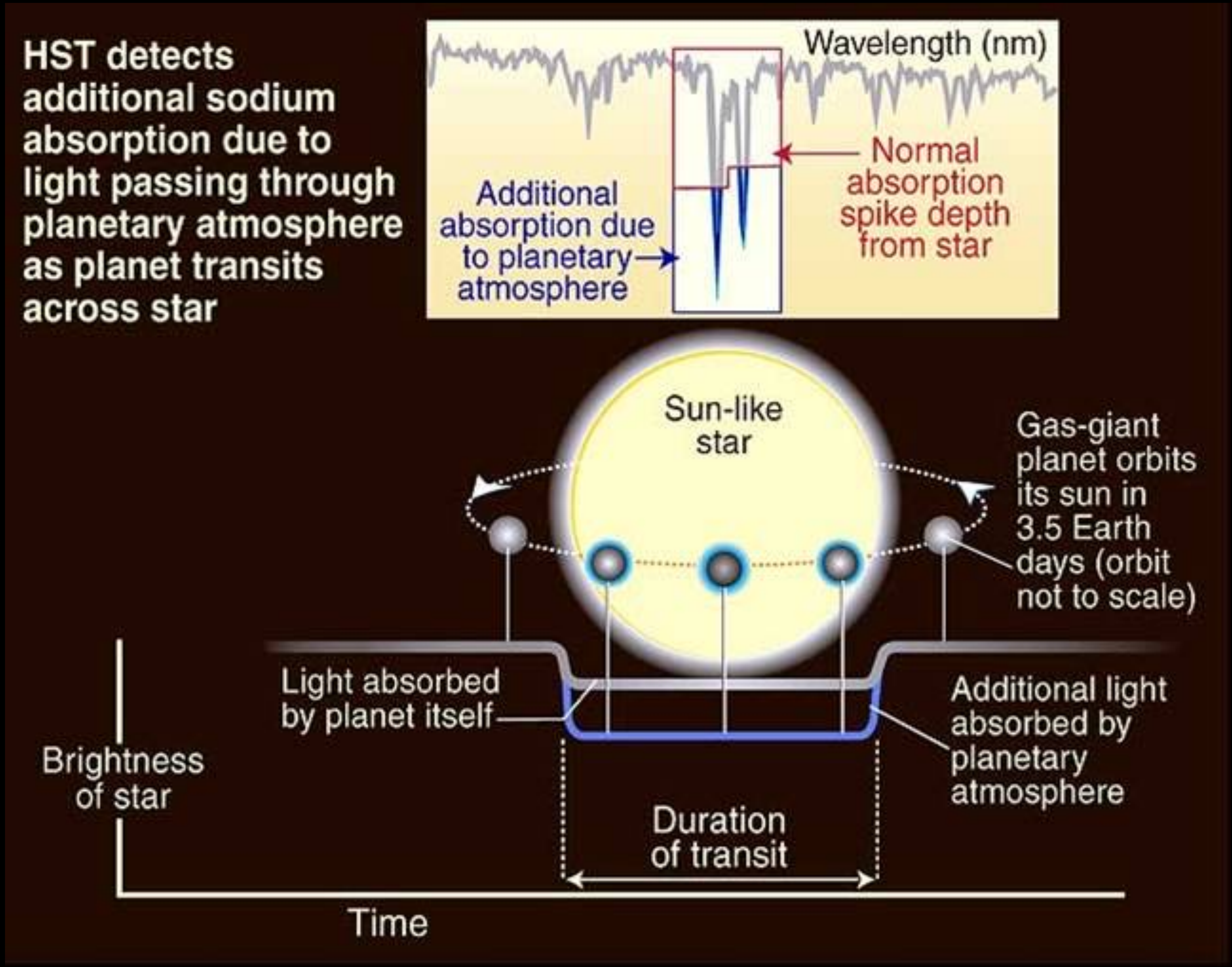


Hubble provided first detection of an exoplanet atmosphere



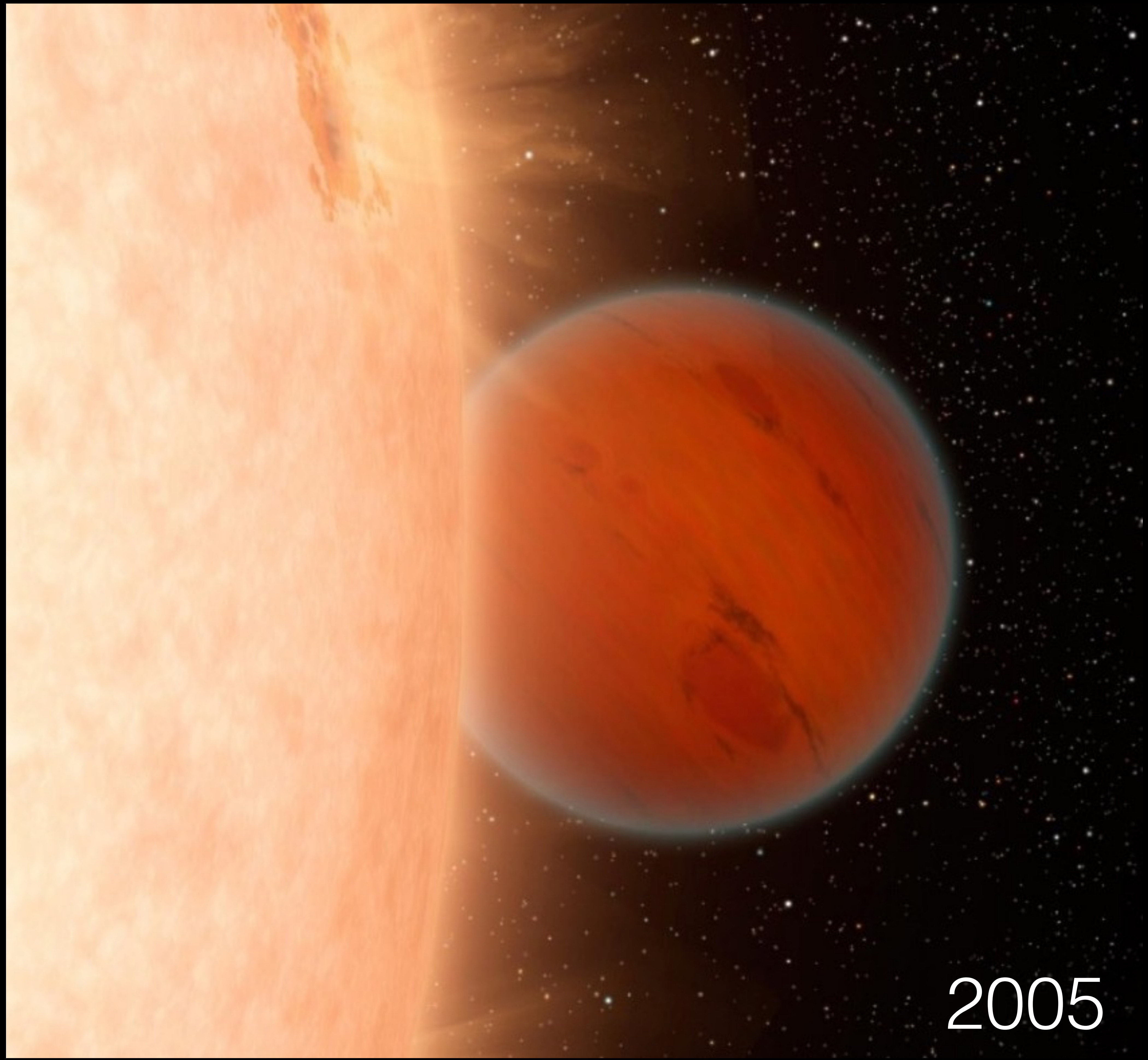
Artist's View of Planet around the Star HD 209458

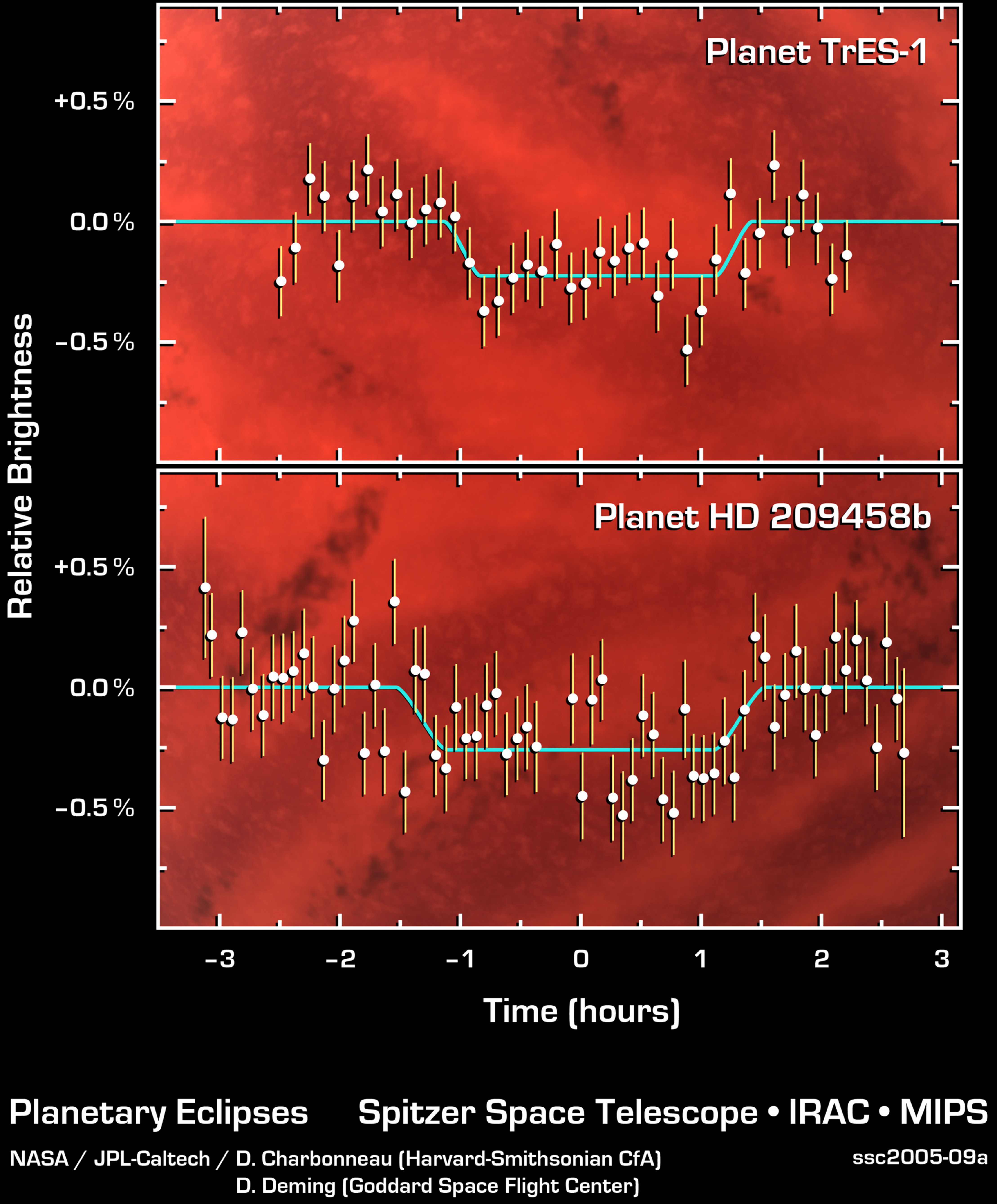
NASA and G. Bacon (STScI) • STScI-PRC01-38



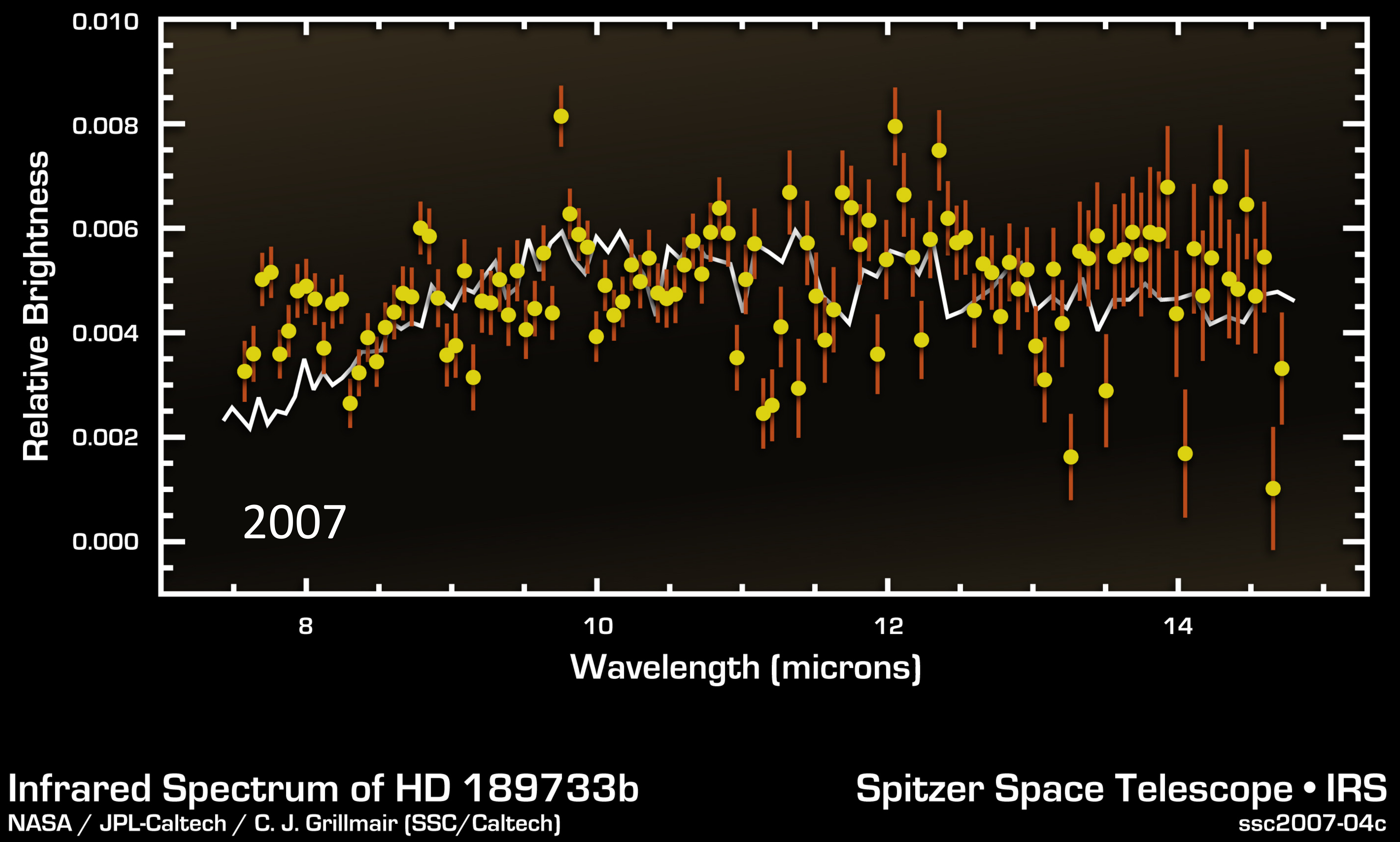
2001 – *Hubble's* STIS Instrument

Spitzer was among the first to measure the light (or absence thereof) from an exoplanet

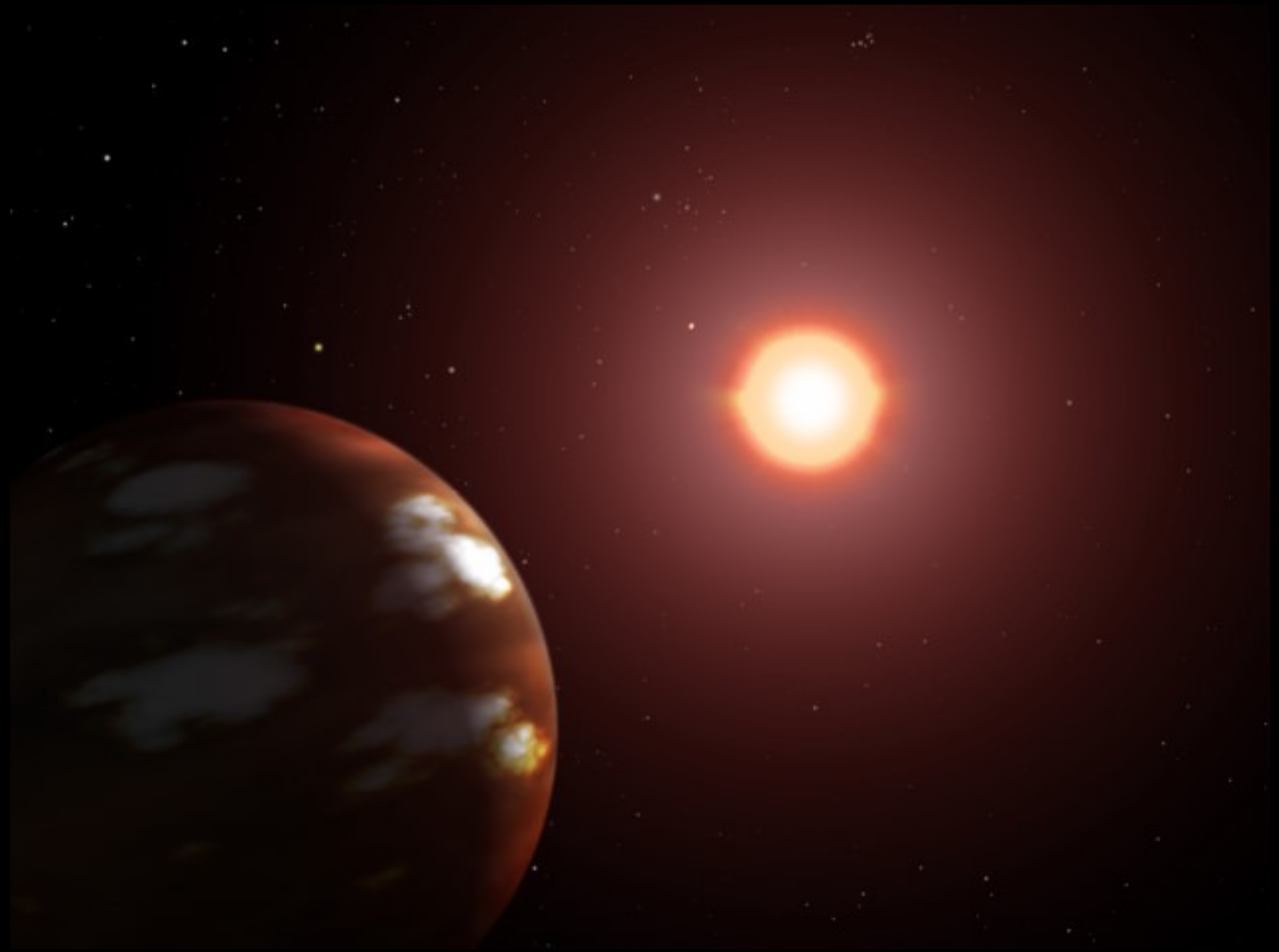




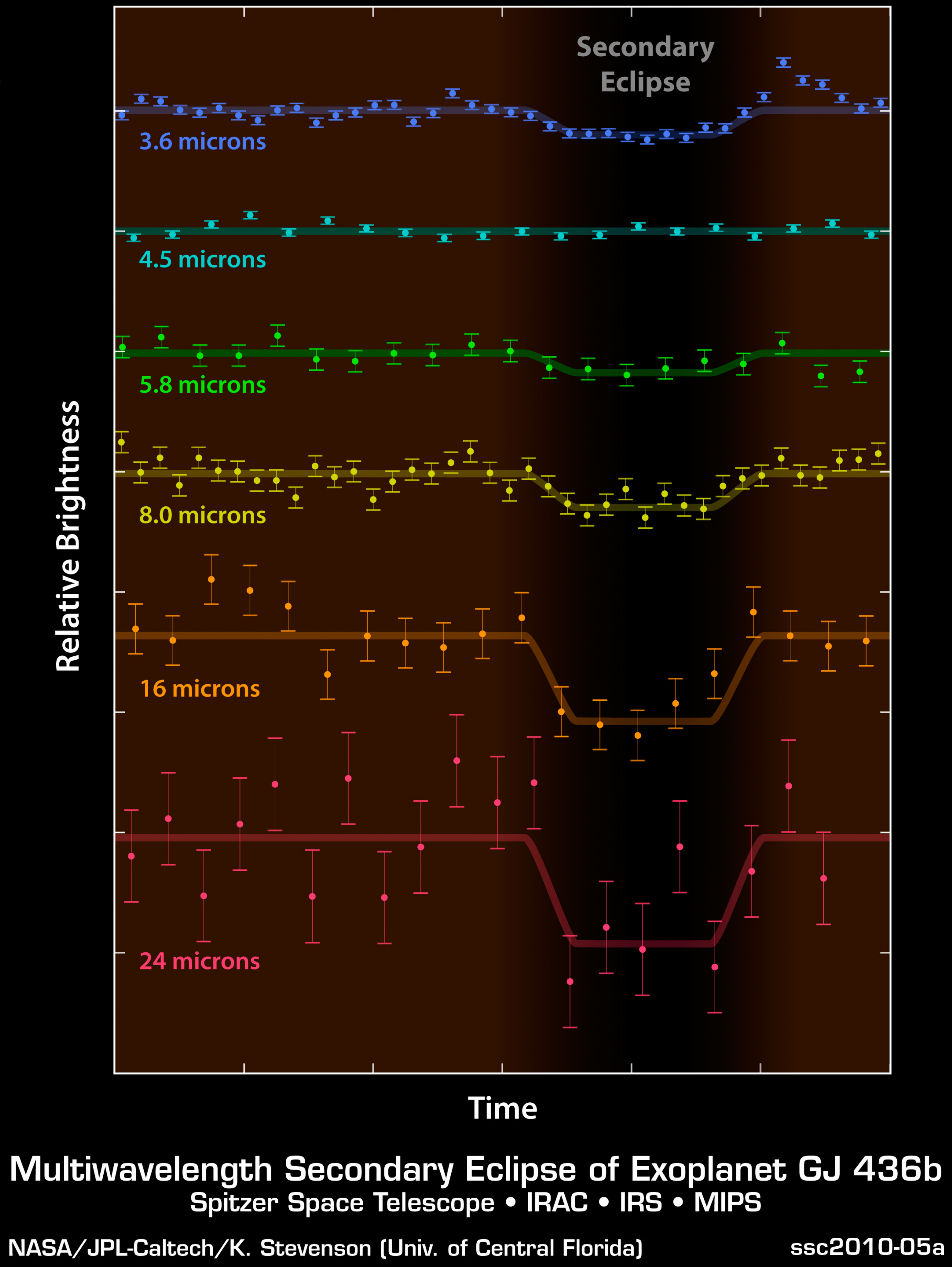
Spitzer obtained the first mid-infrared emission spectra of exoplanets



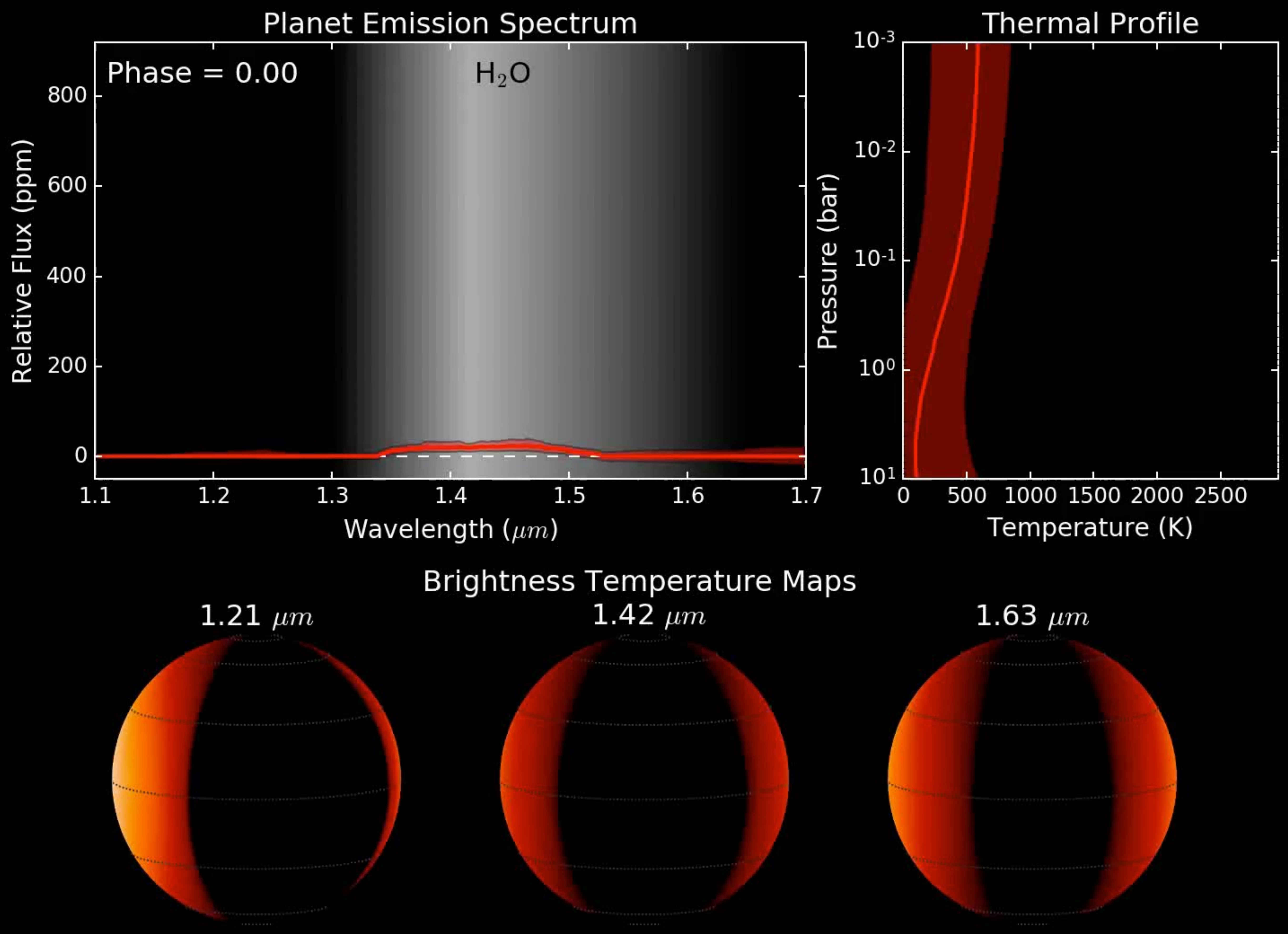
Spitzer provided our first insights into the complex chemistry in sub-Jovian sized worlds



2010

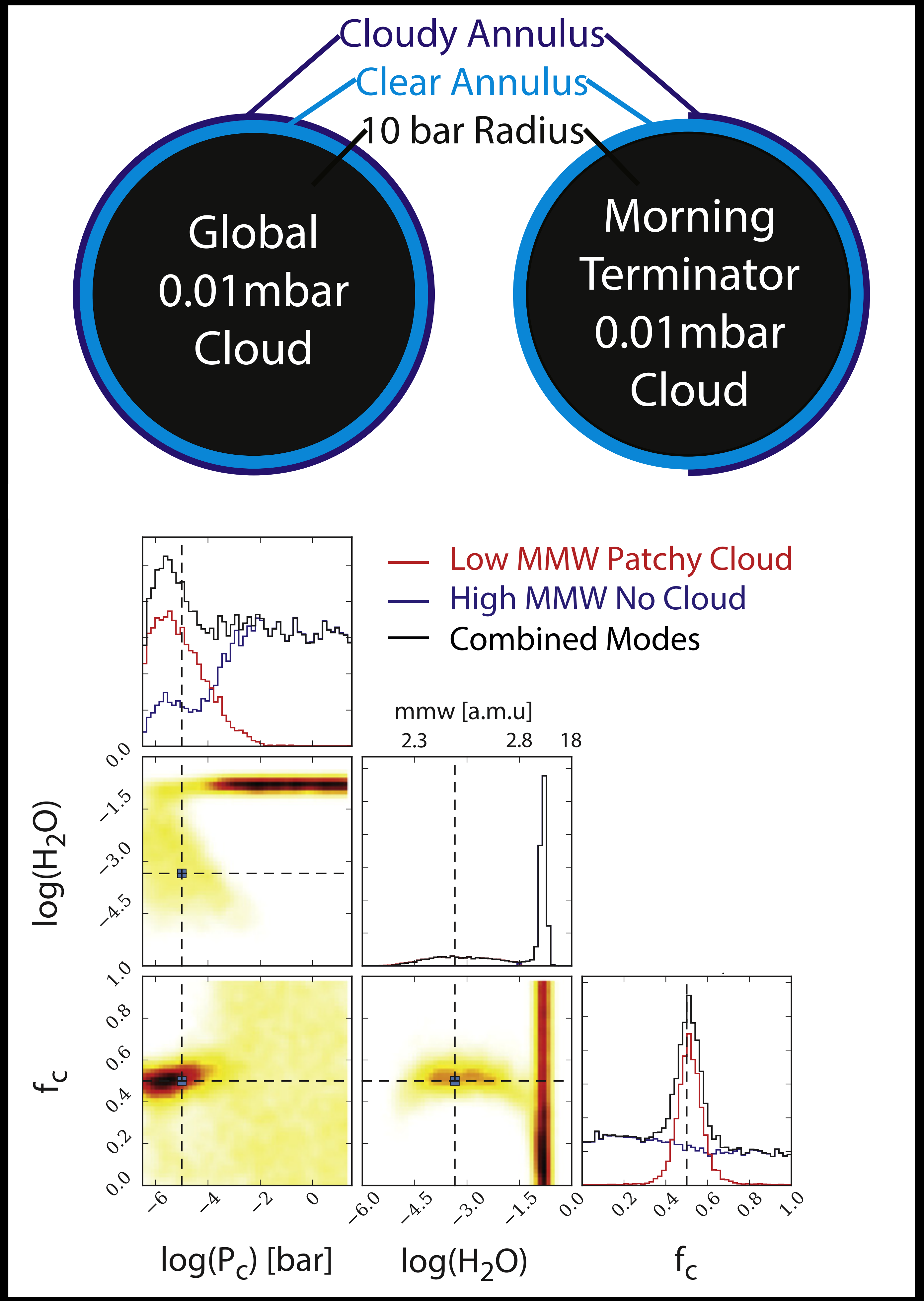


Improved observational techniques brought higher fidelity multi-dimensional views of exoplanet atmospheres



2014

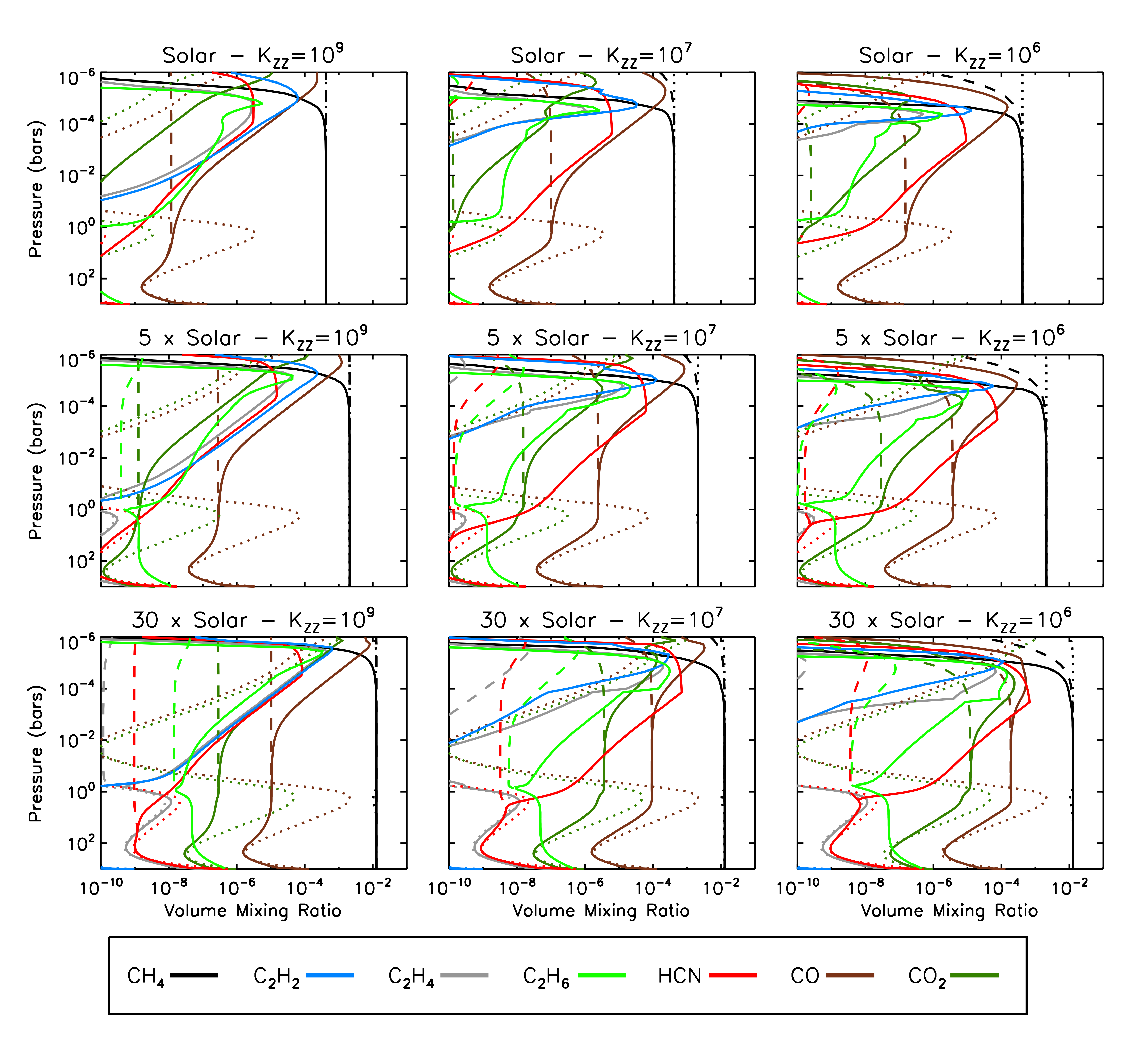
K. B. Stevenson (2014)



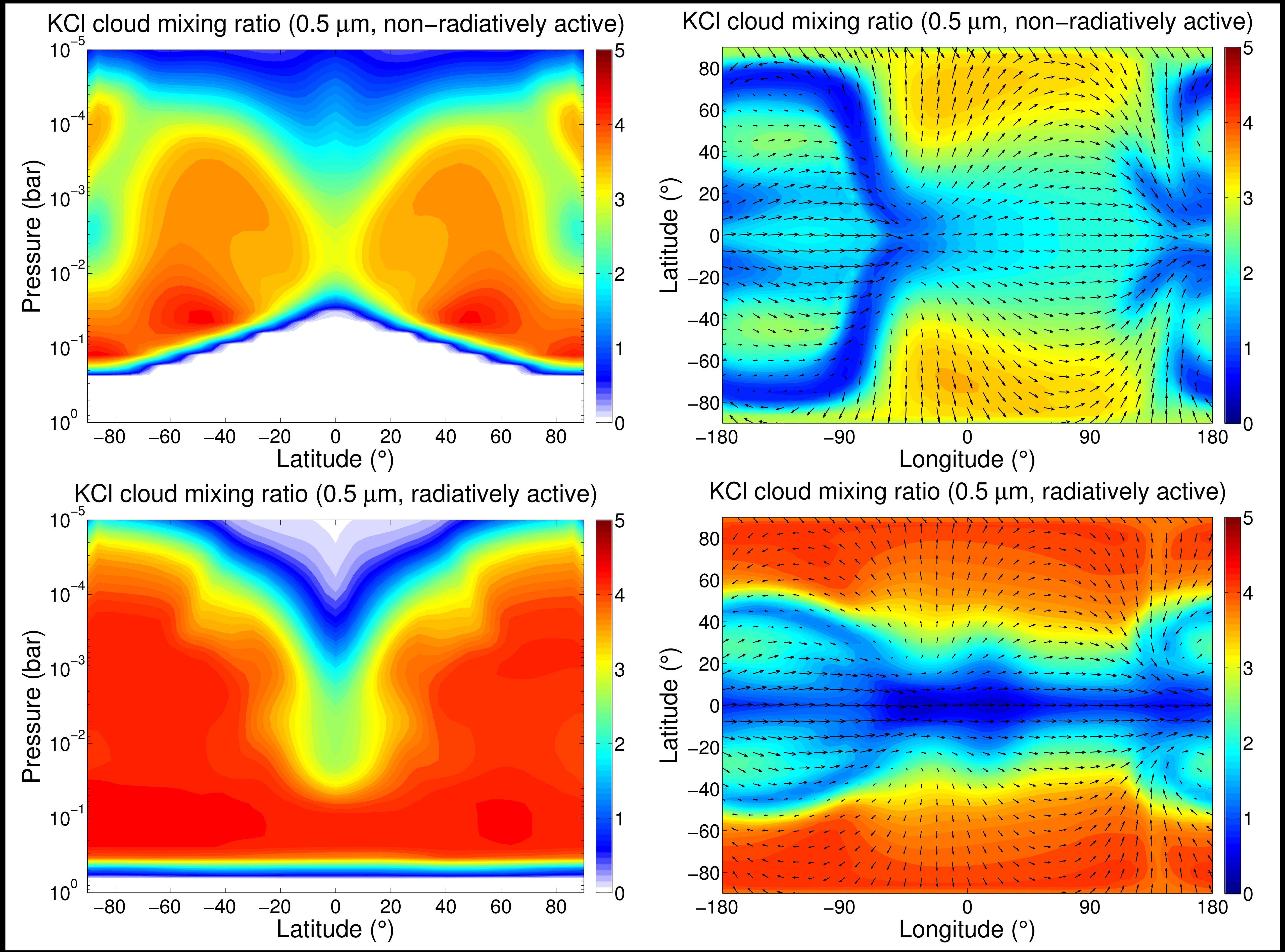
Line & Parmentier (2016)

The high-precision offered by *Hubble's* WFC3 spatial scanning mode that came online in 2012 has given us some of the highest-definition looks at exoplanet atmospheres to date.

Atmospheric theorists rose to the challenges presented by observational data and developed models of growing complexity

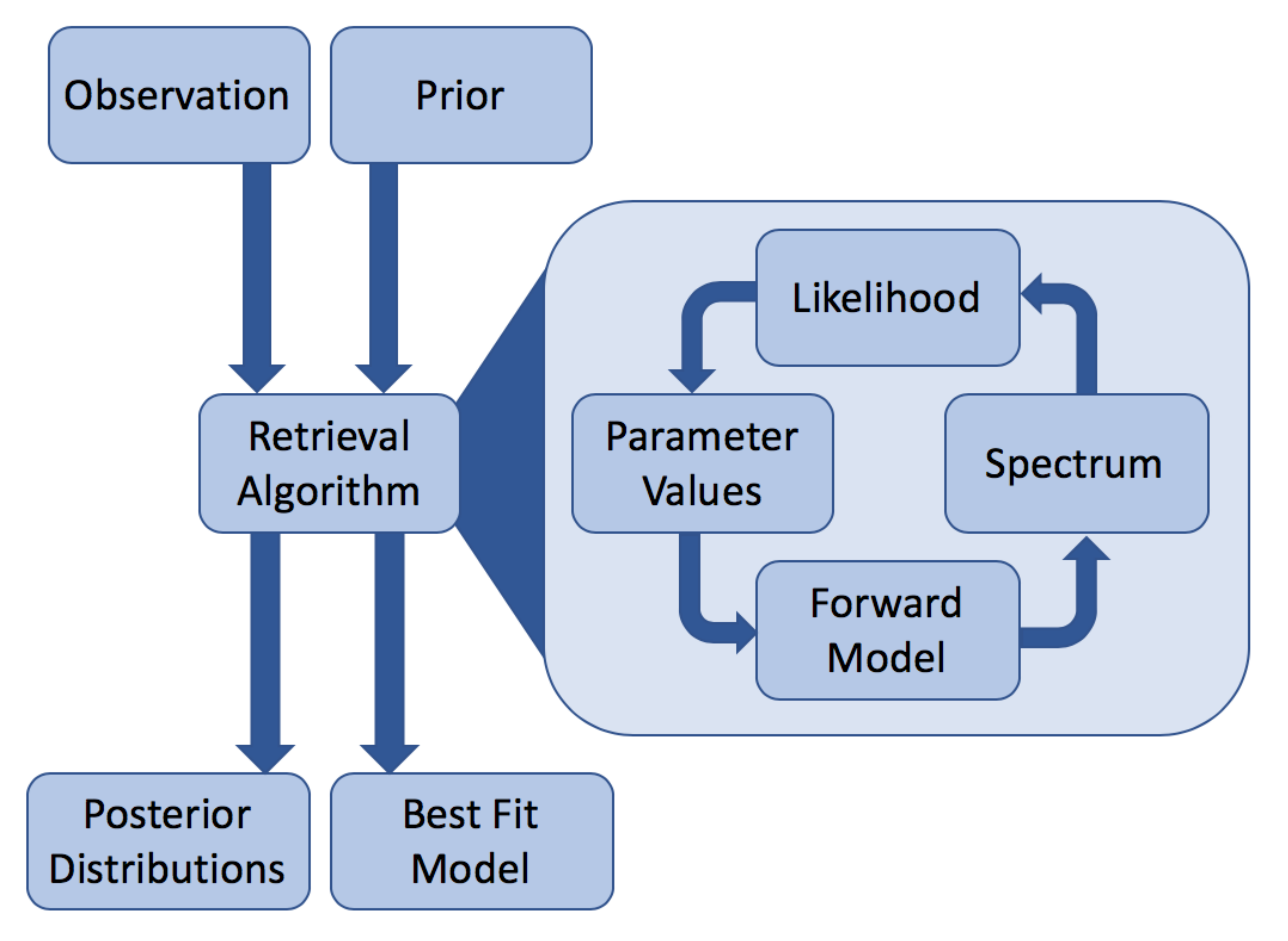


Kempton et al. (2011)

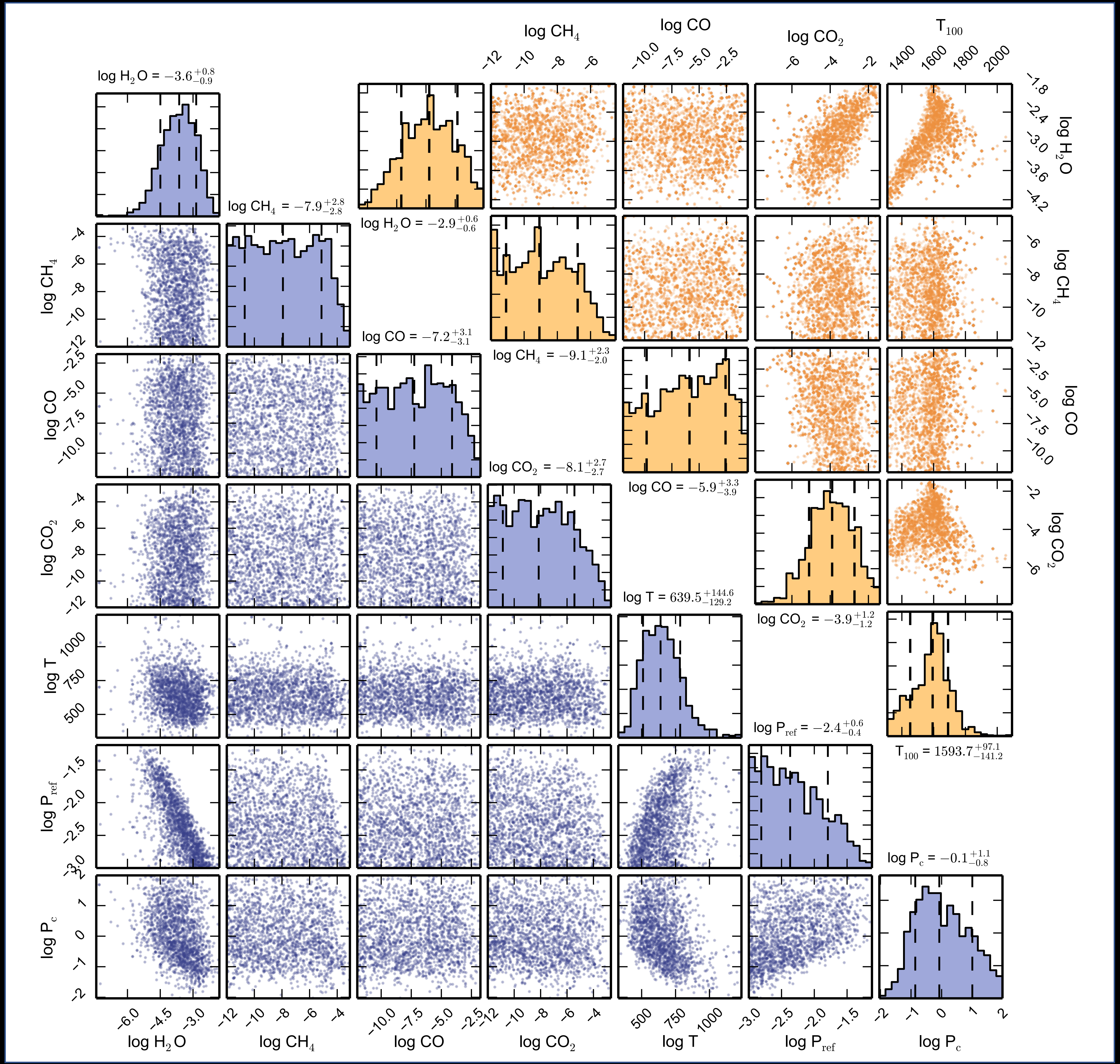


Charnay et al. (2015)

The development and application of exoplanet atmospheric retrieval algorithms transformed our view of exoplanet atmospheres

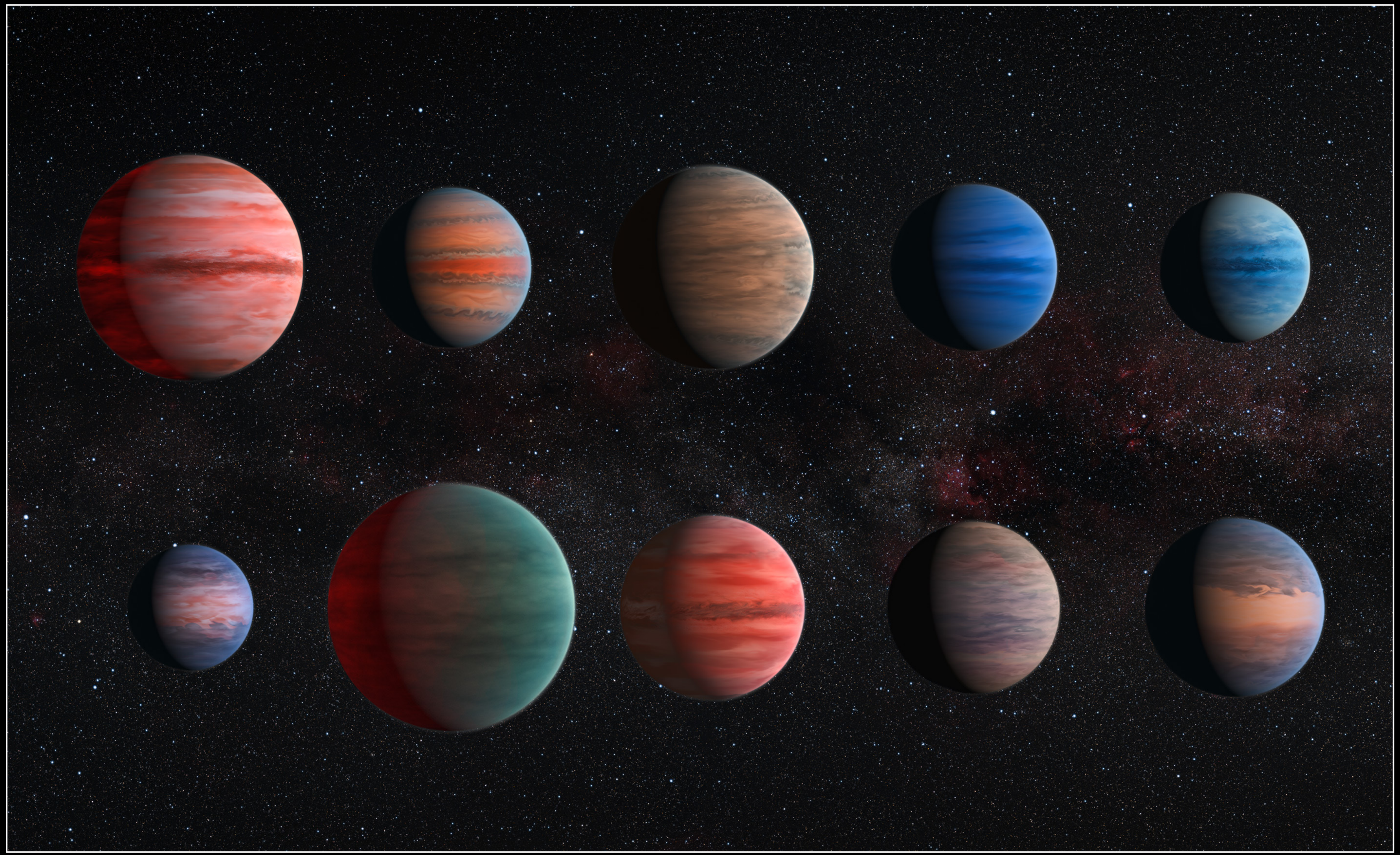


Barstow & Heng (2020)

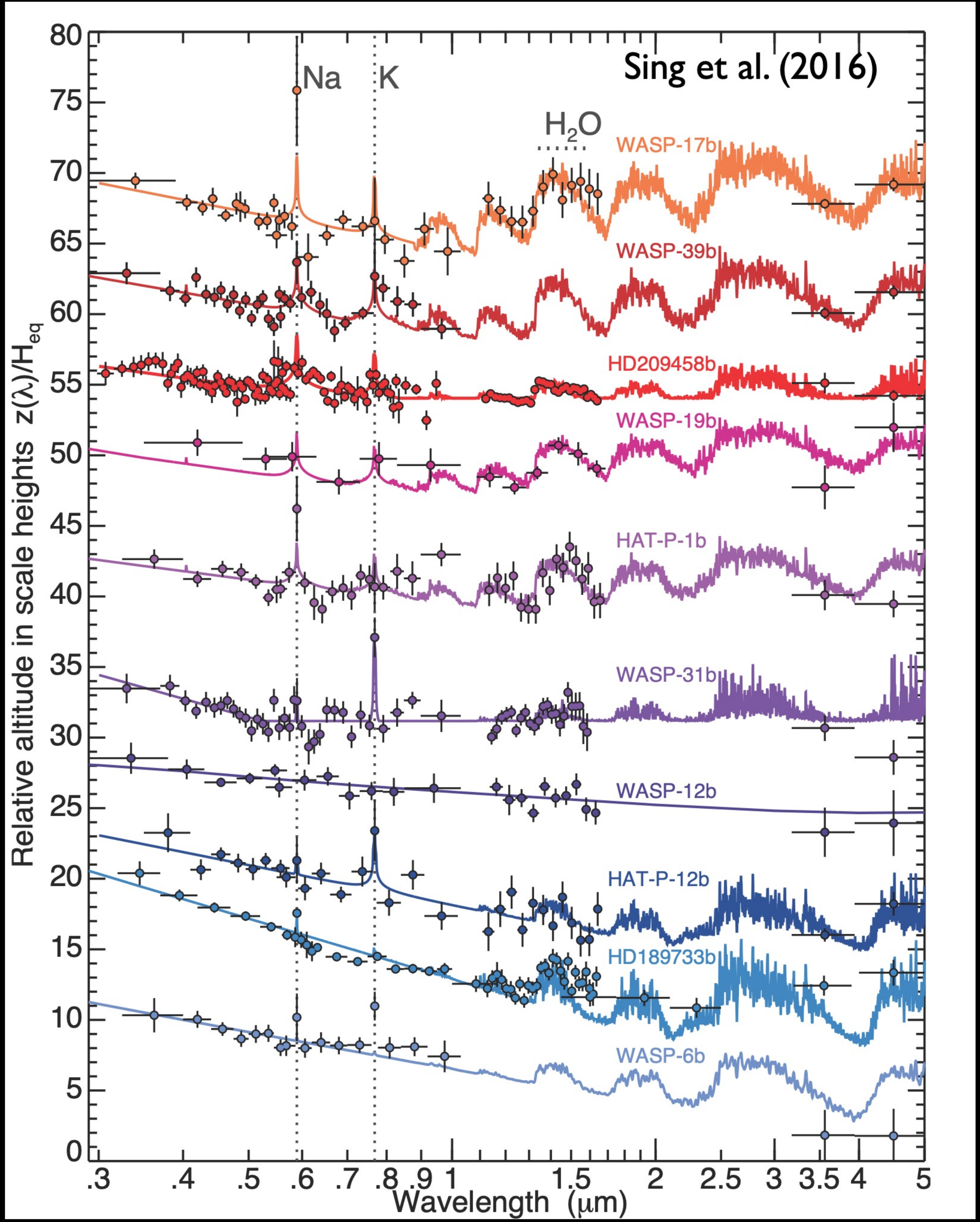


Kreidberg et al. (2014)

Eventually a comparative sample of exoplanet atmospheres evolved…

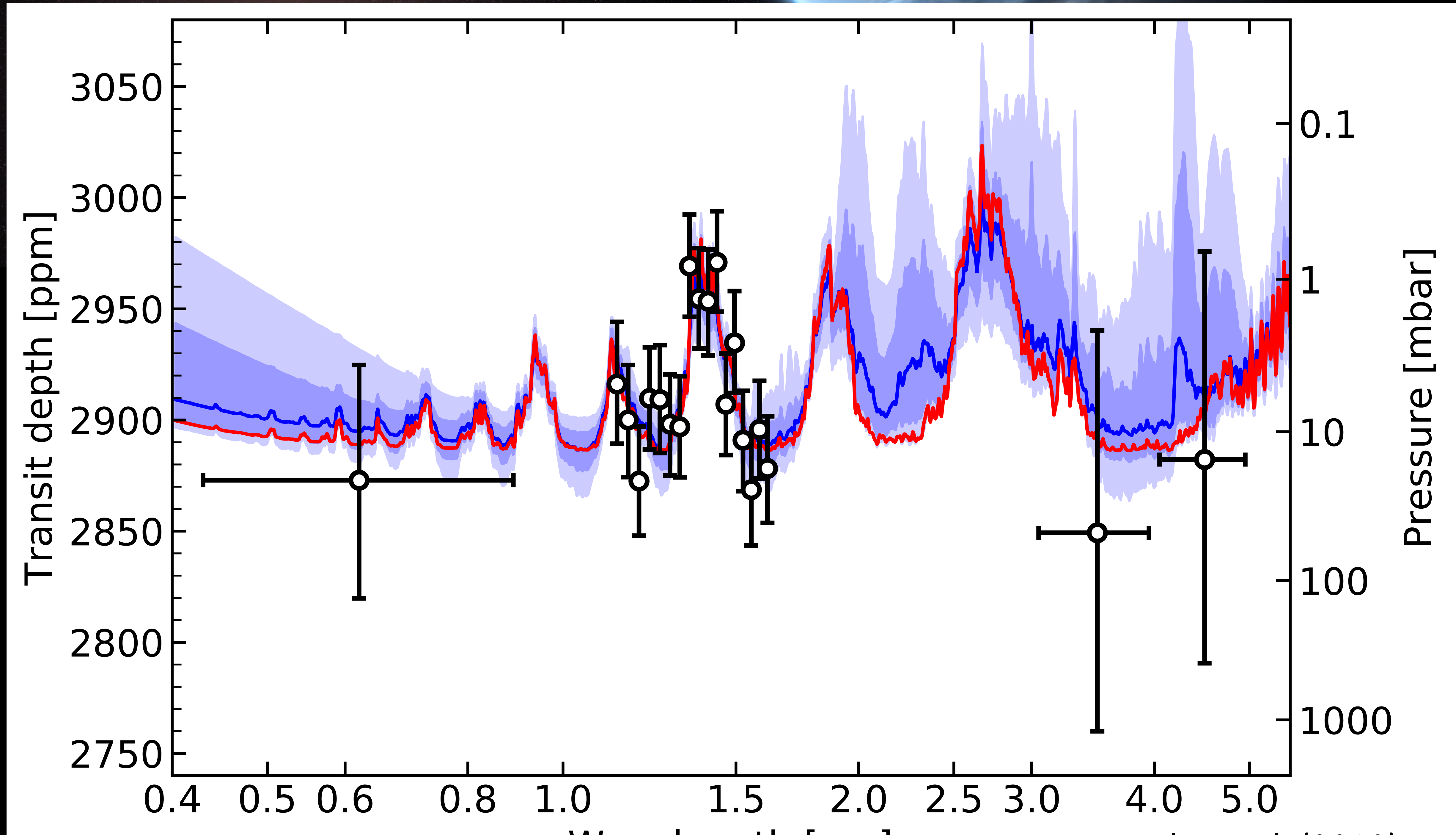


Artist's Impression of "Hot Jupiter" Exoplanets
NASA and ESA ▪ STScI-PRC15-44b

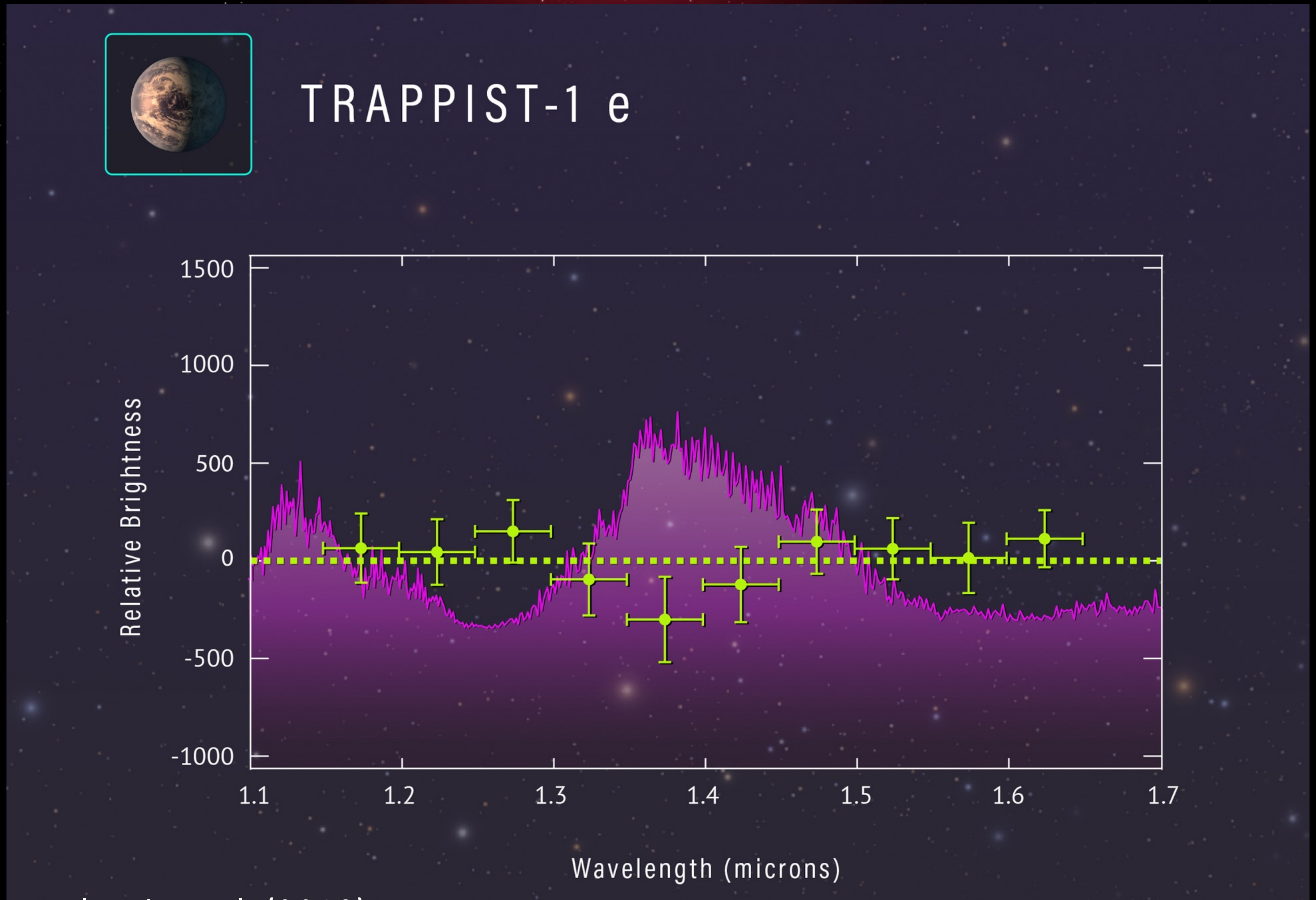


Observations from *Hubble* and *Spitzer* have provided detections of H_2O, Na, K, TiO, H, He, aerosols, and hints of many other atmospheric components.

With *Spitzer* and *Hubble* we embarked on our first probes of the atmospheres of habitable zone worlds



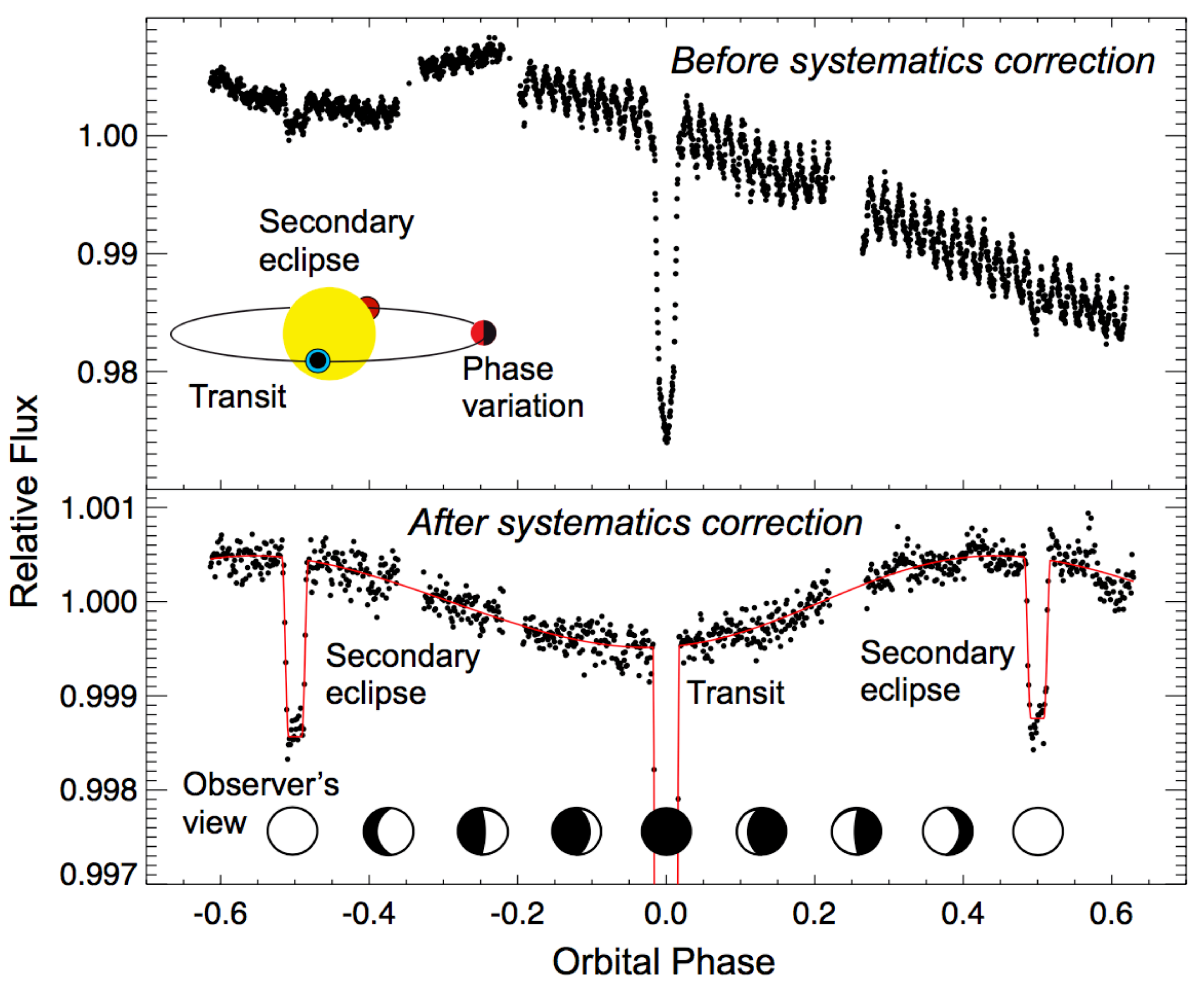
Benneke et al. (2019)



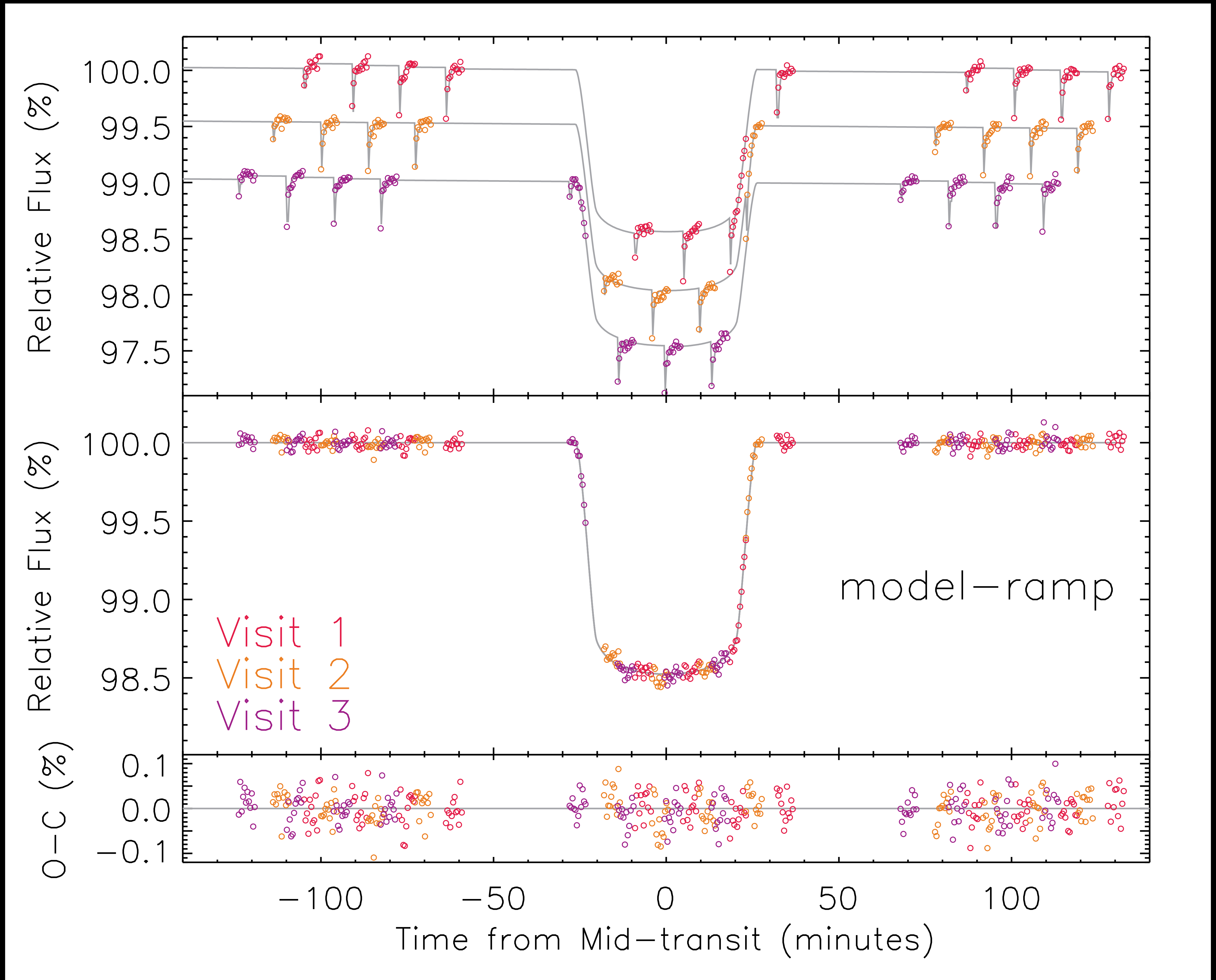
deWit et al. (2018)

Image Credits: NASA/ESA/STScI

A reminder of the instrument systematics and other noise sources tackled in the era of *Hubble* and *Spitzer*



Bean et al. (2018), adapted from Knutson et al (2012)



Berta-Thompson et al. (2012)

Precision "records": *Spitzer* ~ 20 ppm, *Hubble*~30 ppm


In the era of JWST
Potential for >500 transiting exoplanets with atmospheric characterization observations
In the era of Hubble & Spitzer
>100 transiting exoplanets with atmospheric characterization observations

JWST Transiting Exoplanets Cycle 1 & 2 Targets

~120 Individual Targets
300+ Observations
~2800 hours
20% of JWST GO Time

207 Transits
90 Eclipses
20 phase-curves

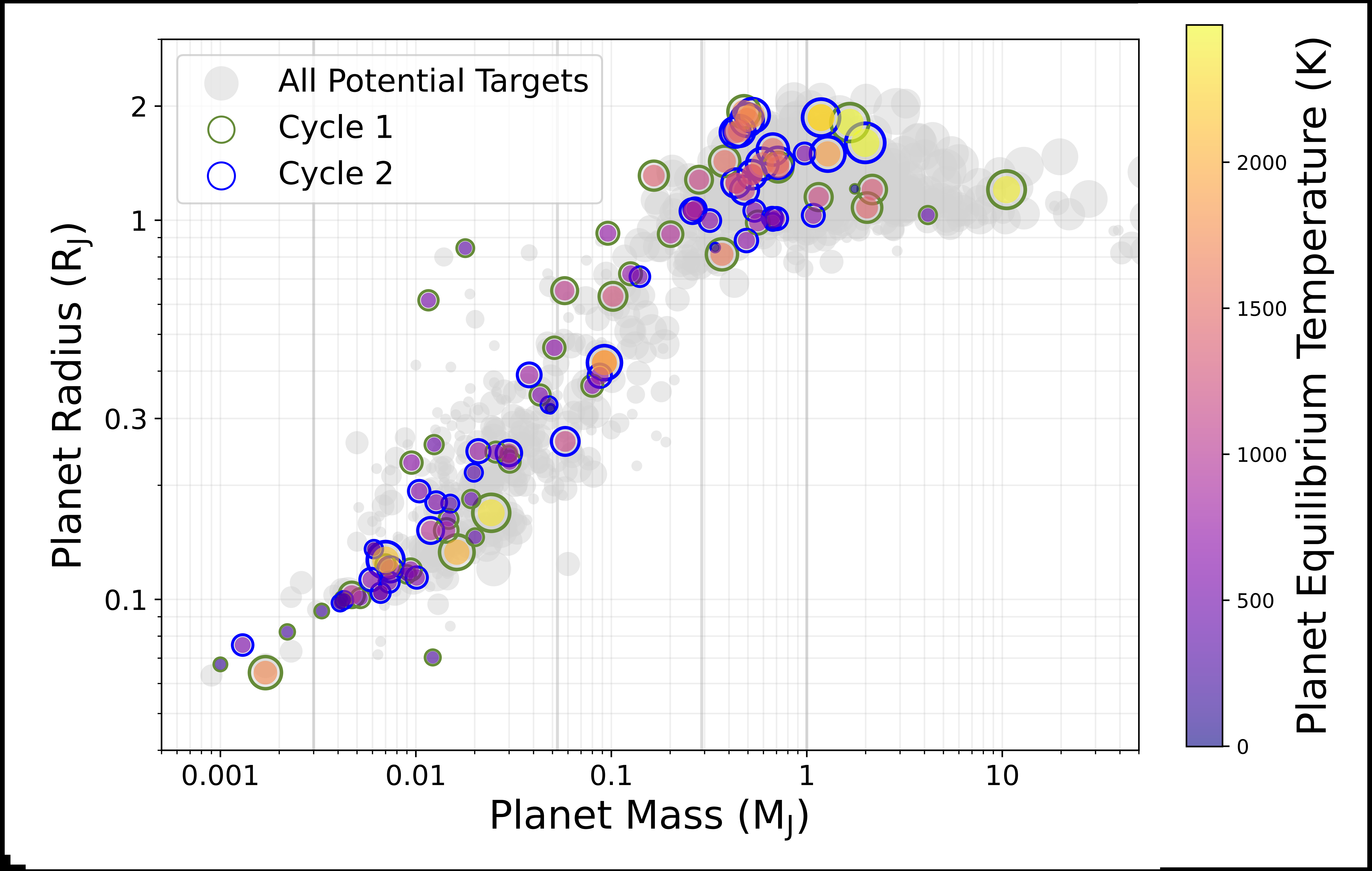


Figure Credit: Hannah Wakeford/Sarah Moran

Image Credit: NASA

“Your future is whatever you make it, so make it a good one.”

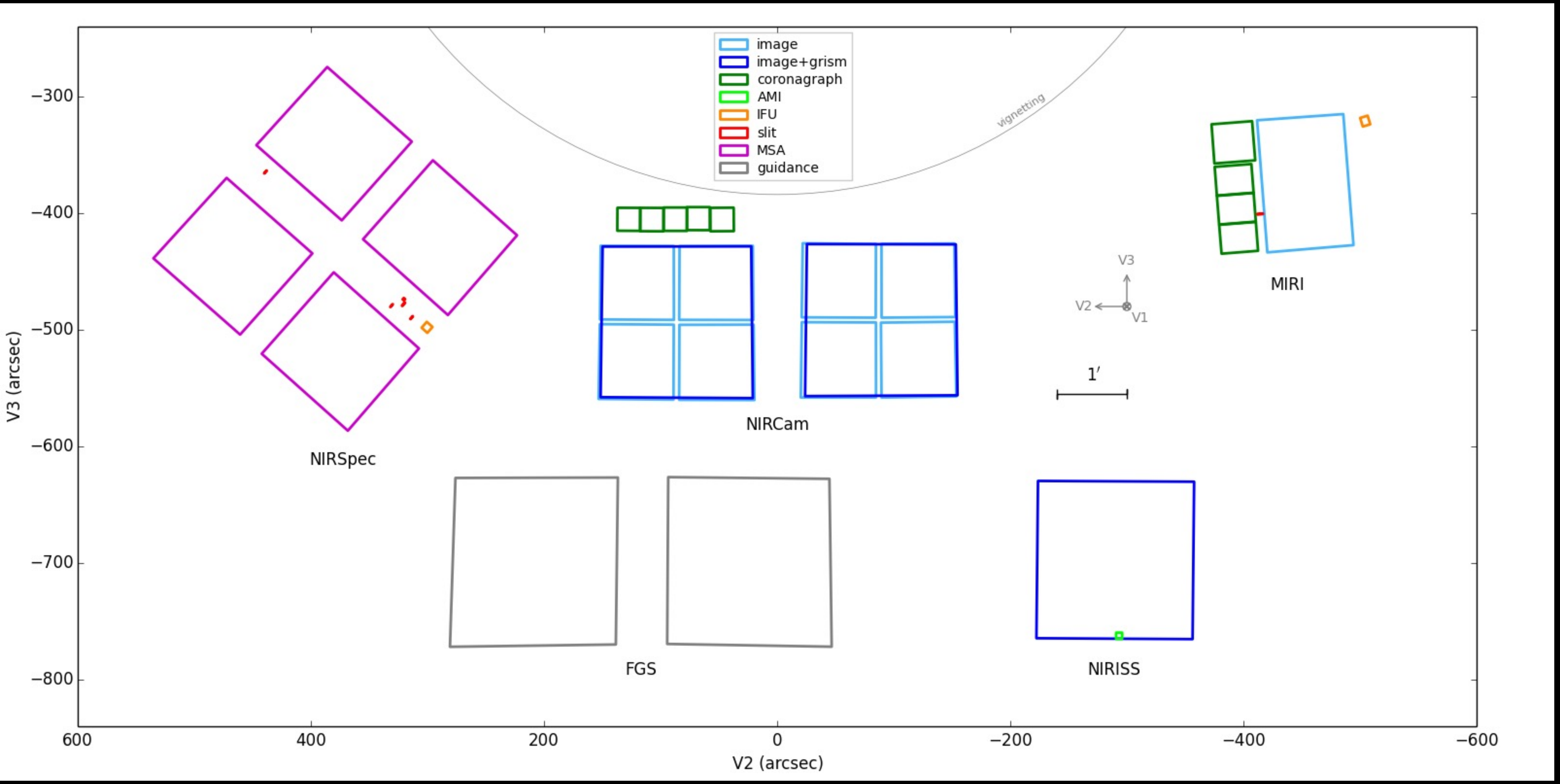
-Doc Brown

JWST Cycle 3 GO deadline = Wednesday October 25th, 2023

JWST High-Precision Bright-Object Time-Series Modes

NIRCam
0.6-5 microns
Spectroscopy
2.5-5.0 microns
K > 3.5, R~1450
Photometry
0.7-4.8 microns
K > 1.0

NIRSpec BOTS
1-5 microns
Spectroscopy
J > 5, R~2700
J > 6, R~1000
J > 9.5, R~100



https://jwst-docs.stsci.edu/methods-and-roadmaps/jwst-time-series-observations

MIRI
5-28 microns
Slitless Spectroscopy
K > 5, R~100
IFU Spectroscopy
4.9-27.9 microns
K > 2, R~1500-3500
Photometry
5.6-25.5 microns
K > 2

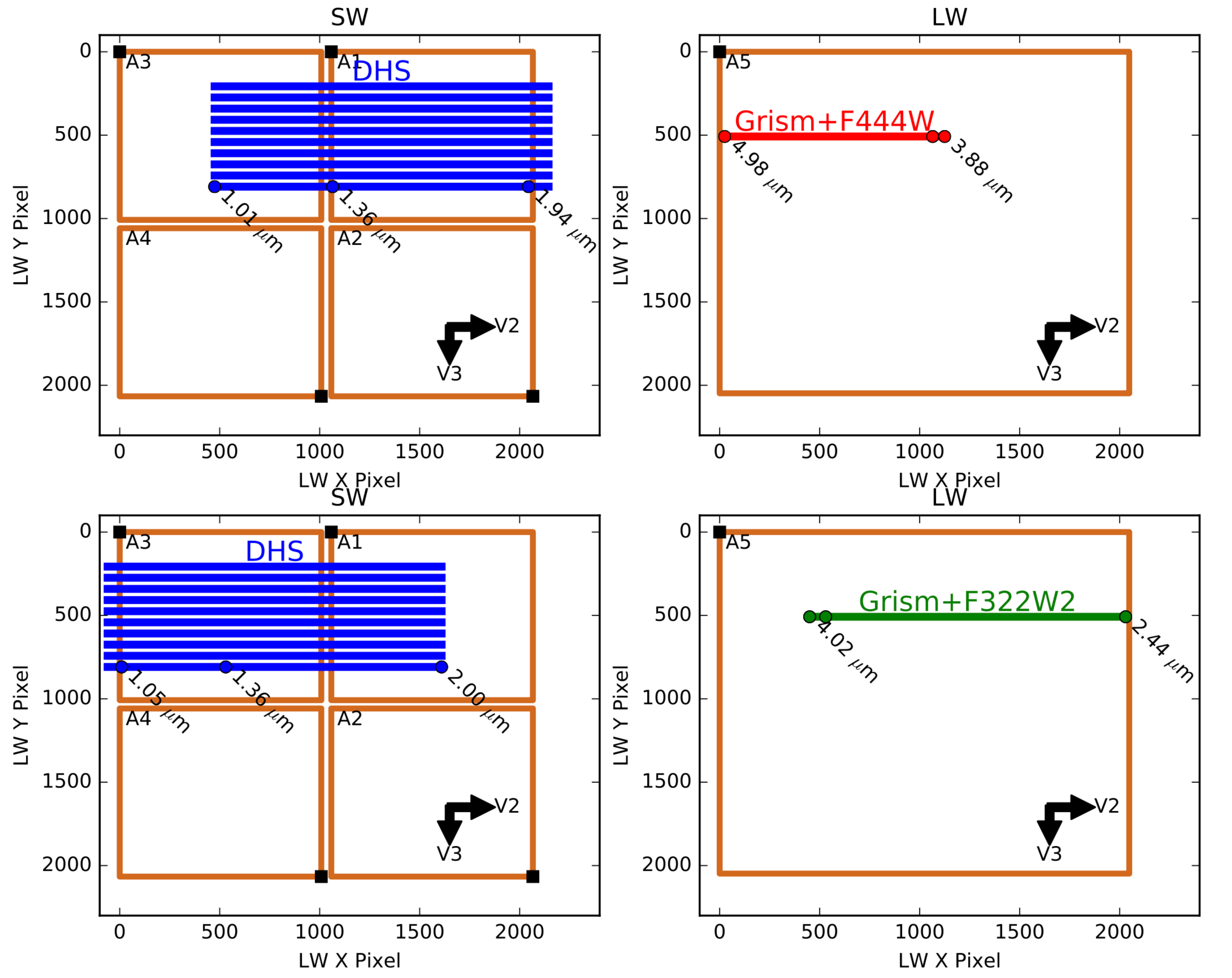
NIRISS SOSS
0.6-2.8 microns
Spectroscopy
J > 6, R~700

JWST High-Precision Bright-Object Time-Series Modes: New for Cycle 3!

1.0-2.0 µm spectra can be taken at the same time as the standard, longer wavelength, F322W2 (2.5-4.0 µm) or F444W (4.0-5.0 µm) spectra on the long wavelength detectors

NIRCam DHS produces 10 R~300 spatially separated spectra

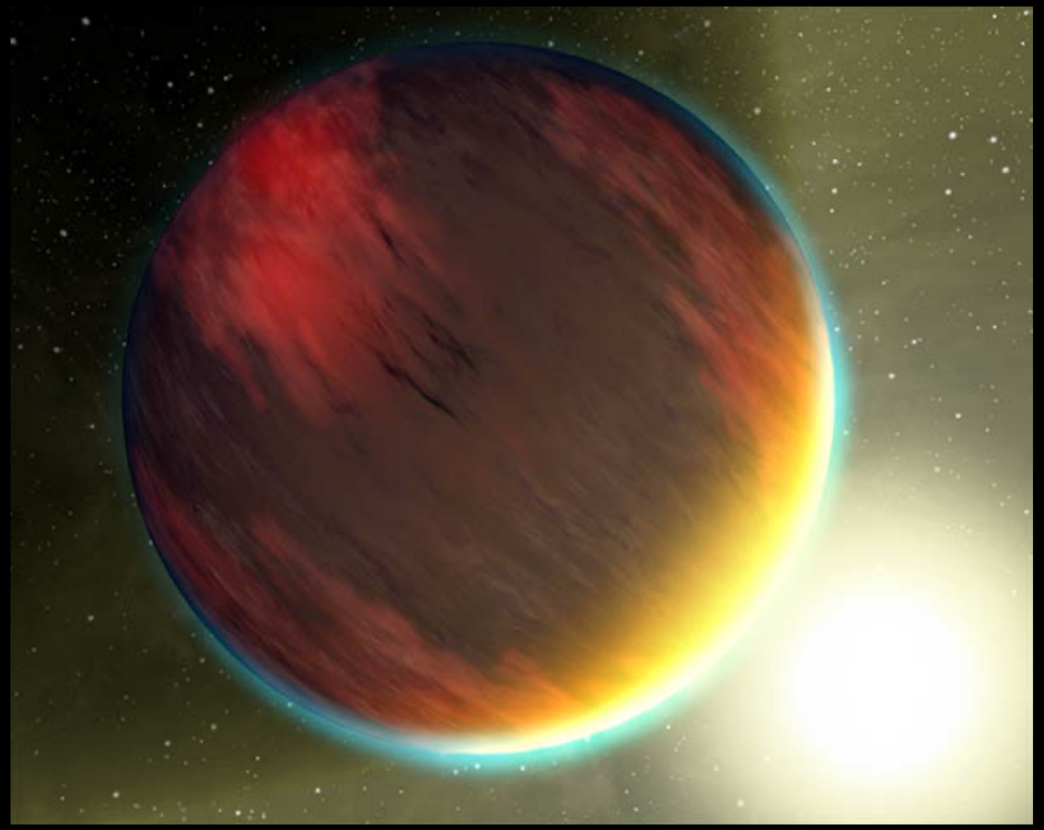
Targets as bright as K~1 can be observed with this mode!



Schlawin et al. 2017

JWST Transiting Exoplanet Proposal Roadmap

1) Science Question



2) Targets and Models

https://jwst.etc.stsci.edu/

PandExo

Batalha et al. (2017), https://natashabatalha.github.io/PandExo/

3) Modes and Precision

4) Make sure you have the team necessary to tackle proposal and future observations

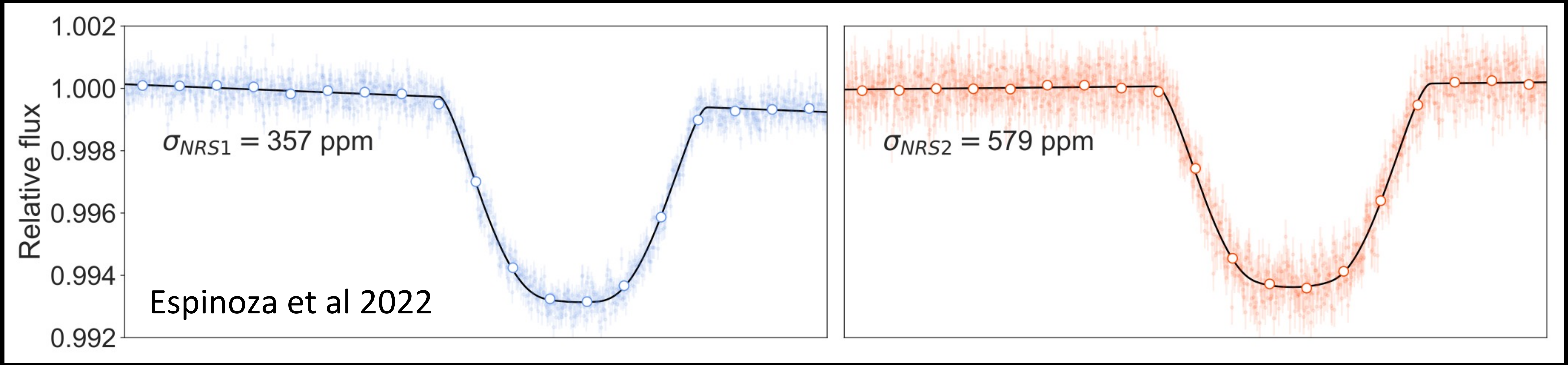
apt.stsci.edu

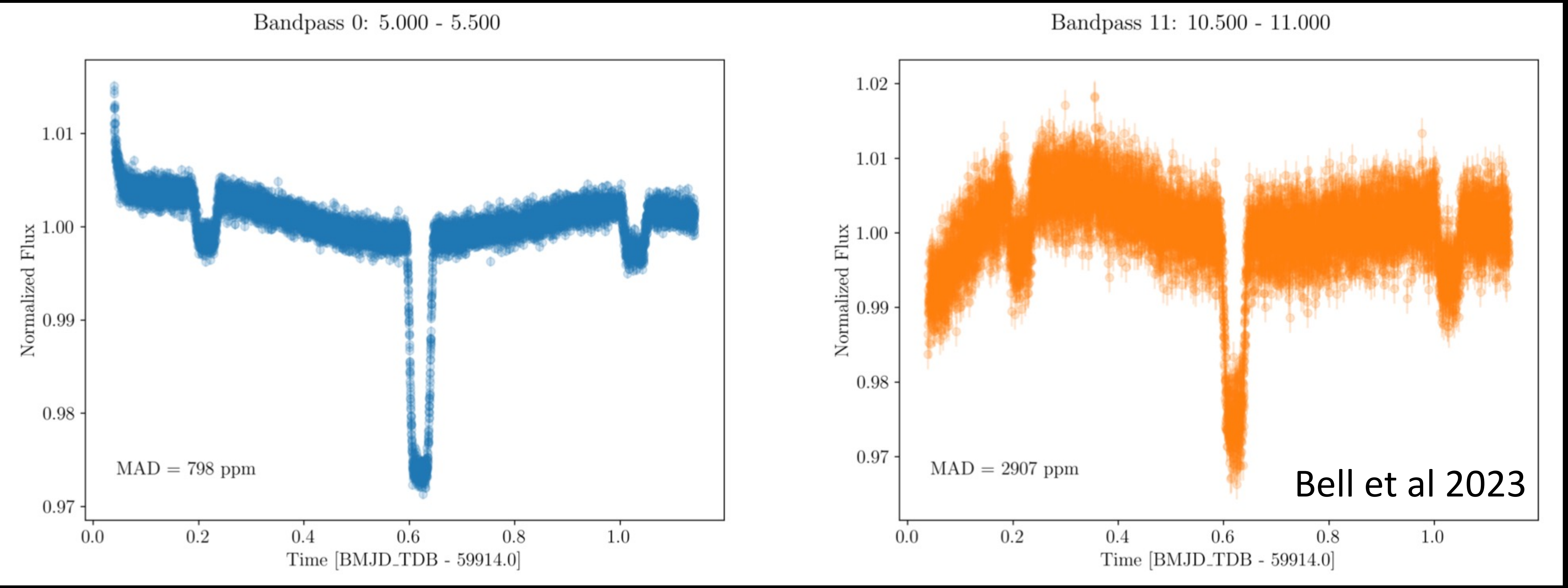
5) Iterate, polish, submit and wait..

"There are no insurmountable challenges to Transiting Exoplanet Observations with JWST."

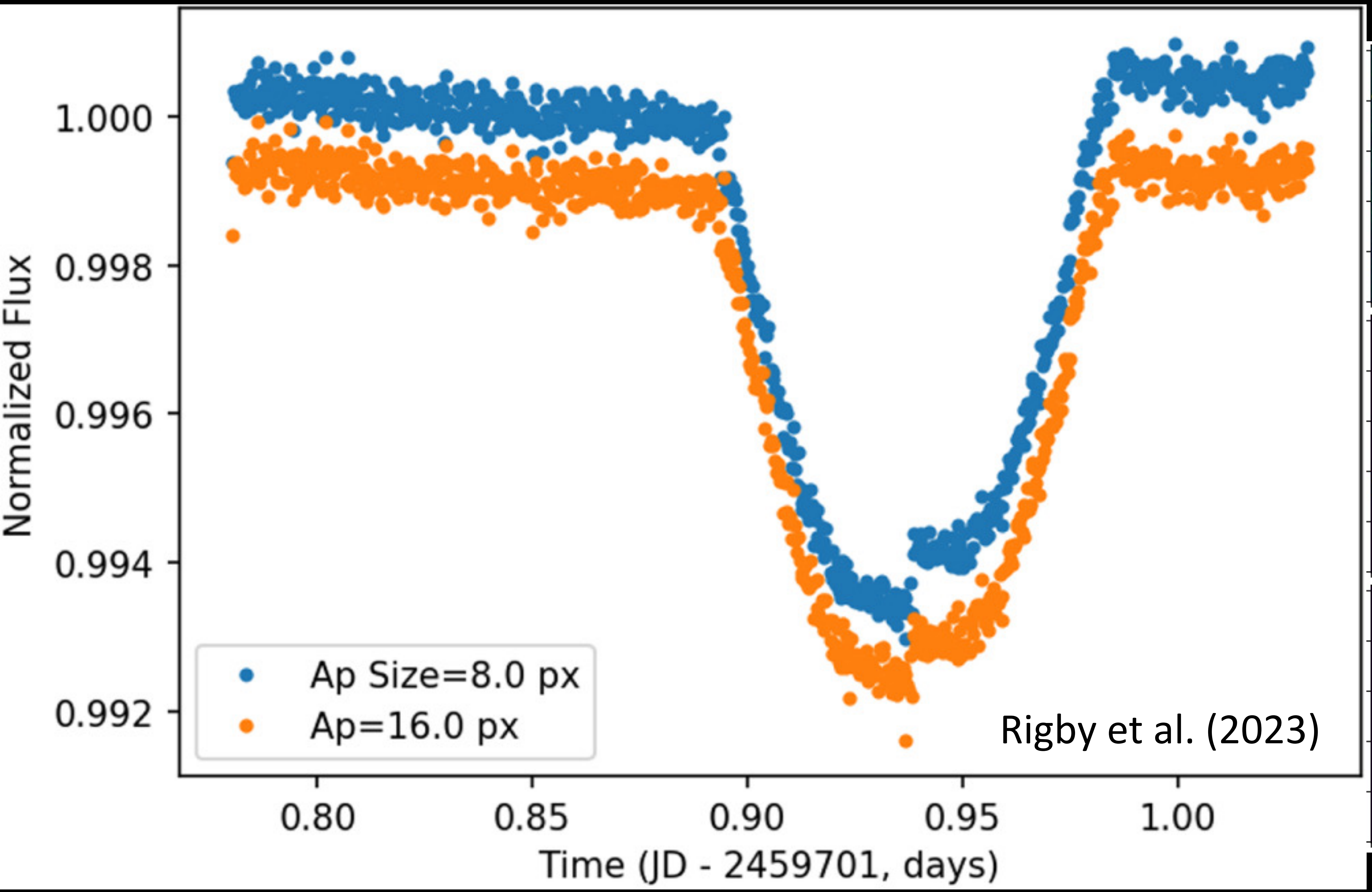
-Nikole Lewis

Surmountable challenges for JWST transiting exoplanet atmospheric characterization observations

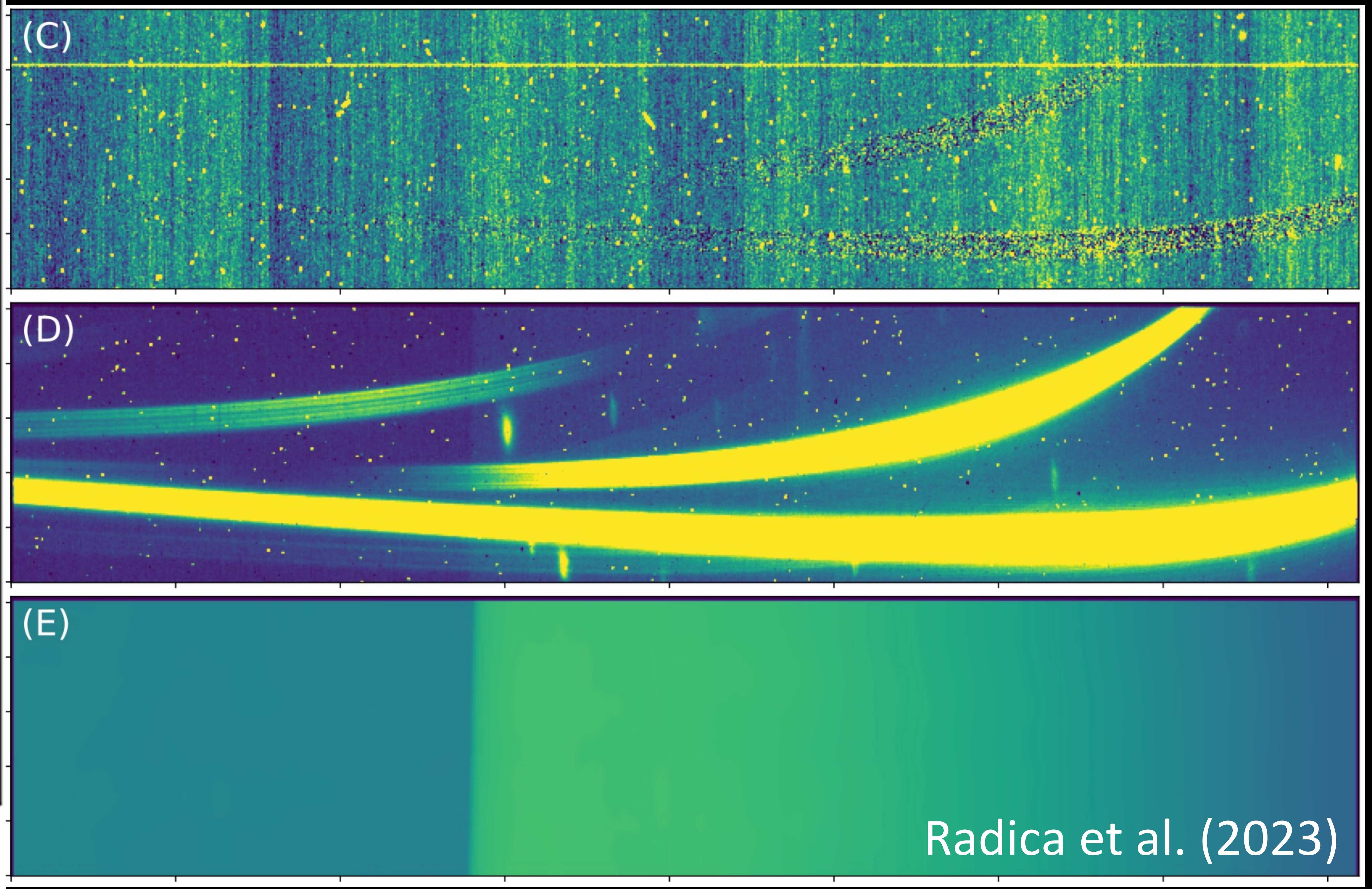




Surmountable challenges for JWST transiting exoplanet atmospheric characterization observations

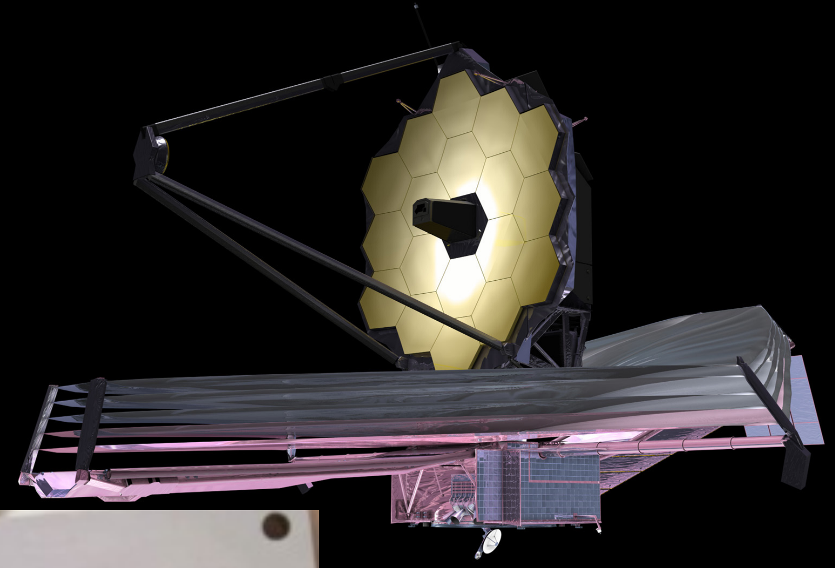


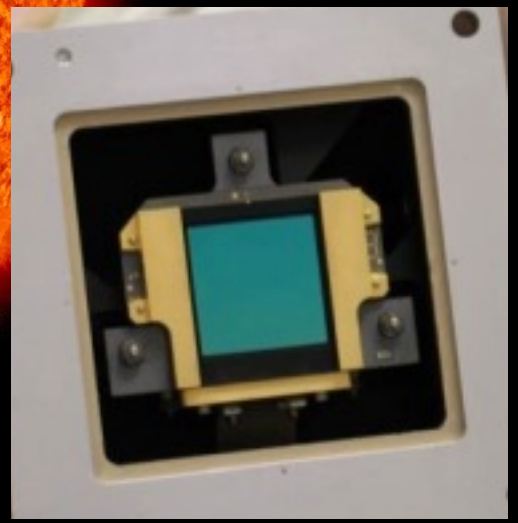
Mirror Tilt Events



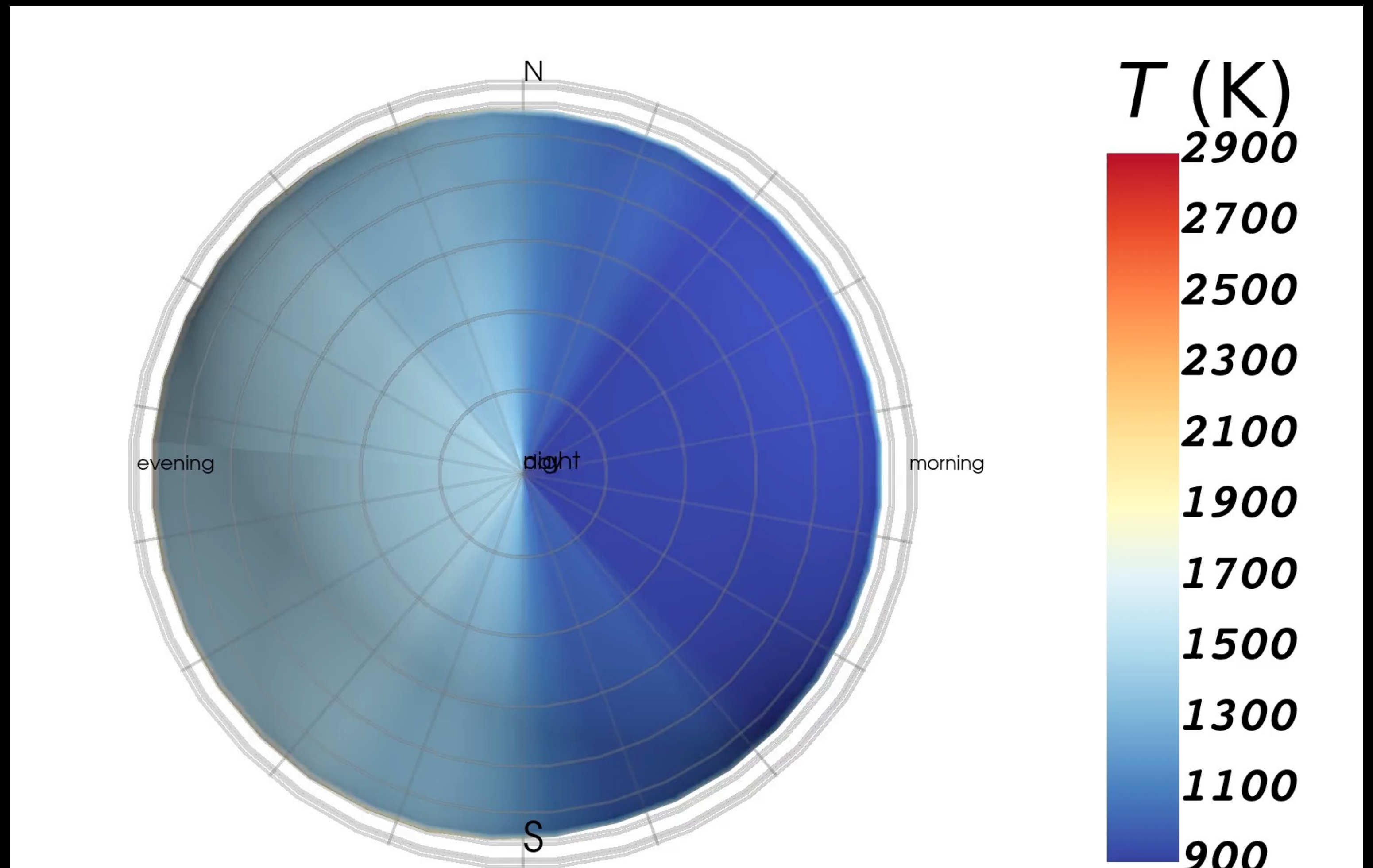
1/f and background noise

Surmountable Challenges for JWST exoplanet atmospheric characterization observations



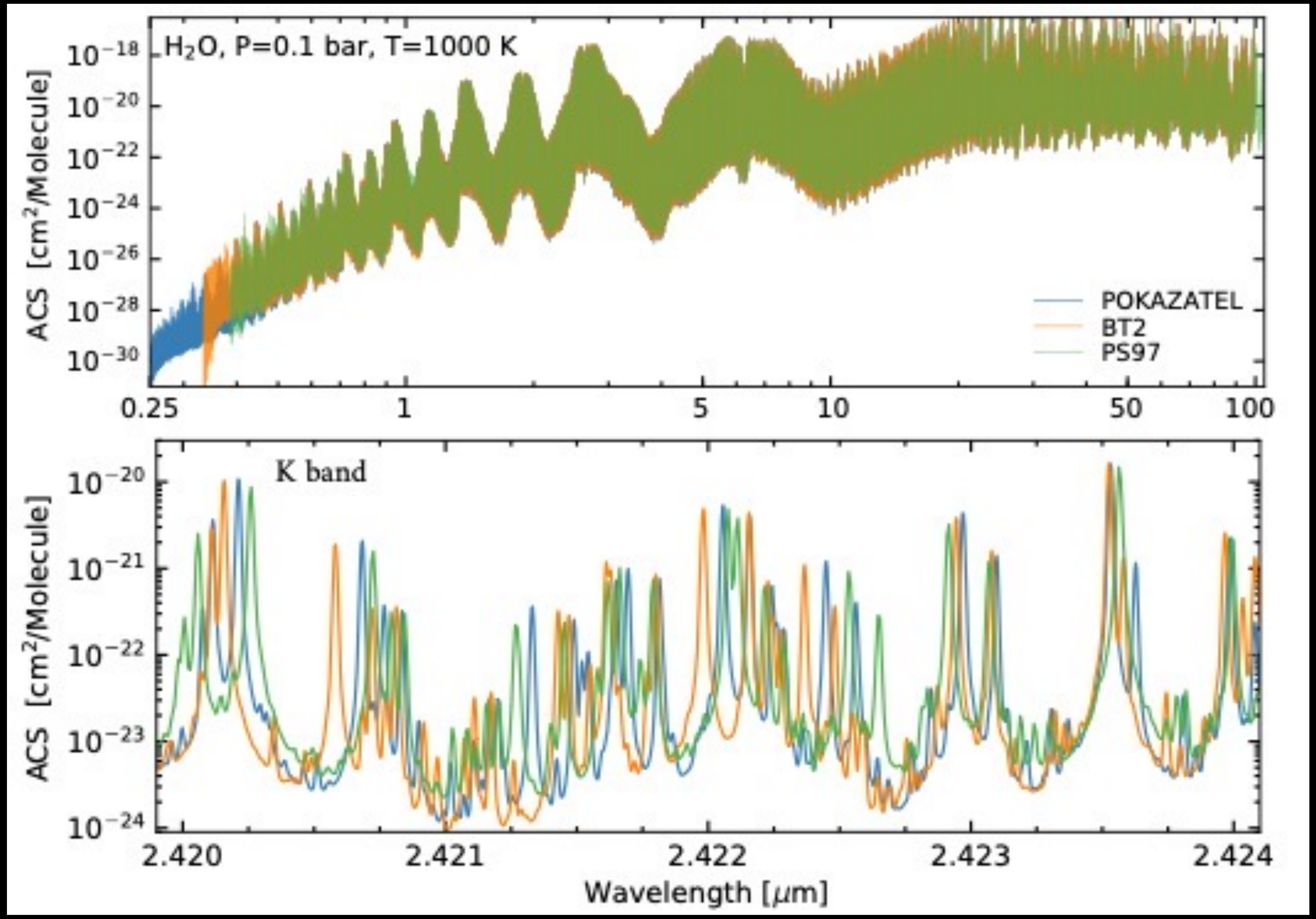


Noise Sources

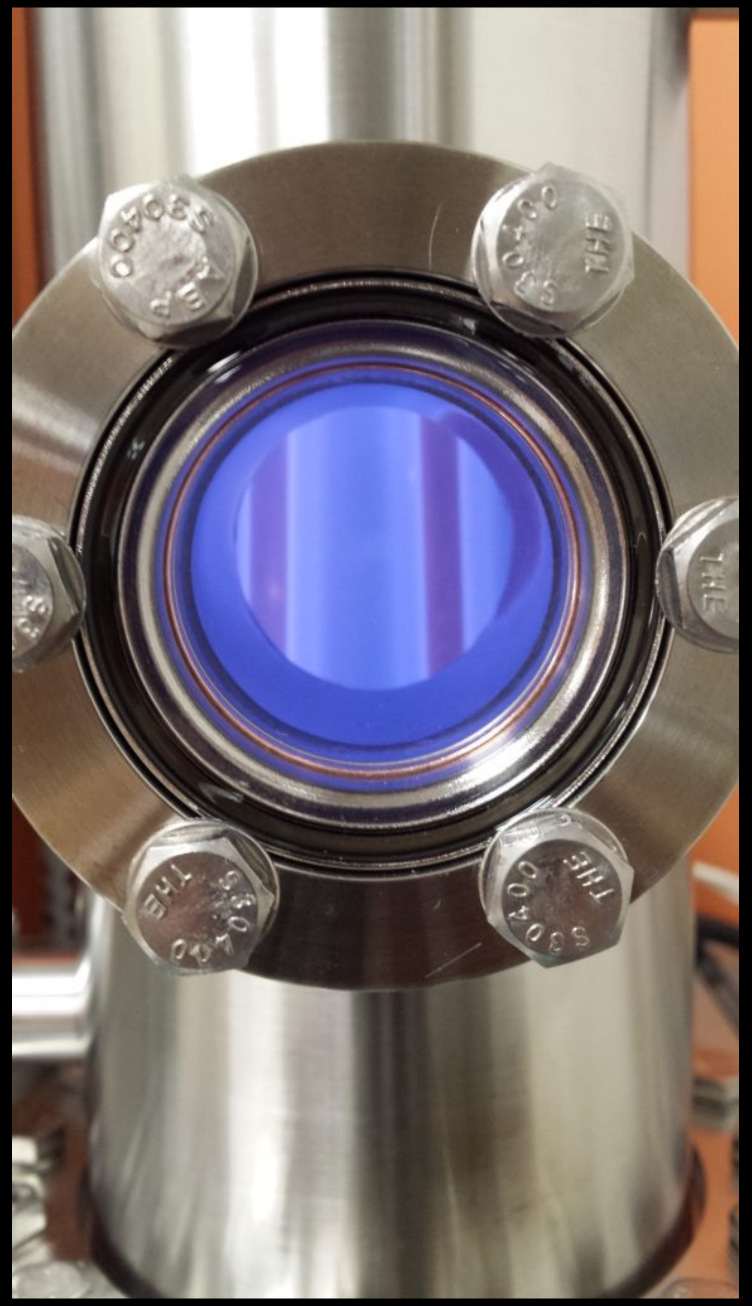


MacDonald & Lewis (2022)

3D atmospheric structure and processes



Gharib-Nezhad et al. (2021)



Hörst et al. (2018)

Robust chemistry/opacity databases
Supporting laboratory investigations

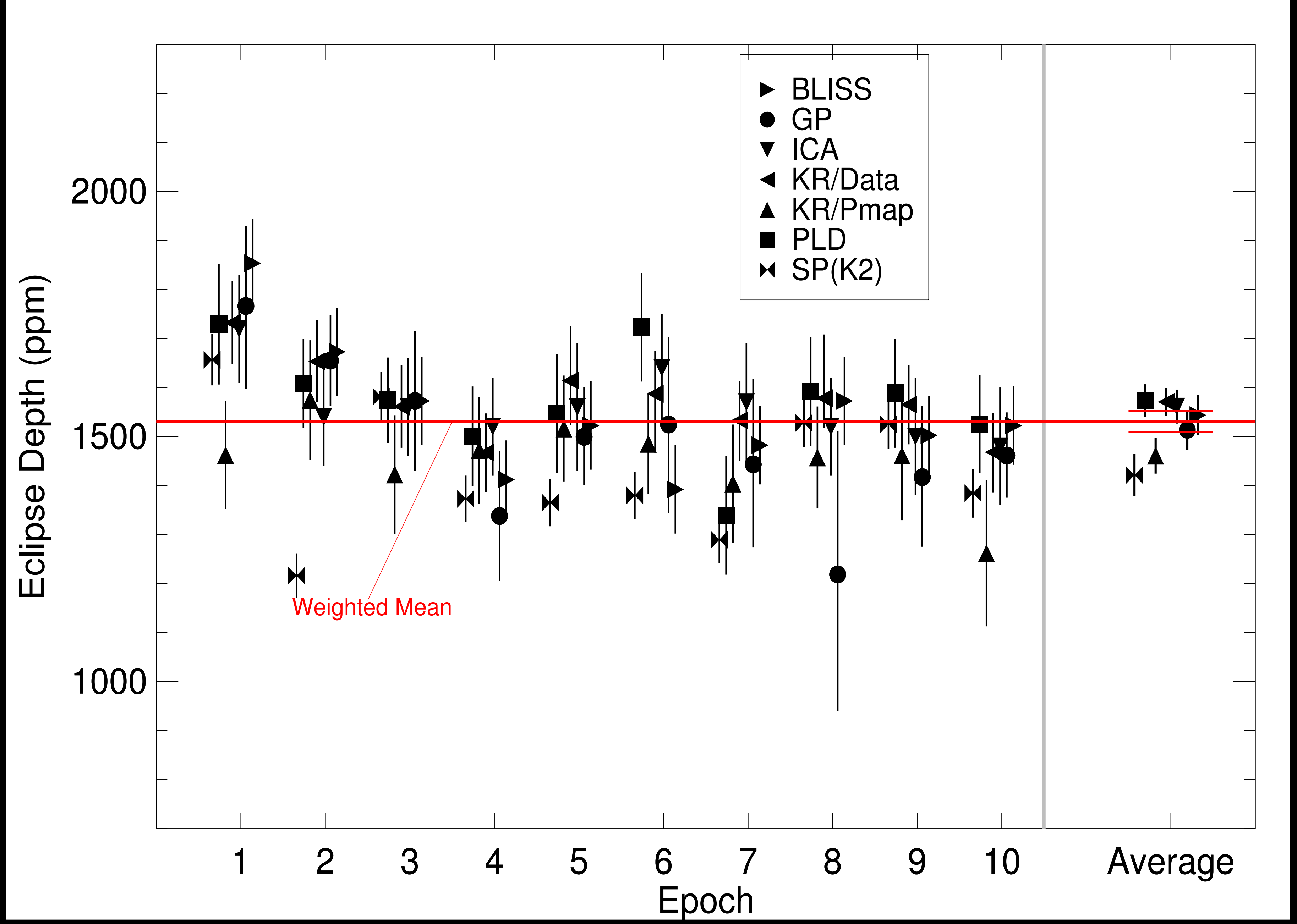
See Fortney and 80+ co-authors whitepapers

Surmountable challenges for JWST transiting exoplanet atmospheric characterization observations

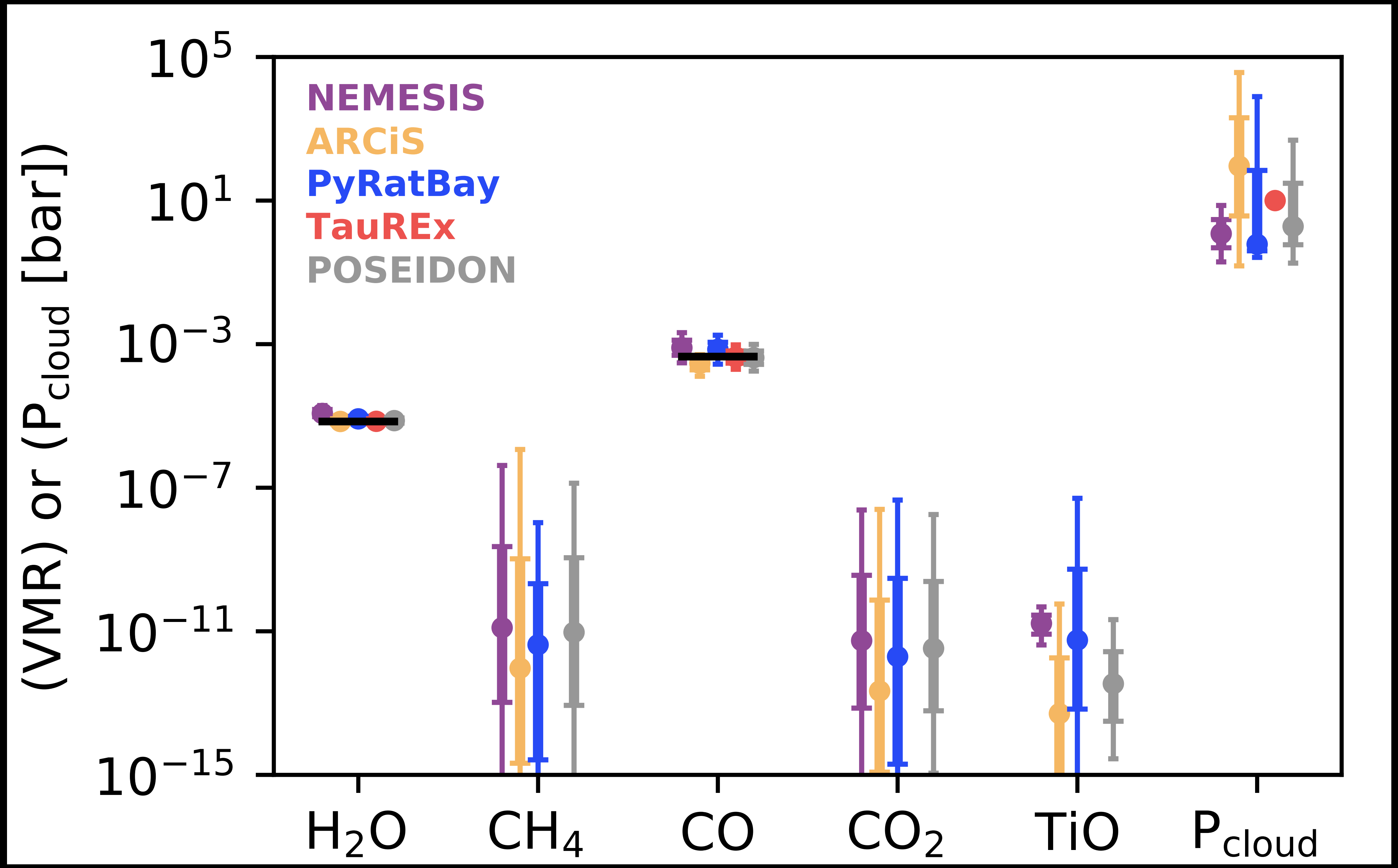
“If you want to go fast, go alone.
If you want to go far, go together.”

-African Proverb

Community-driven workshops, data challenges, collaborations and open-source software can accelerate the rate at which new insights into exoplanet atmospheres are gained in the coming decade



Spitzer Data Reduction Challenge (Ingalls et al. 2016)



Ariel Atmospheric Retrieval Challenge (Barstow et al. 2022)

JWST Transiting Exoplanet ERS Collaboration (ers-transit.github.io)

In the coming decade JWST will not be the only space-based facility spectroscopically probing transiting exoplanet atmospheres

CUTE – Cubesat
launched in 2021

Pandora – Smallsat
launch in mid-2020s

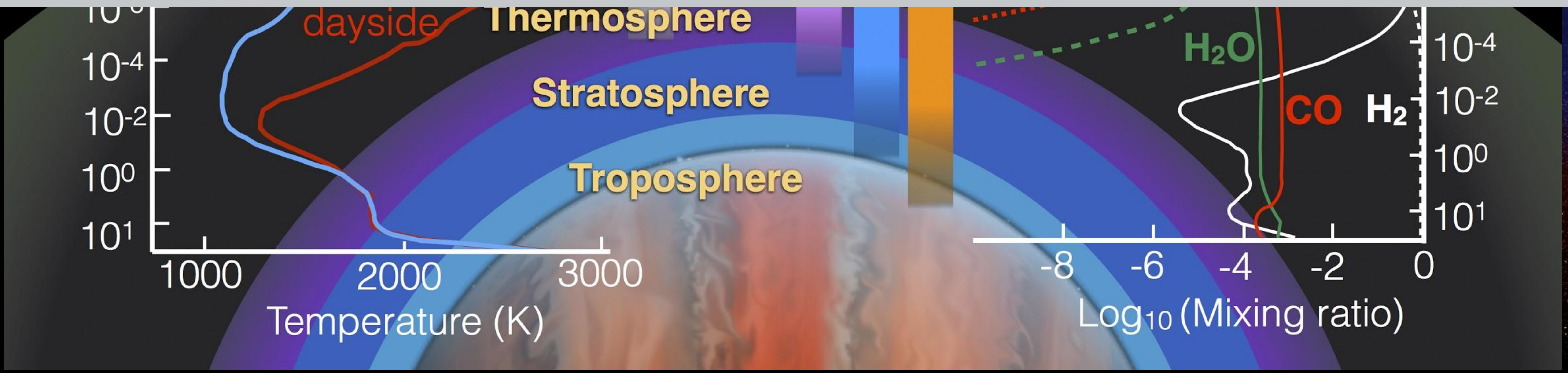
Ariel – M4 Mission
launch in 2029

In the era of JWST, *Hubble* will still provide critical access to UV, Optical, and NIR wavelengths necessary for understanding exoplanet atmospheric chemistry and evolution

<u>Strategic Exoplanet Initiatives with HST and JWST</u> Working Group

https://sites.google.com/view/exoplanet-strategy-wg

Townhall on July 31st, 2023 is reserved for early career researchers!



Credit: Mercedes Lopez-Morales

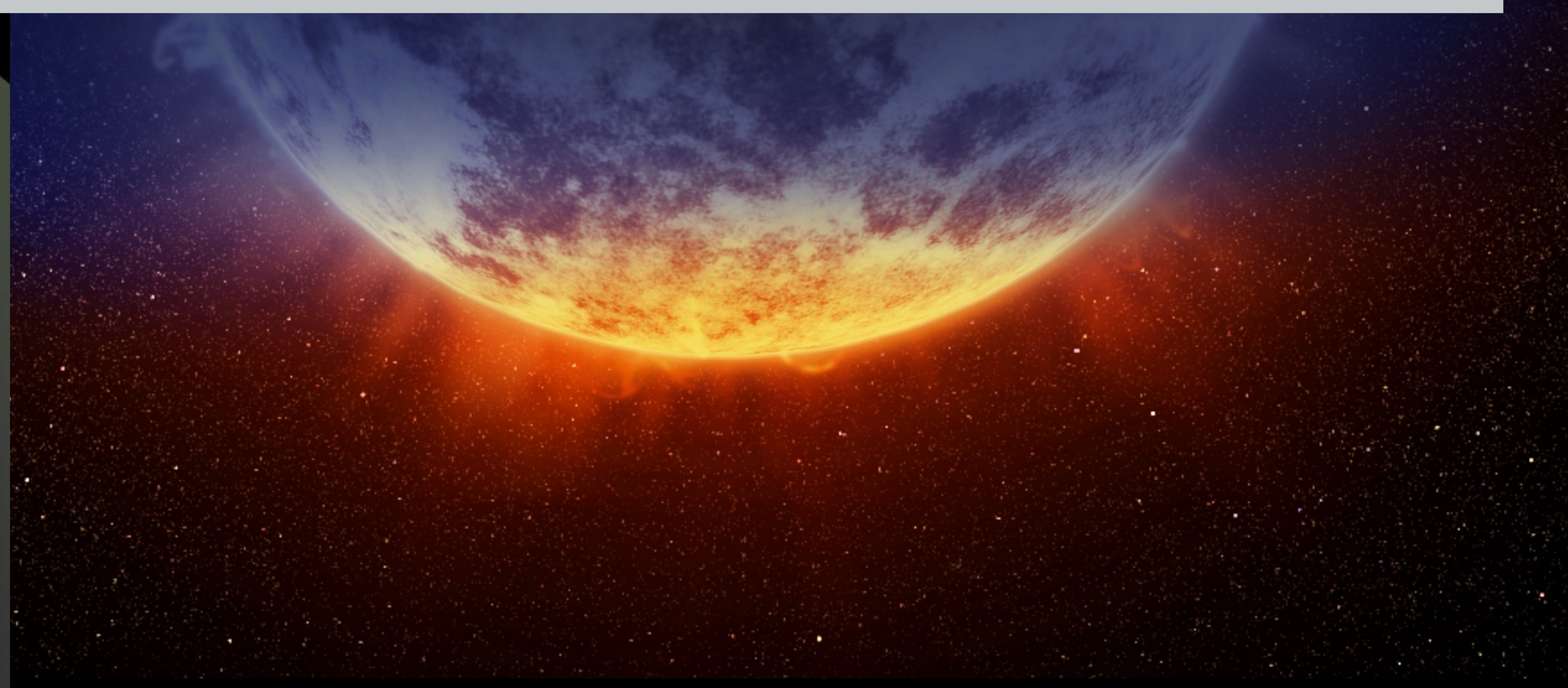
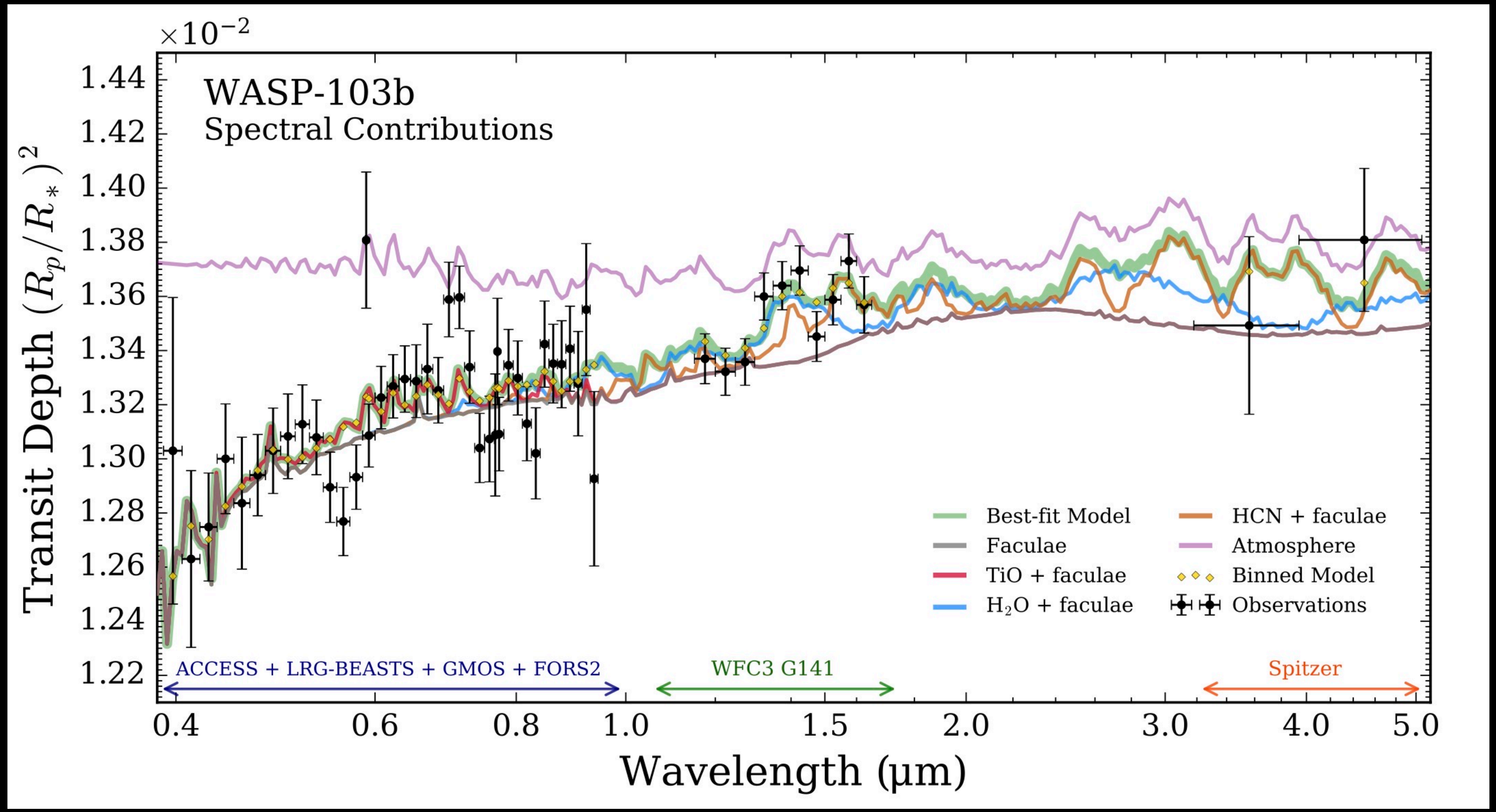
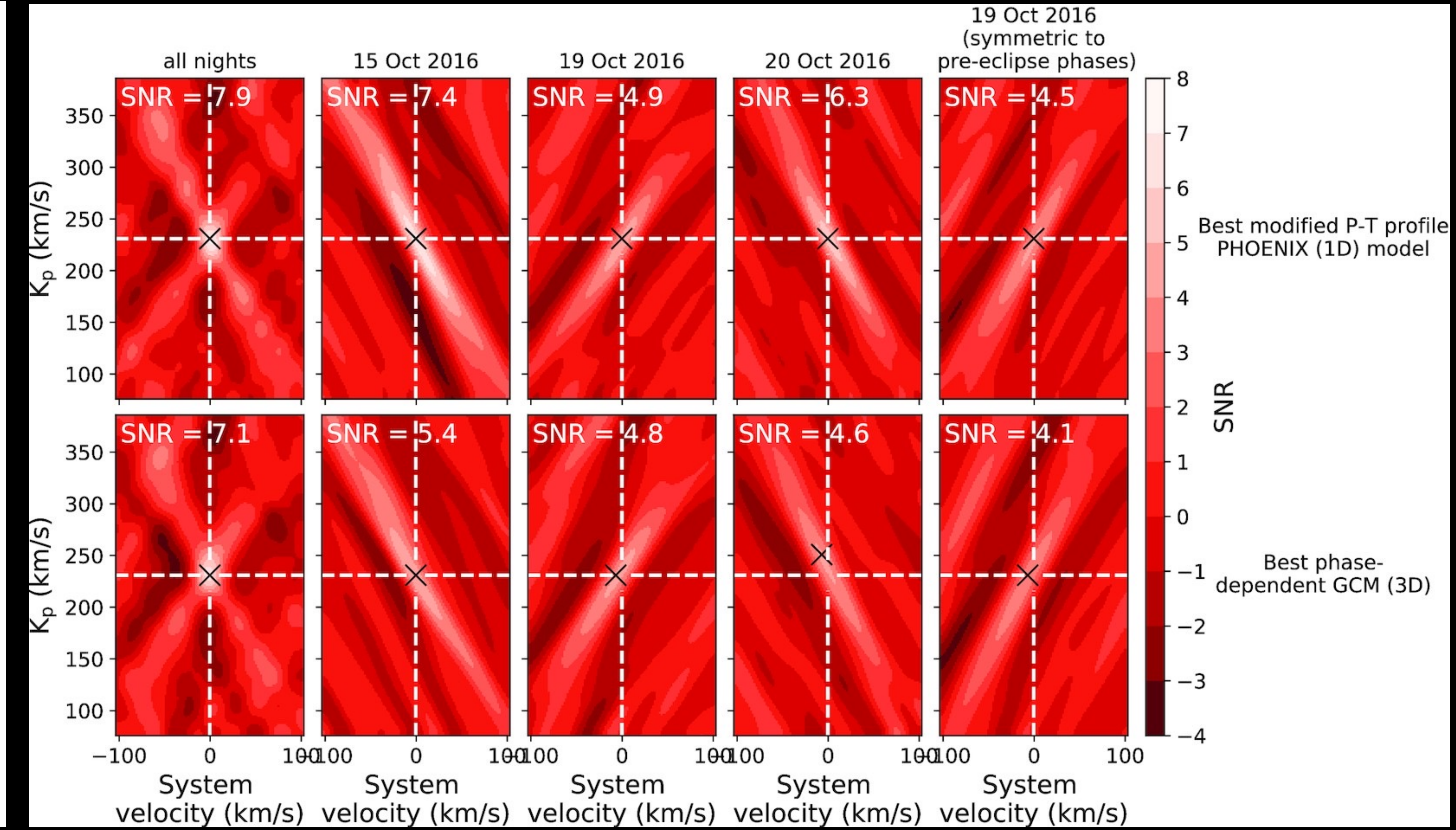


Image Credits: NASA/ESA/STScI

Opportunities for synergies between ground and space-based observatories for transiting exoplanet atmospheric characterization



Kirk et al. (2021)

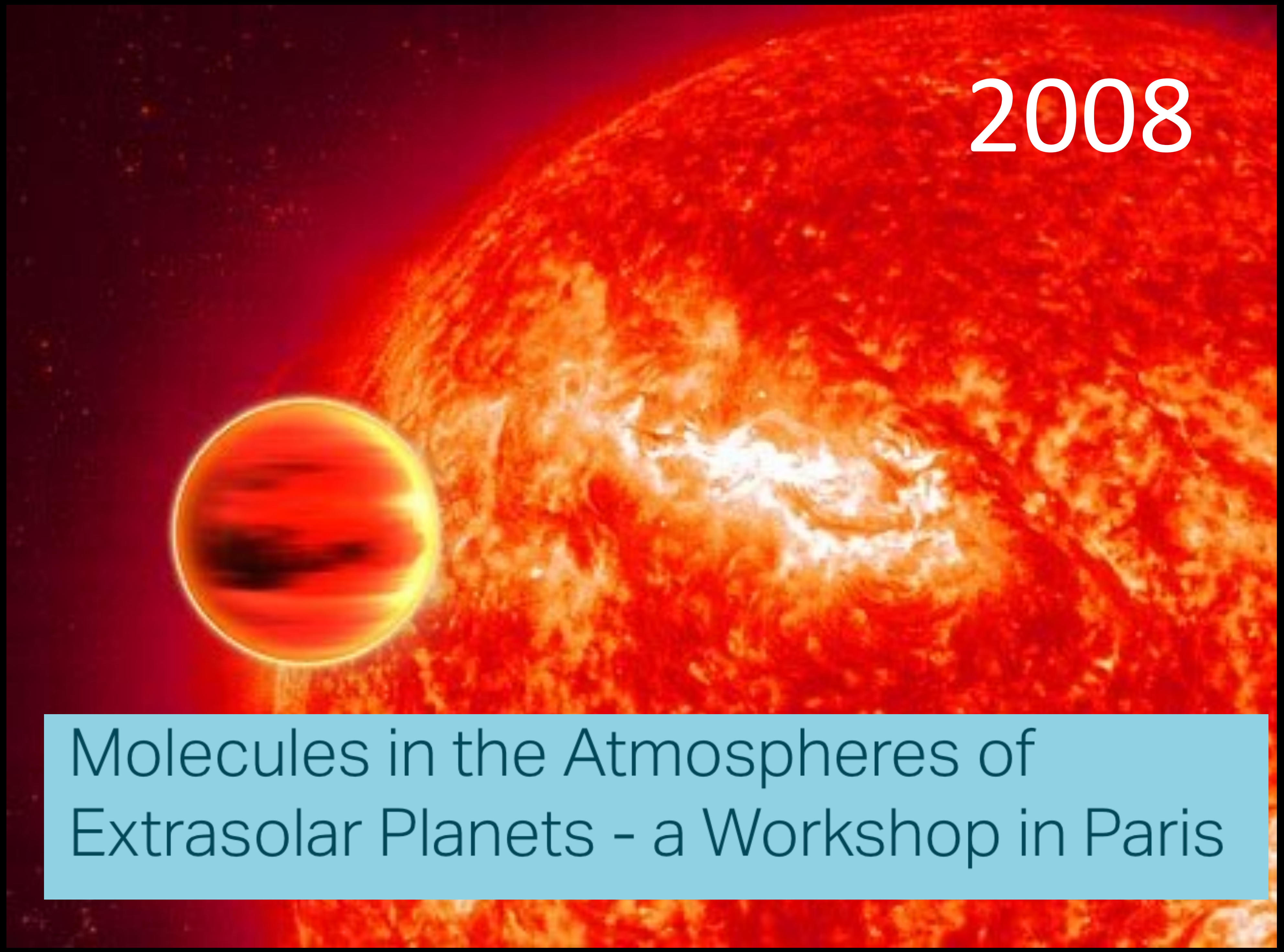


Van Sluijs al. (2023)

Low-resolution optical/NIR transmission spectroscopy and stellar monitoring

High-resolution resolution optical/NIR spectroscopy

Early-career researchers have an important opportunity shape JWST transiting exoplanet science in the coming decade…



My First Exoplanet Meeting (~ 50 people)

To today…. (1000+ people)