STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

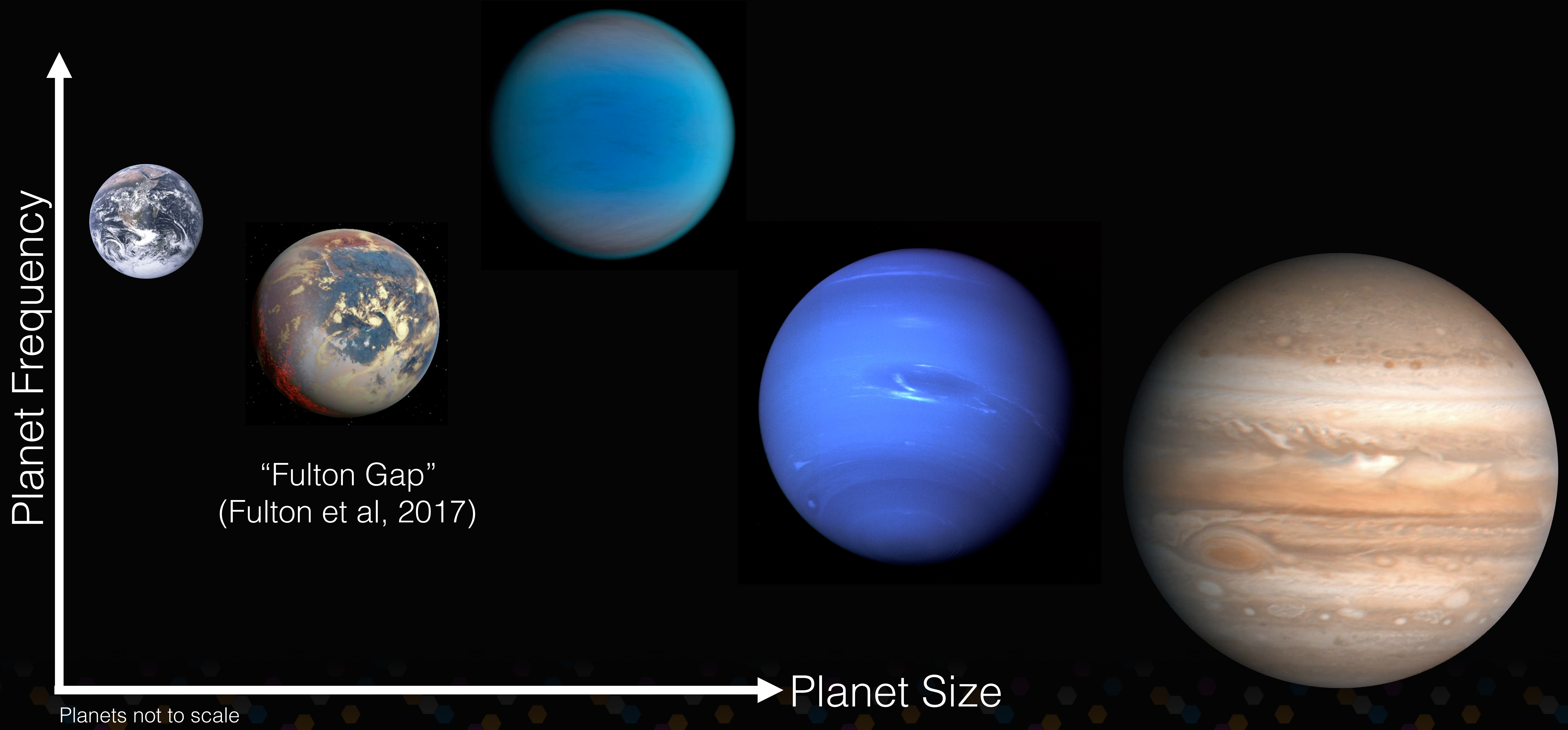
Transiting Exoplanet Science with JWST

Kevin B. Stevenson

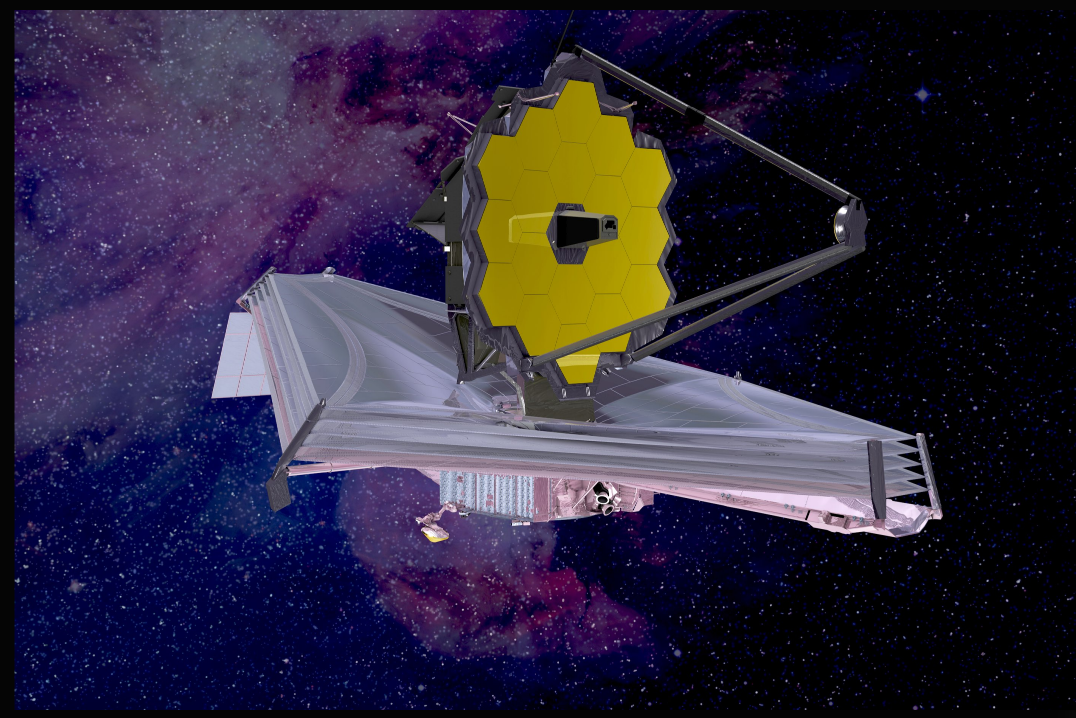
STScI JWST Transiting Exoplanet WG Lead

03/06/18

First exoplanet detected in 1995…

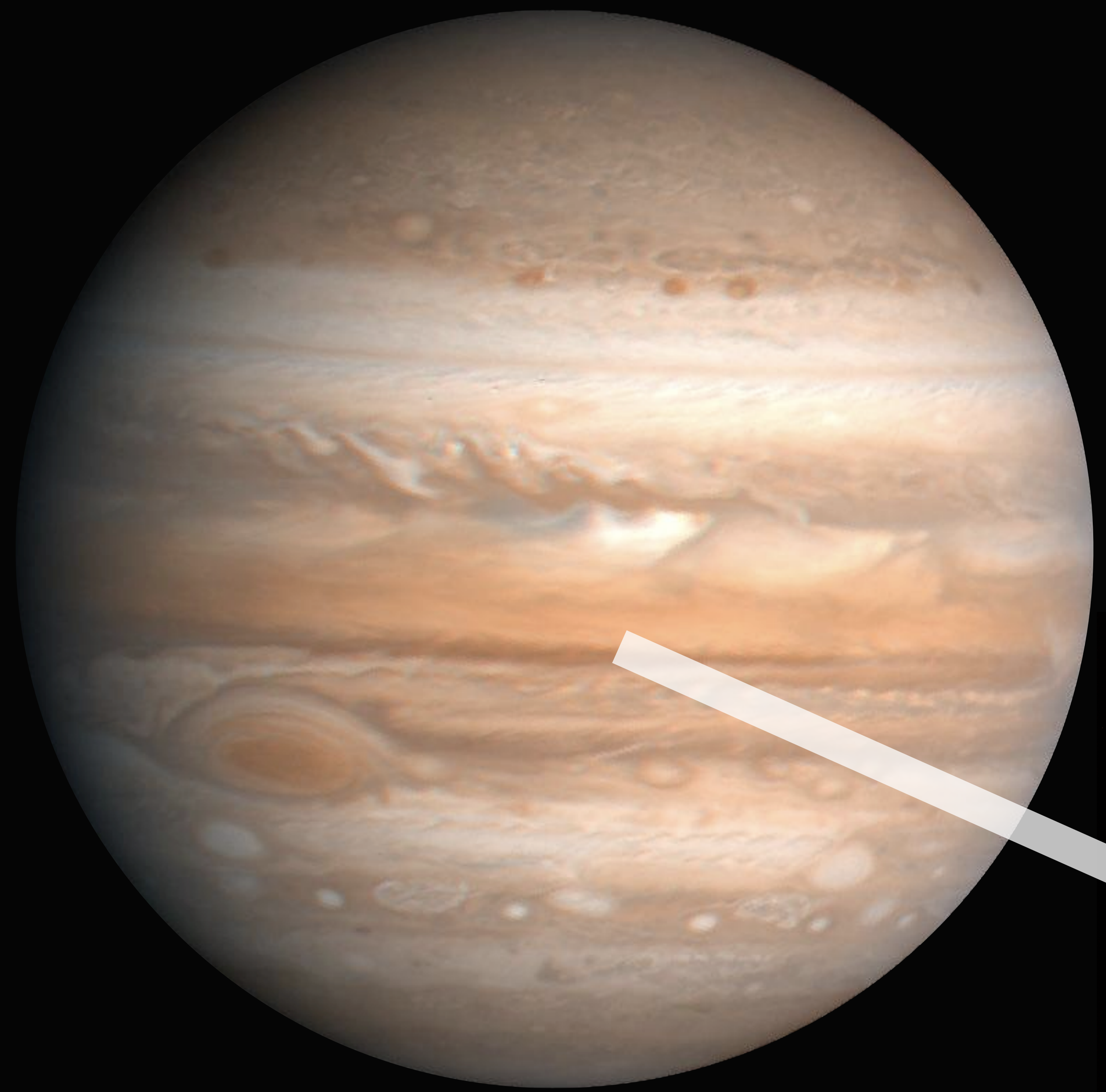


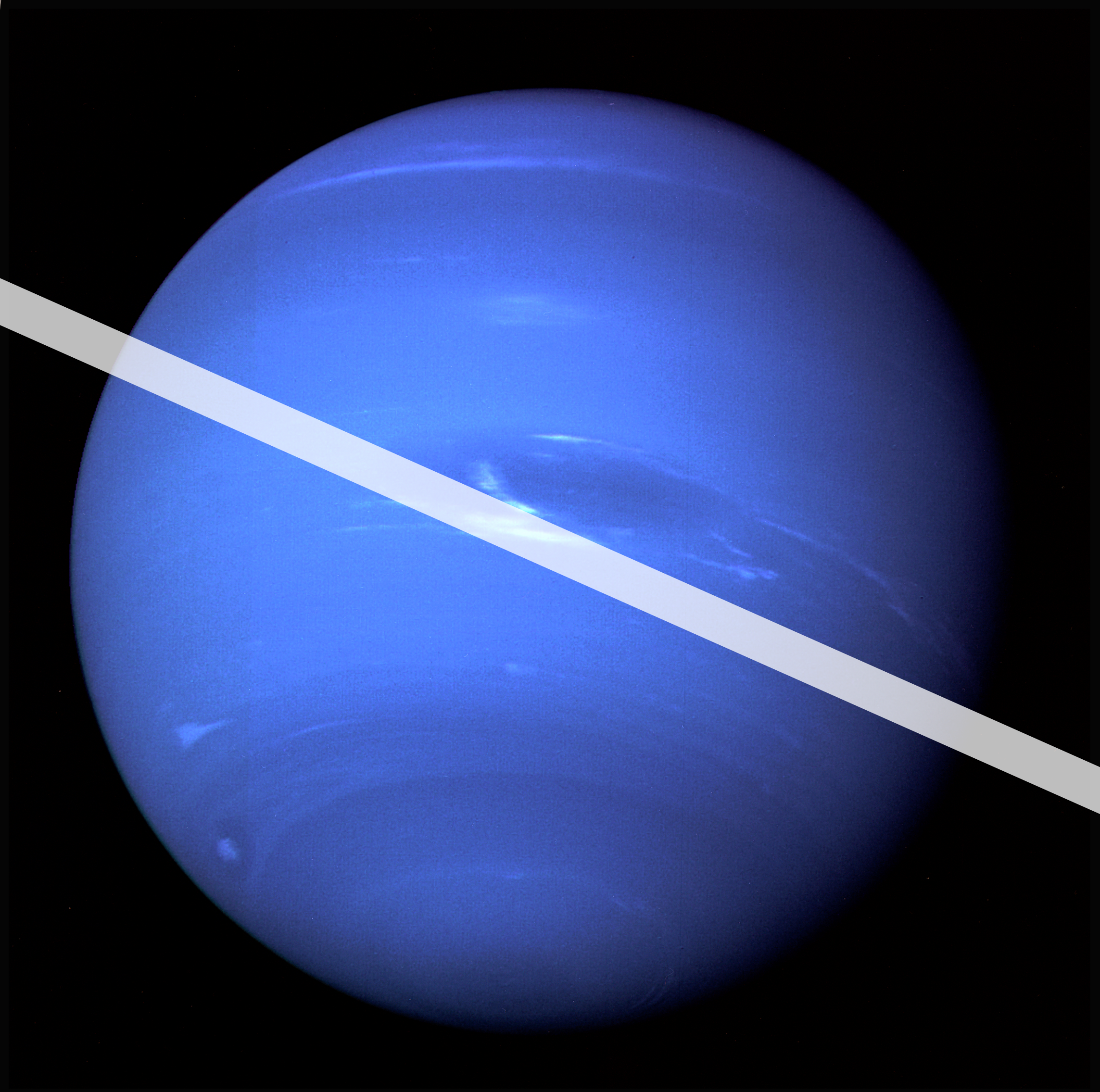
… In 2018, 3700 confirmed exoplanets & 4500 Kepler candidates

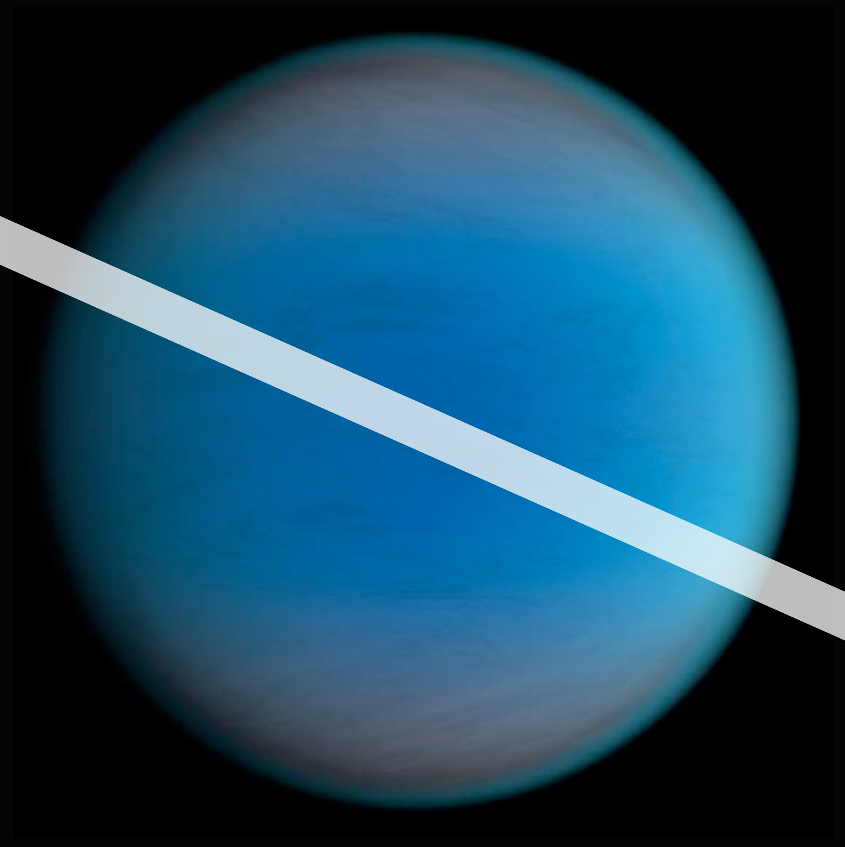


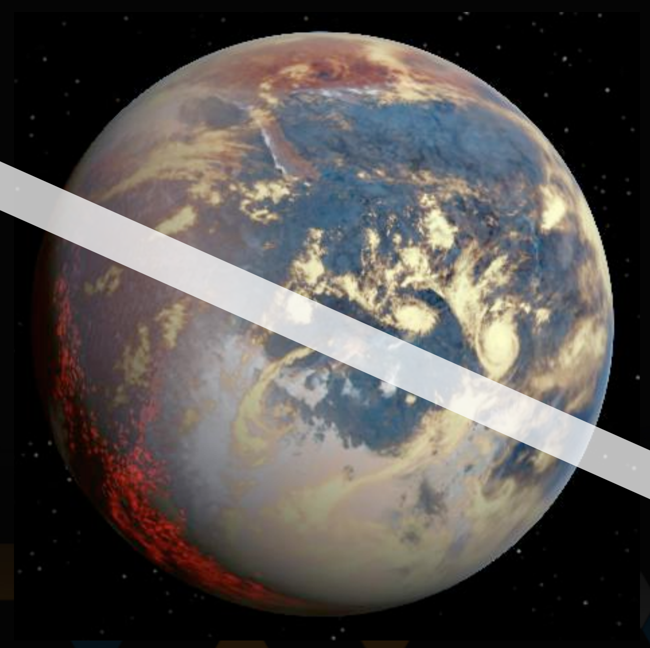
In the era of *Webb*

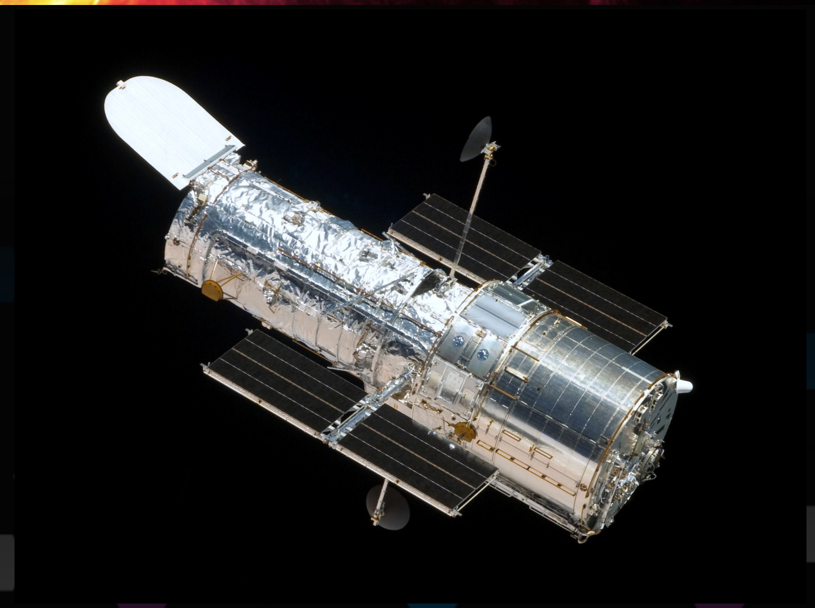
Potential to characterize >300 exoplanets at high resolution and across a broad range of wavelengths







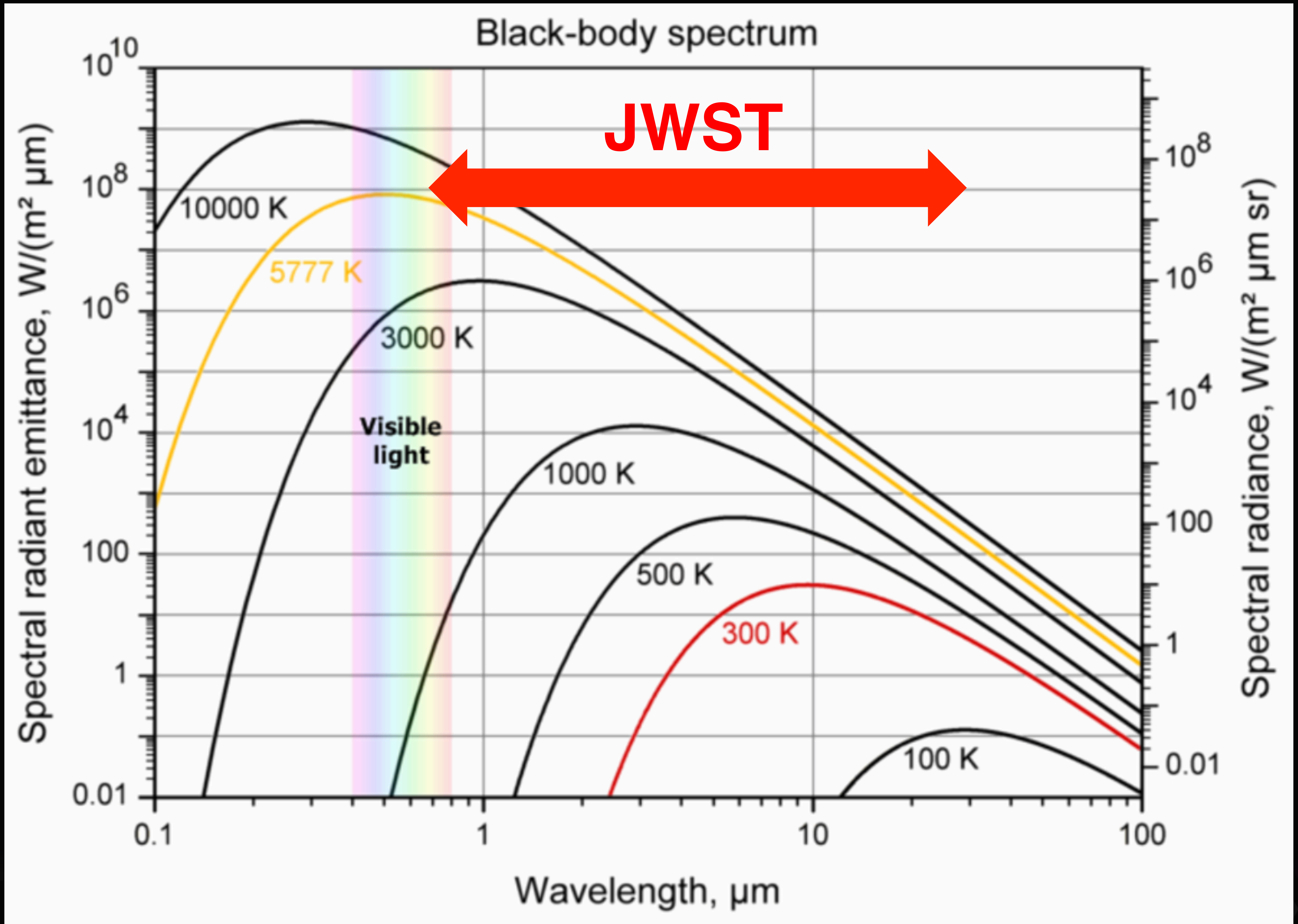


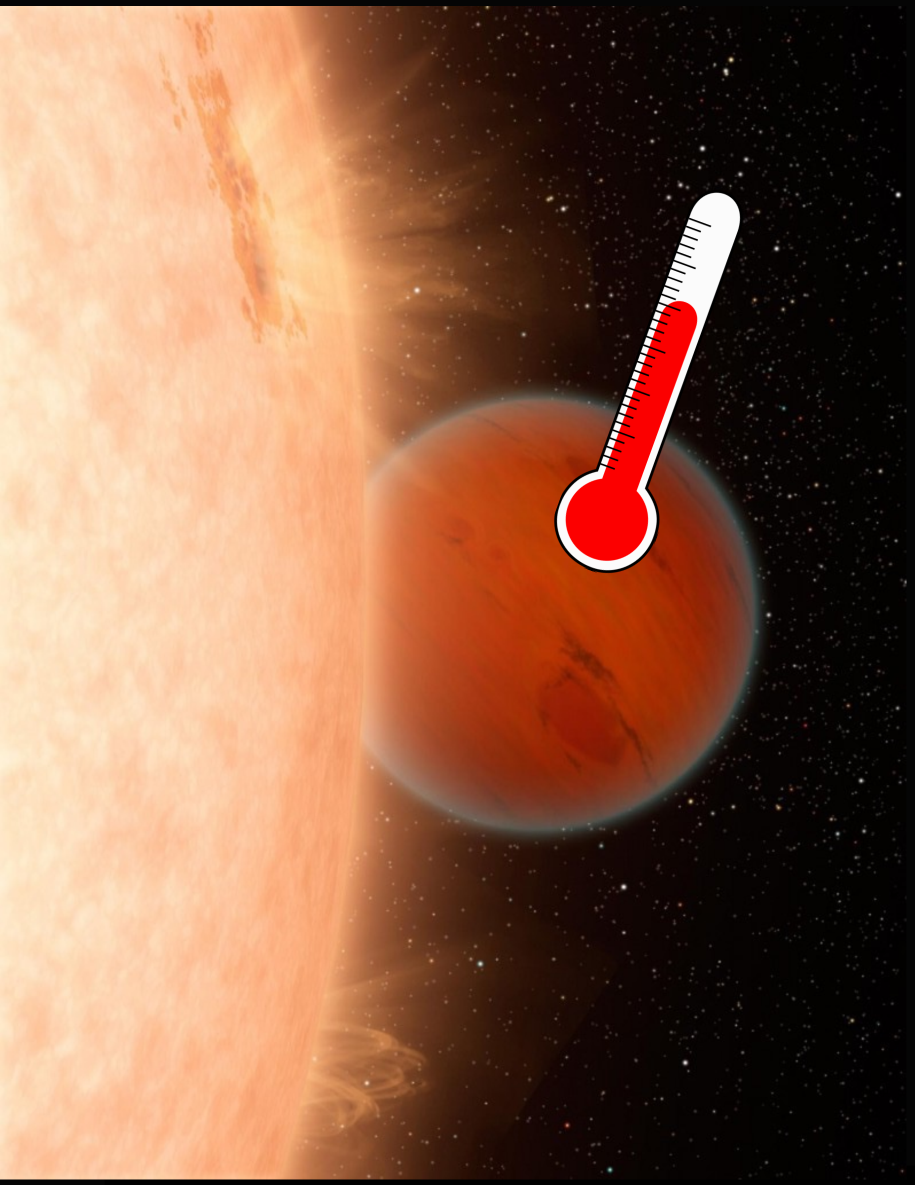


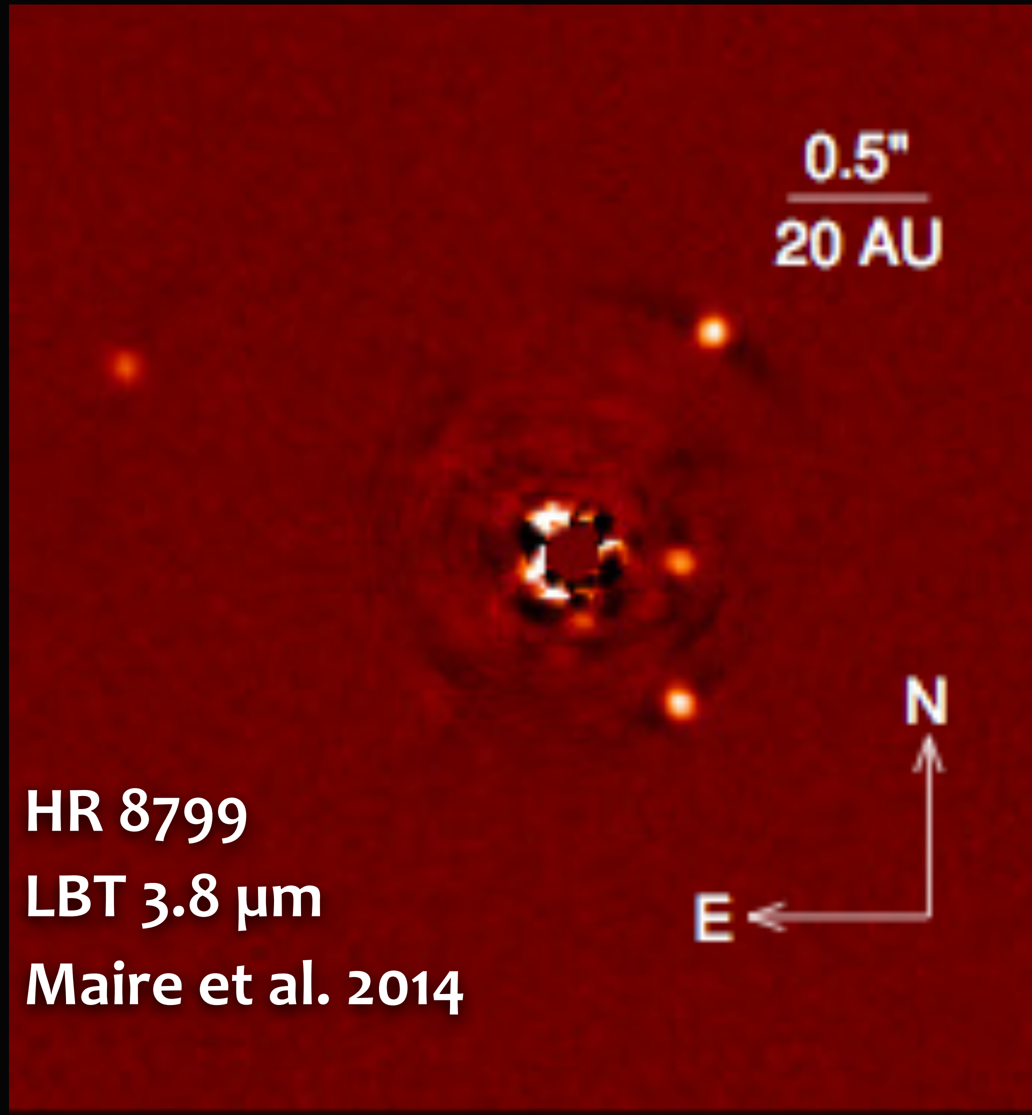
In the era of *Hubble* & *Spitzer*

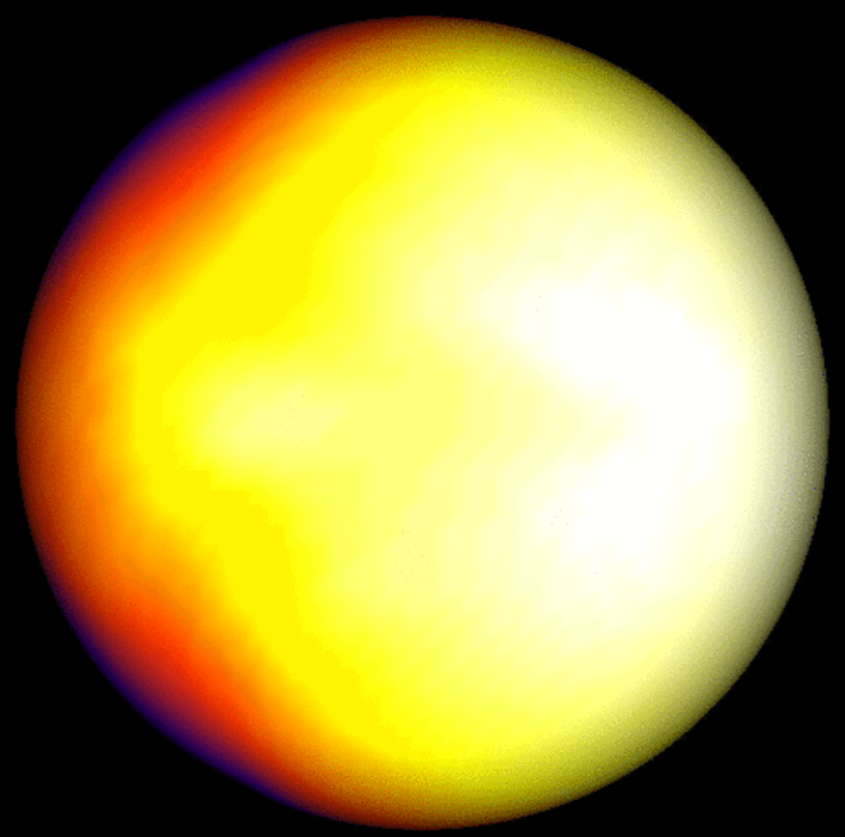
~100 exoplanets observed using low-R spectroscopy or broadband photometry

Webb will observe at infrared wavelengths where exoplanets emit most of their light

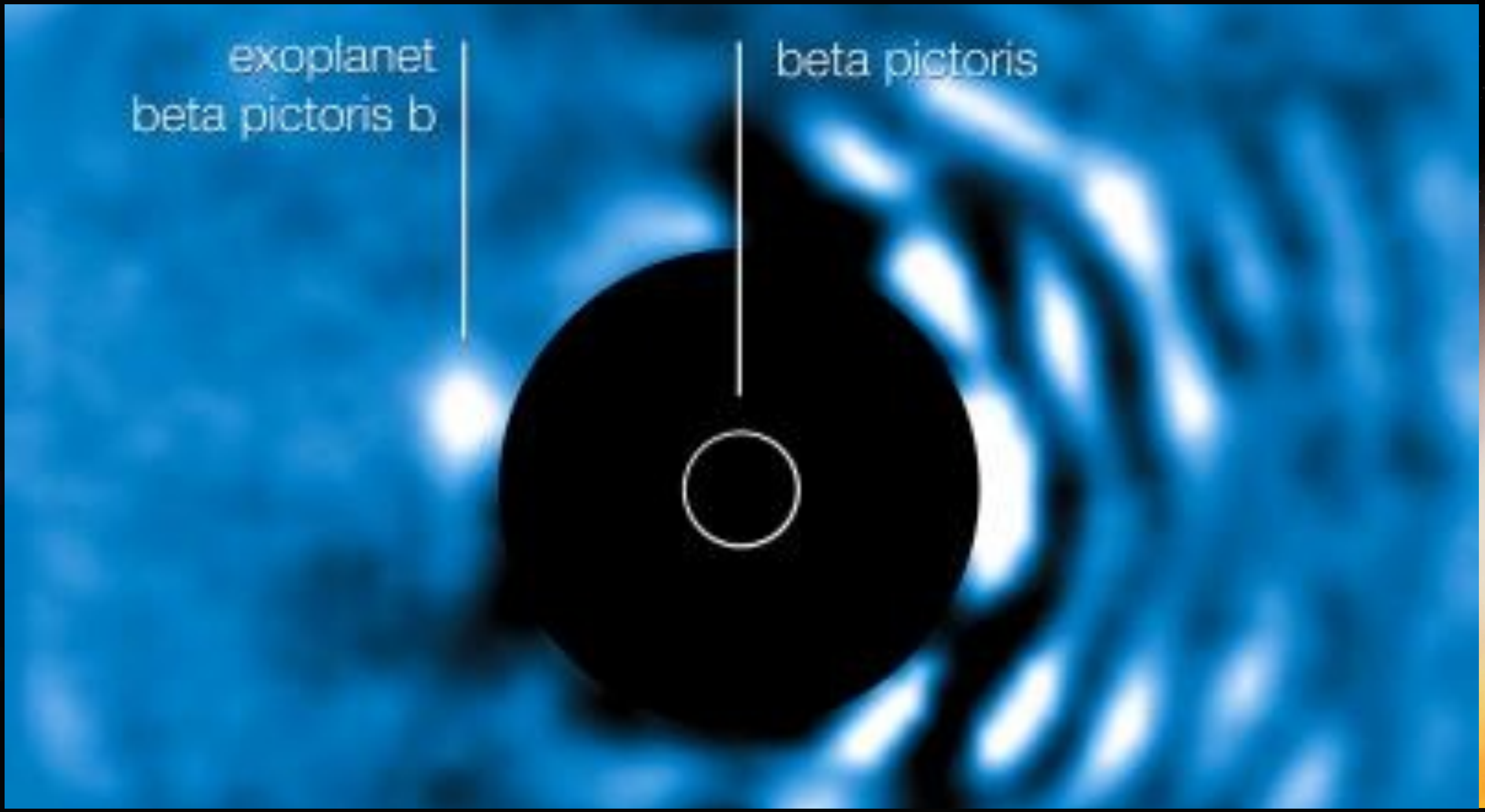




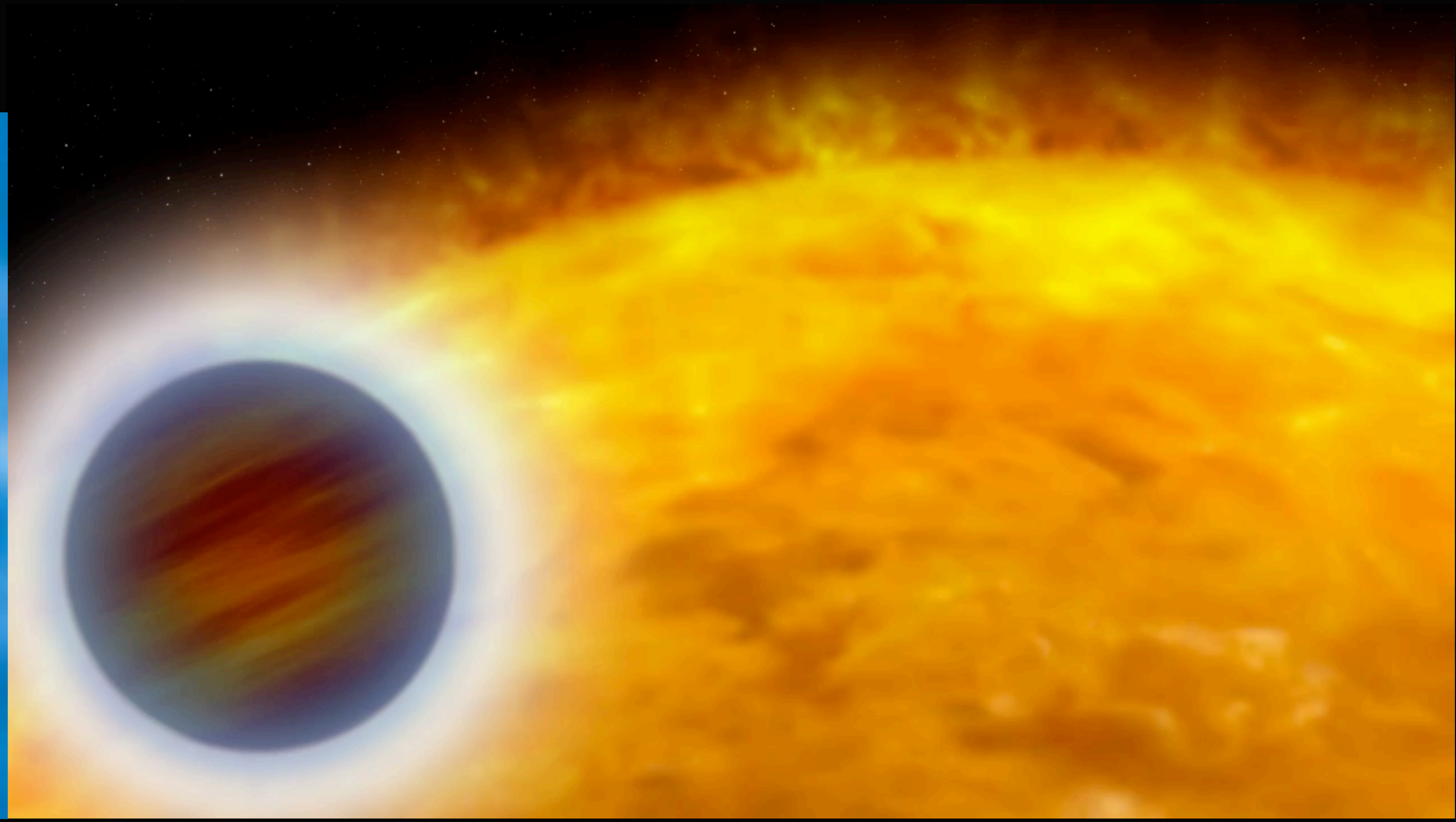




Webb will probe exoplanets in primarily two ways…

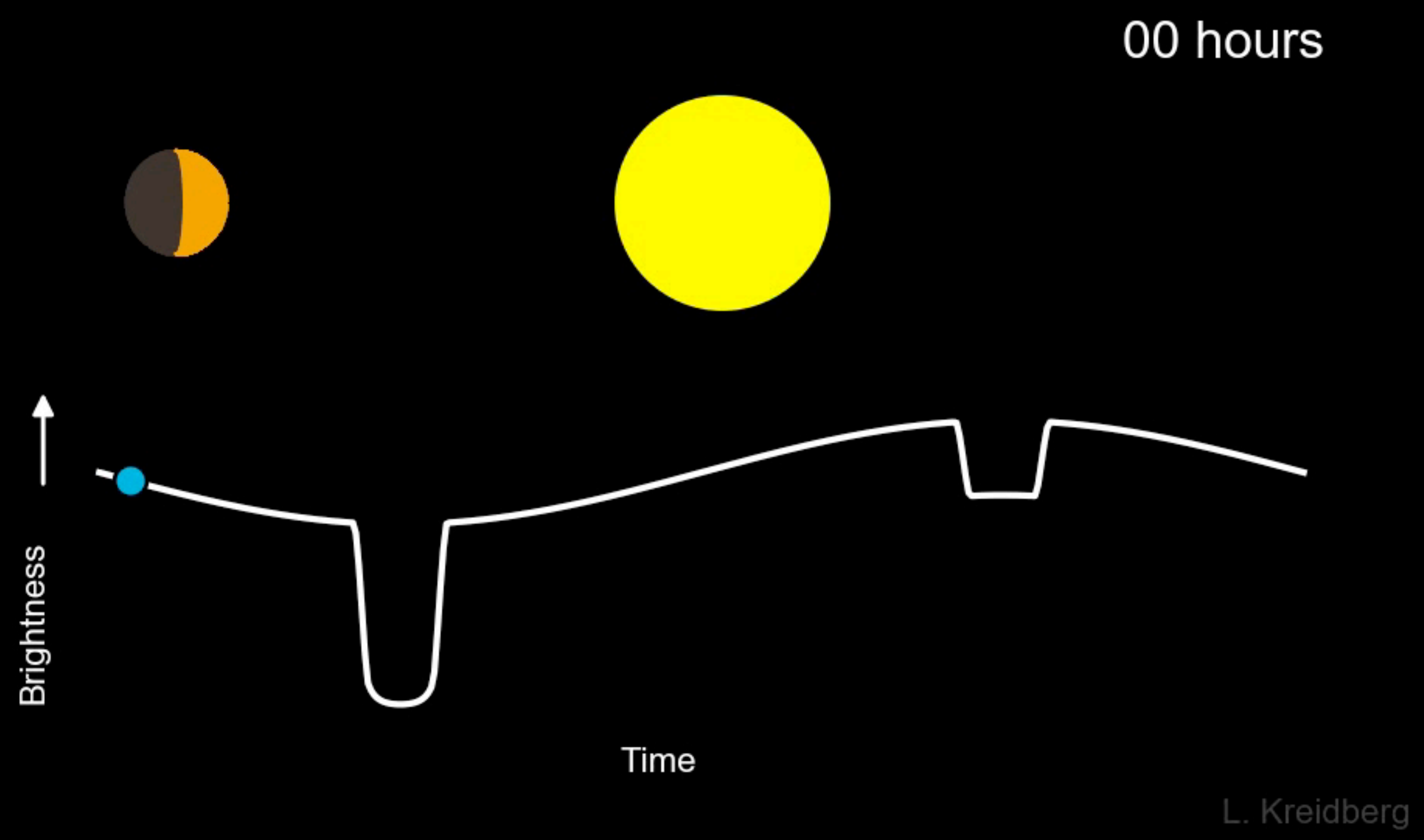


High-Contrast Imaging



High-Precision Time-Series Observations

High-Precision Time-Series Spectroscopy and Imaging with *Webb*



Time-series observation (TSO) modes exist for all four of *Webb*'s instruments:

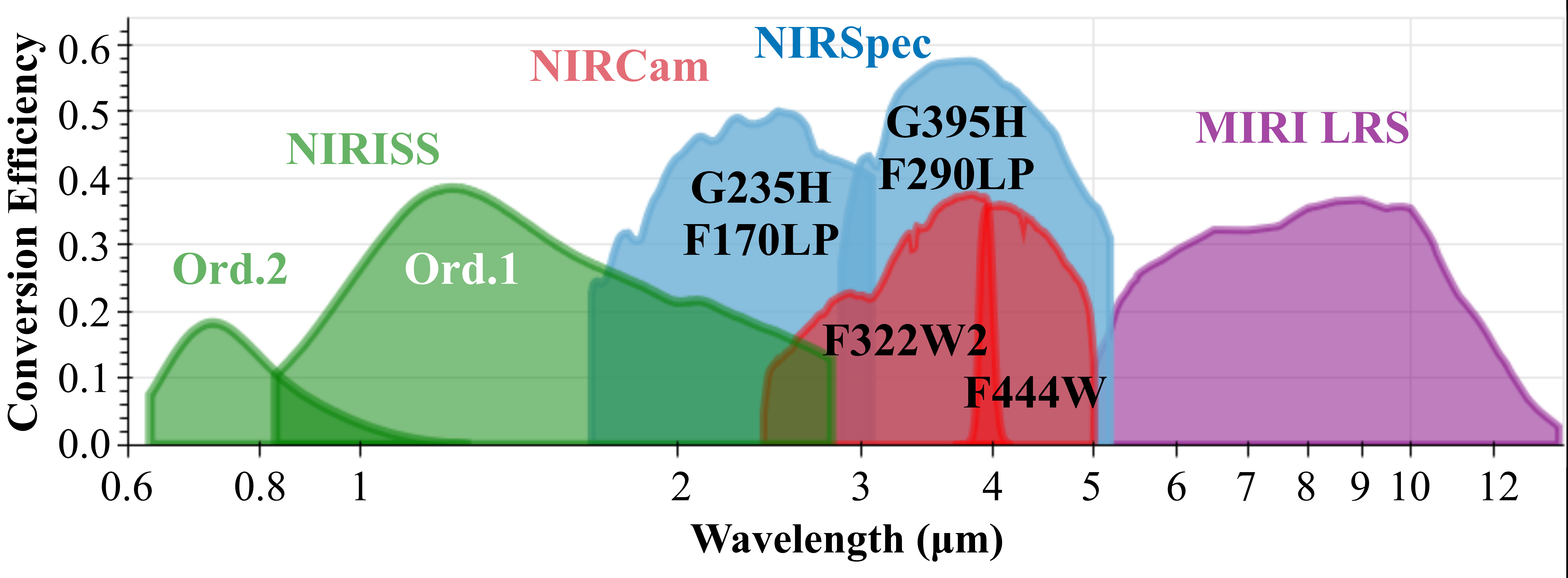
- Disabled dithers by default
- Exposures can exceed 10,000 seconds
- Enabled subarrays for bright targets

Spectroscopy: 0.6 -12 microns (3 instruments)
Photometry: 0.6 - 26 microns

- Enables exploration of a broad range of molecular signatures and more!

Probe exoplanets at mid-IR wavelengths (> 5 microns) for the first time since 2009, the end of the Spitzer Cryogenic Mission!

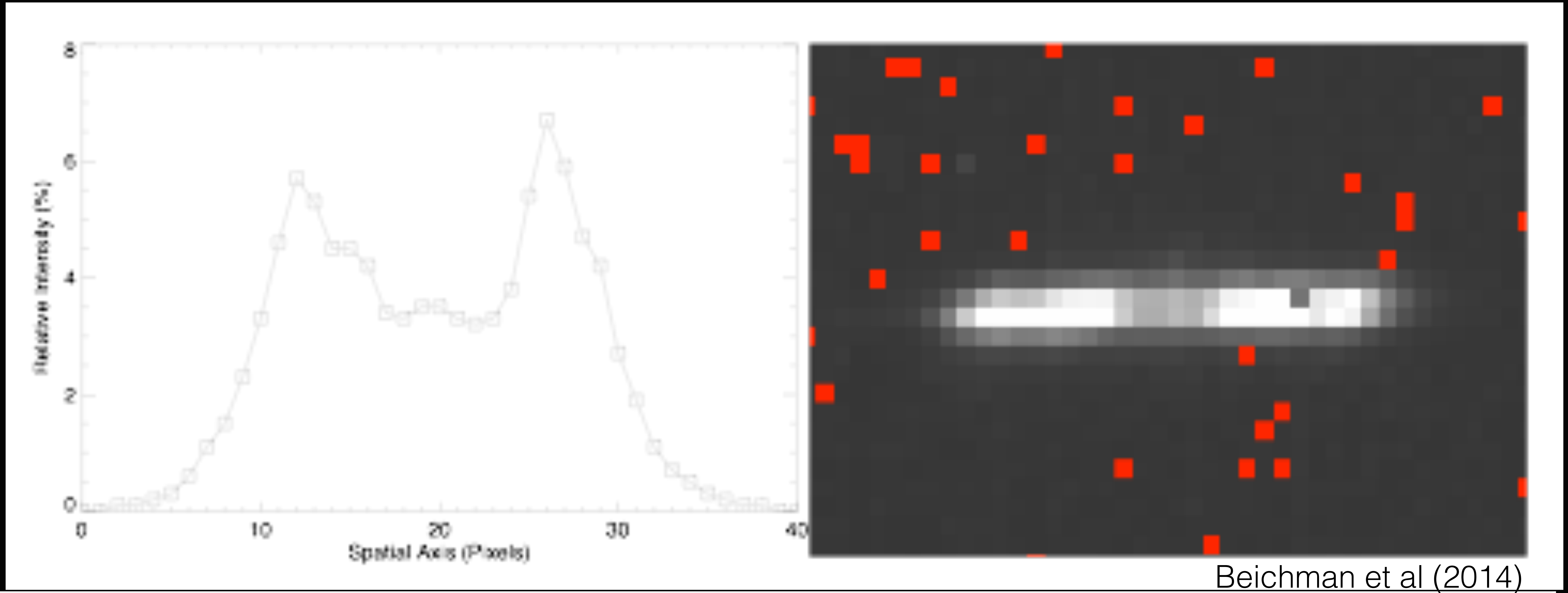
Webb's Most Anticipated Spectroscopic Modes



Bean et al. (in prep)

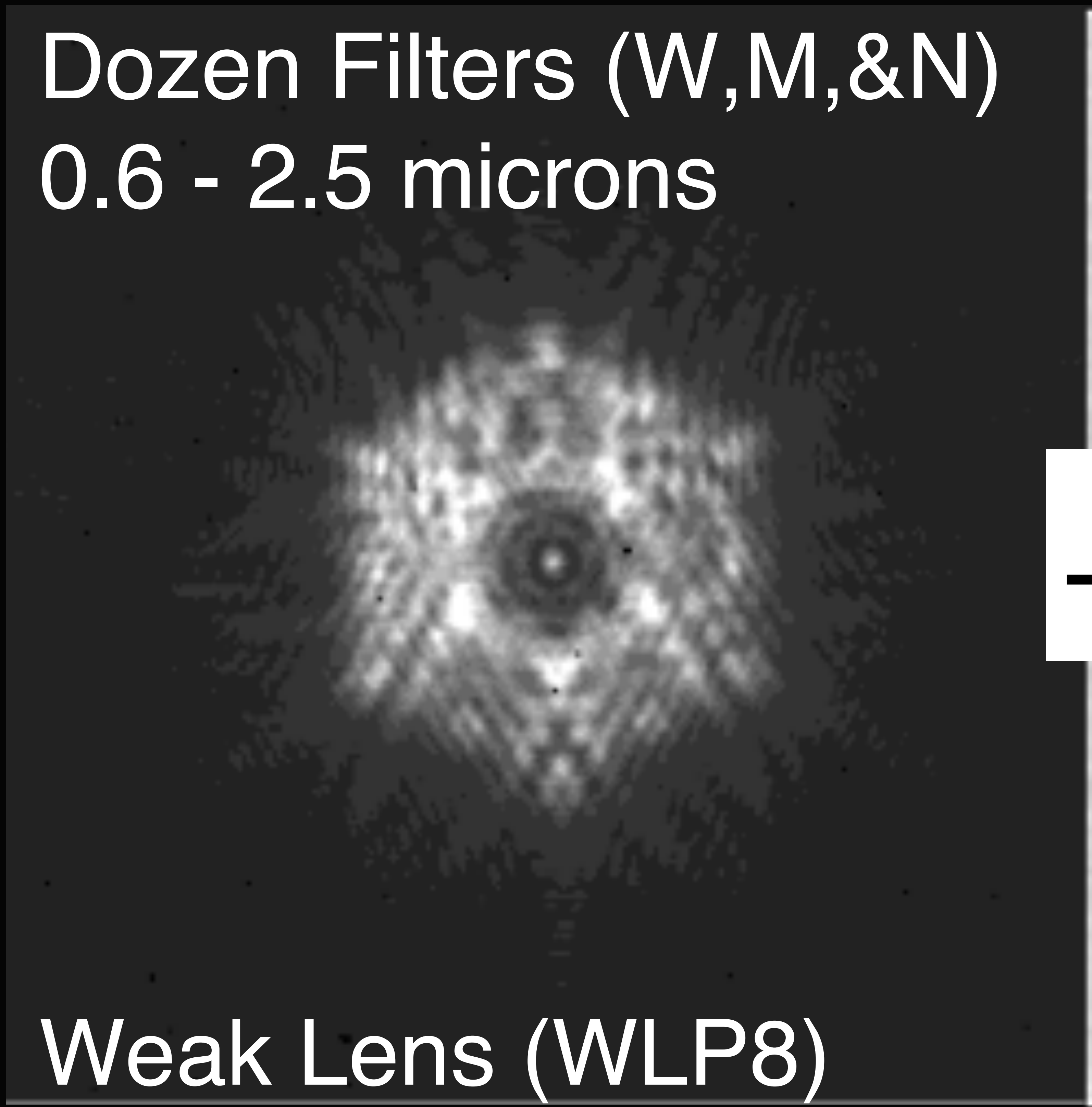
NIRISS Single-Object Slitless Spectroscopy (SOSS)
0.6 - 2.8 microns

First space-based instrument mode designed specifically for high-precision time-series observations of exoplanets!

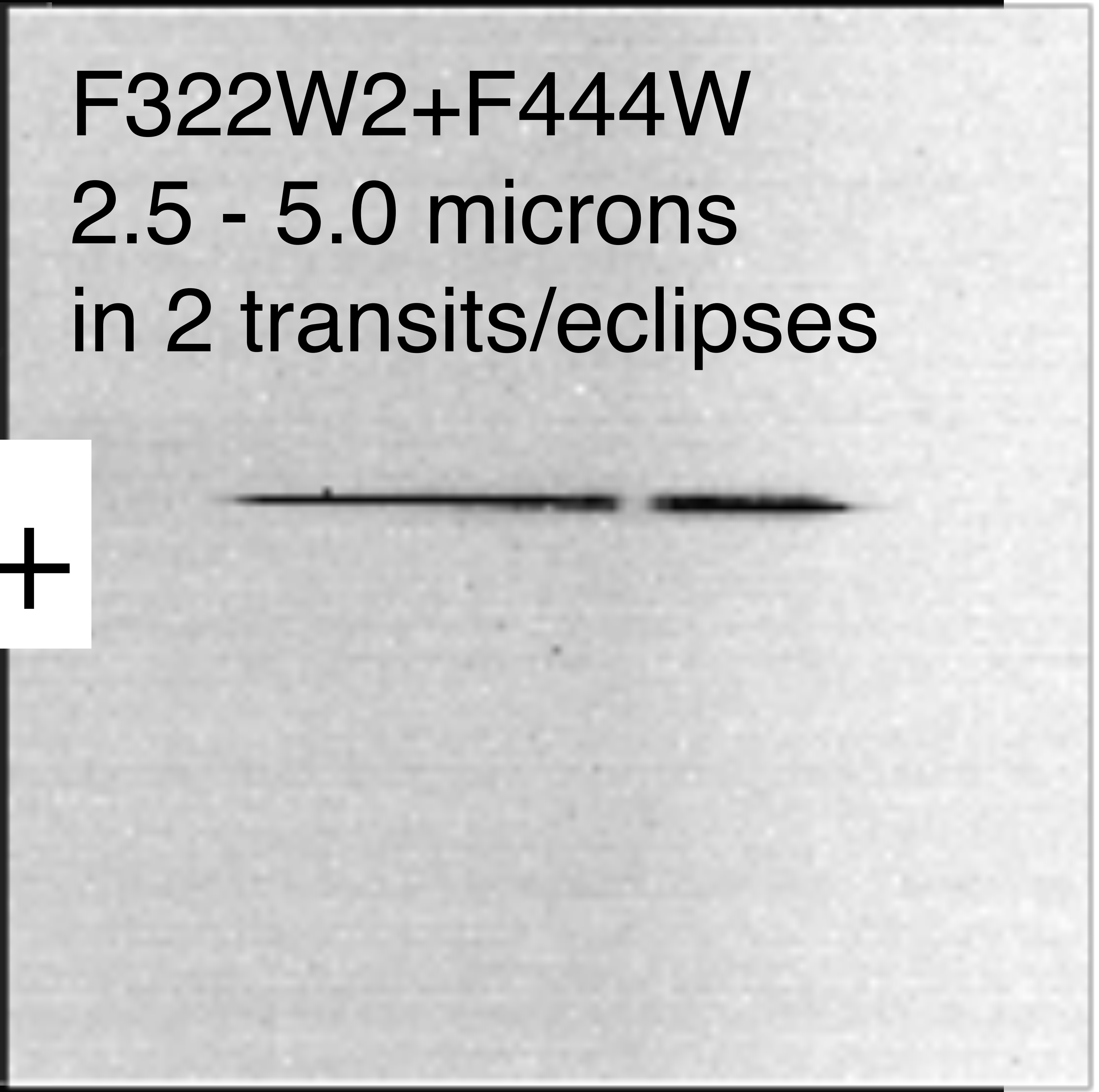


Saturation Limits: J~7.2 (256 x 2048 subarray) J~6.2 (96 x 2048 subarray)

NIRCam Photometry & Slitless Grisms
0.6 - 5 microns

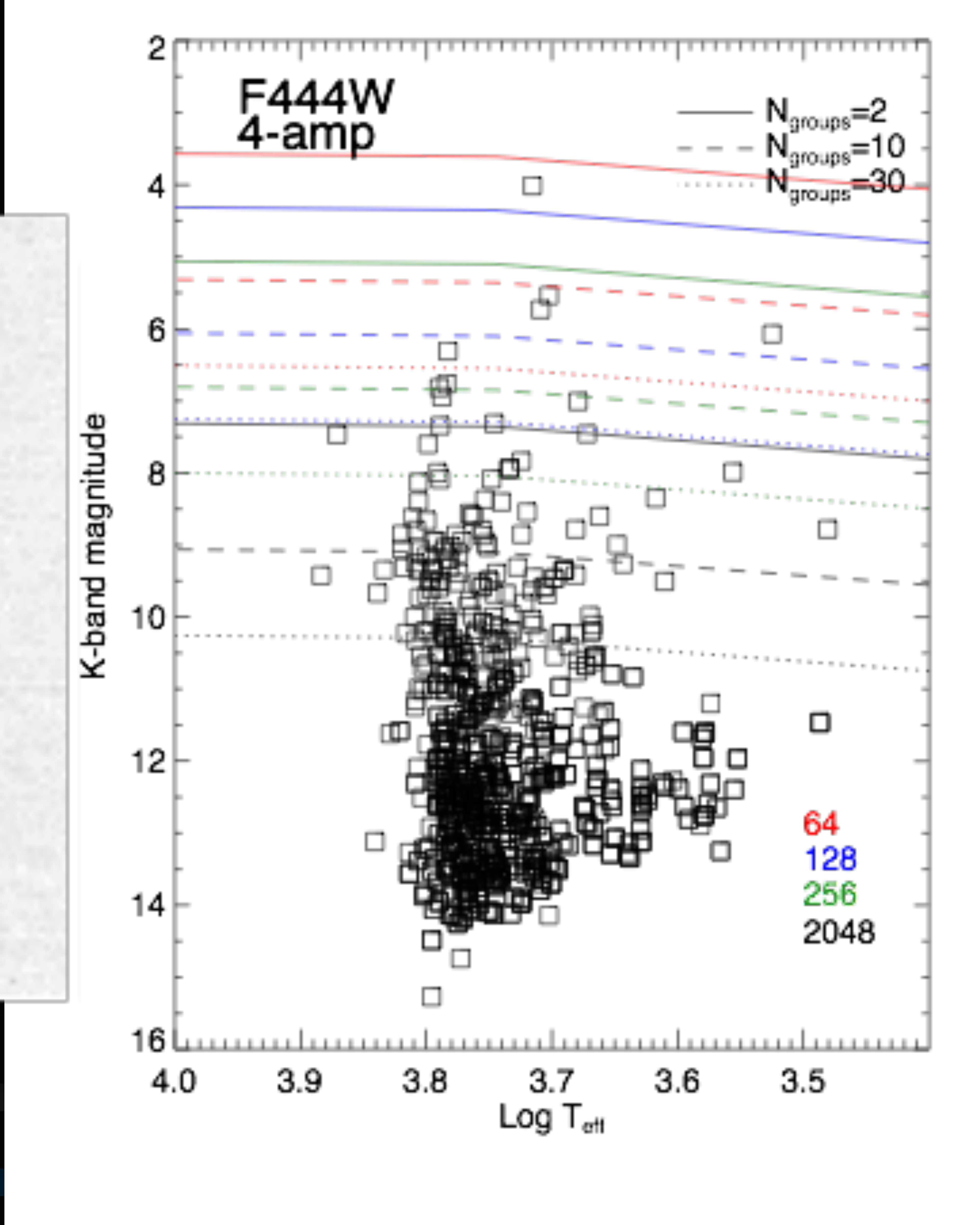


+

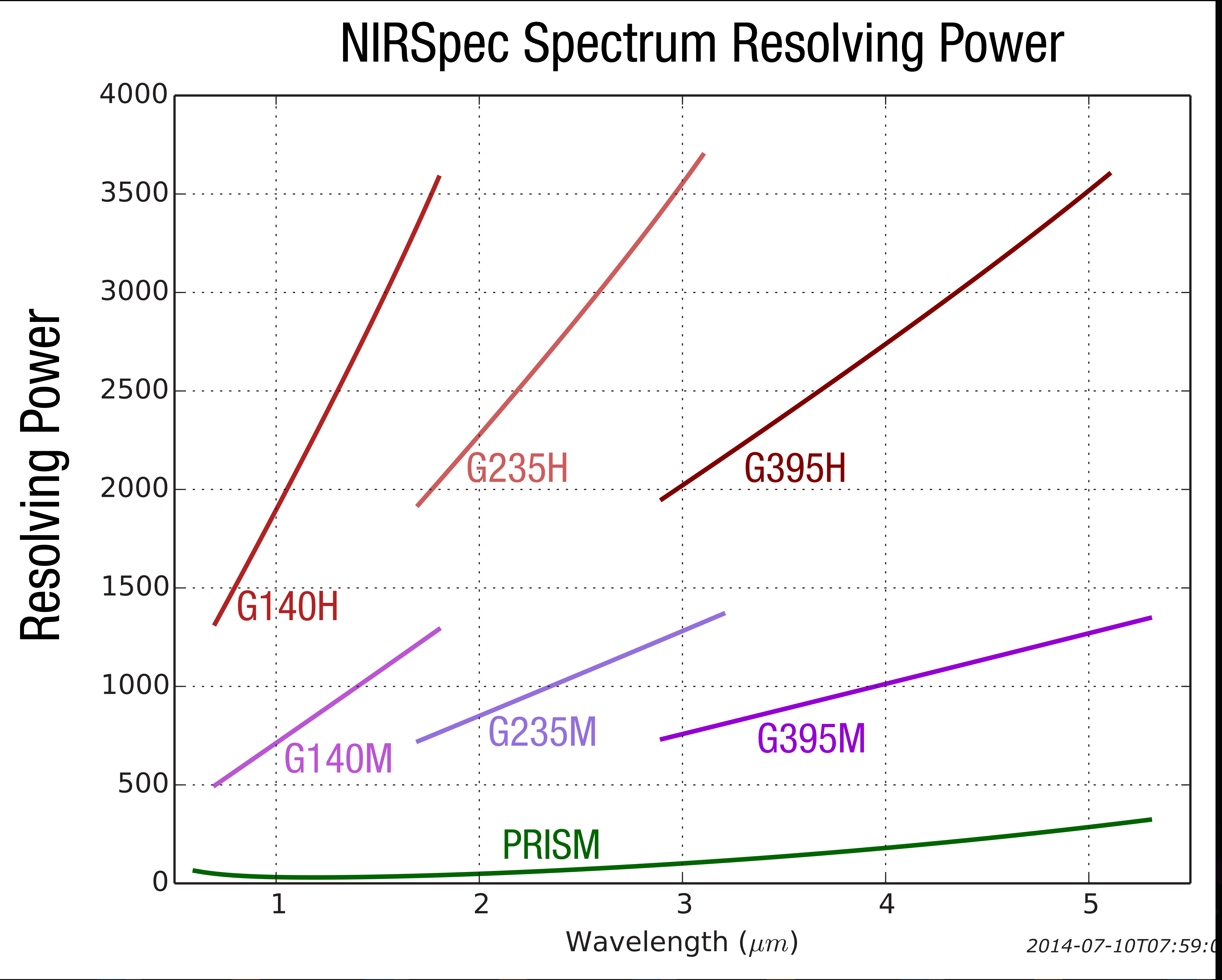


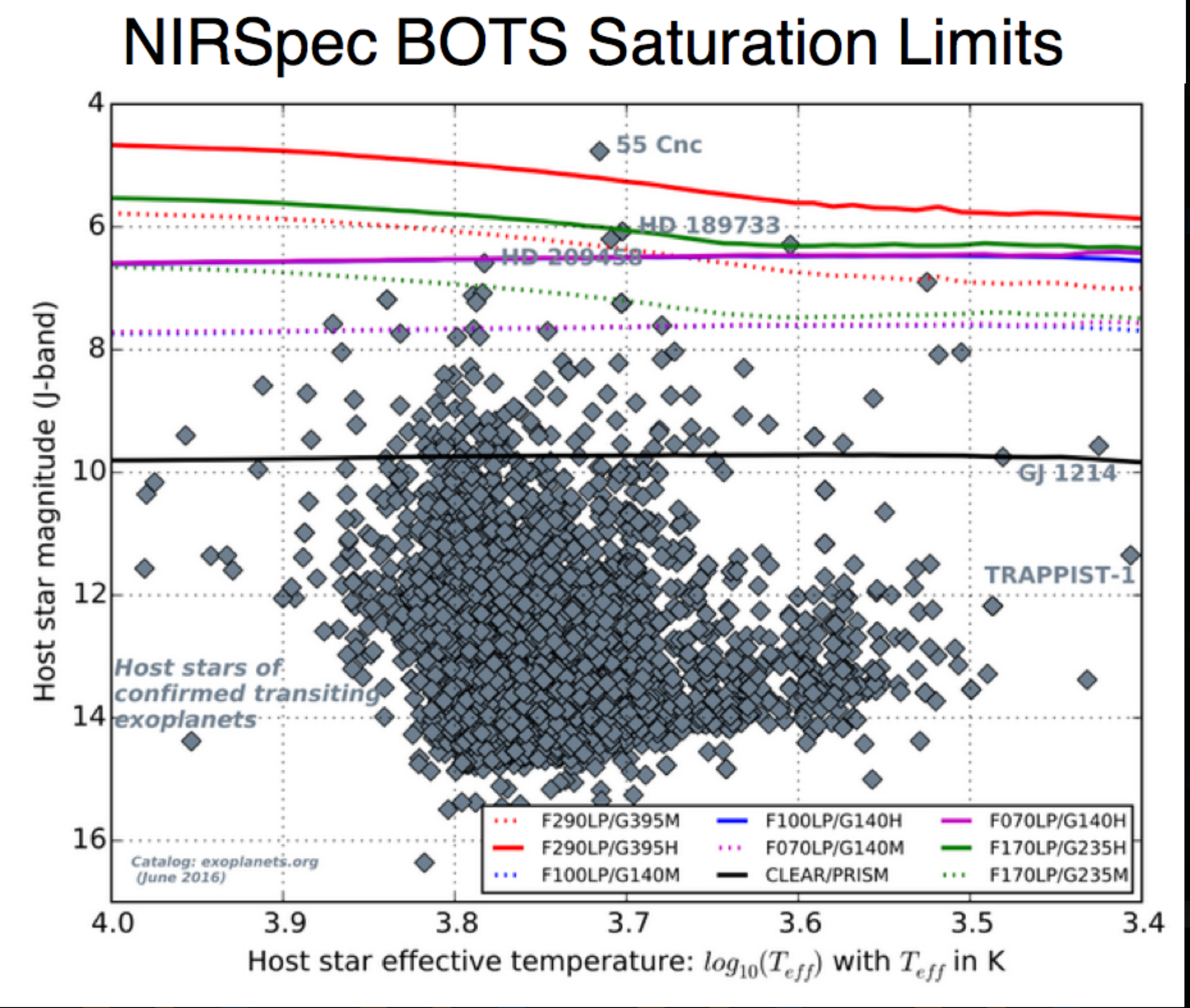
J~4 bright limit

R ~ 1400



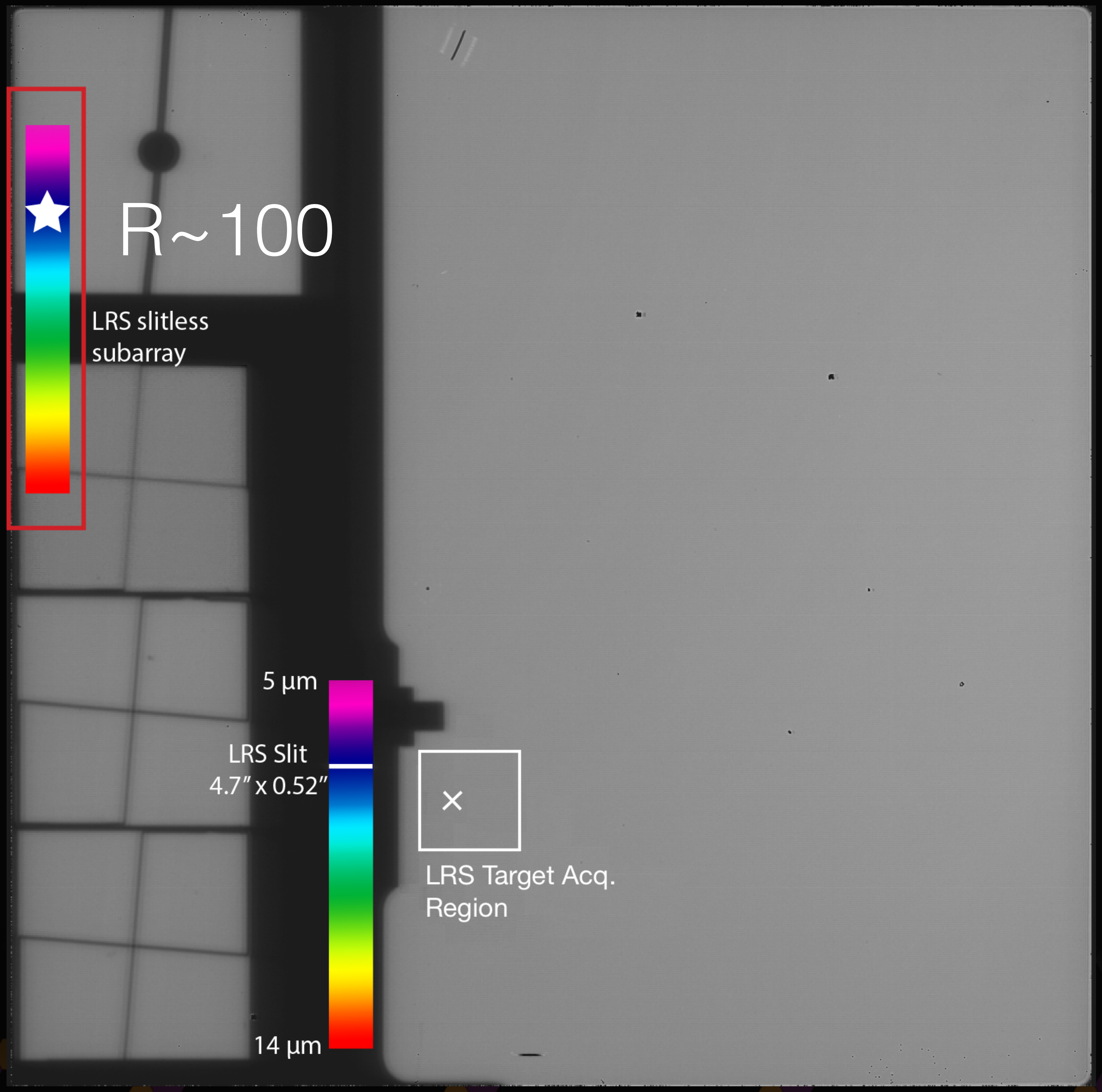
NIRSpec Fixed “Slit” (1.6” x 1.6” aperture) 0.6 - 5 microns

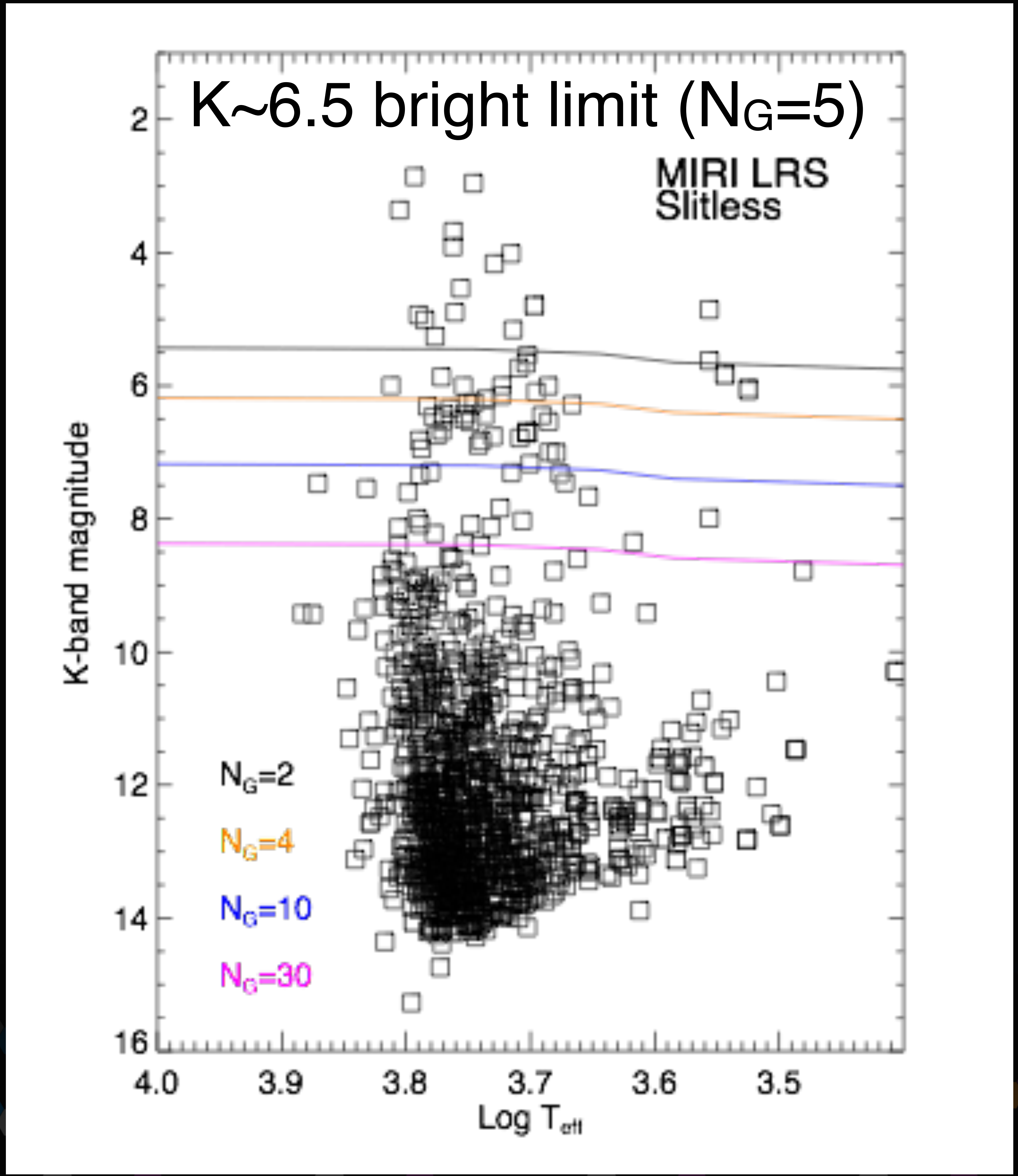




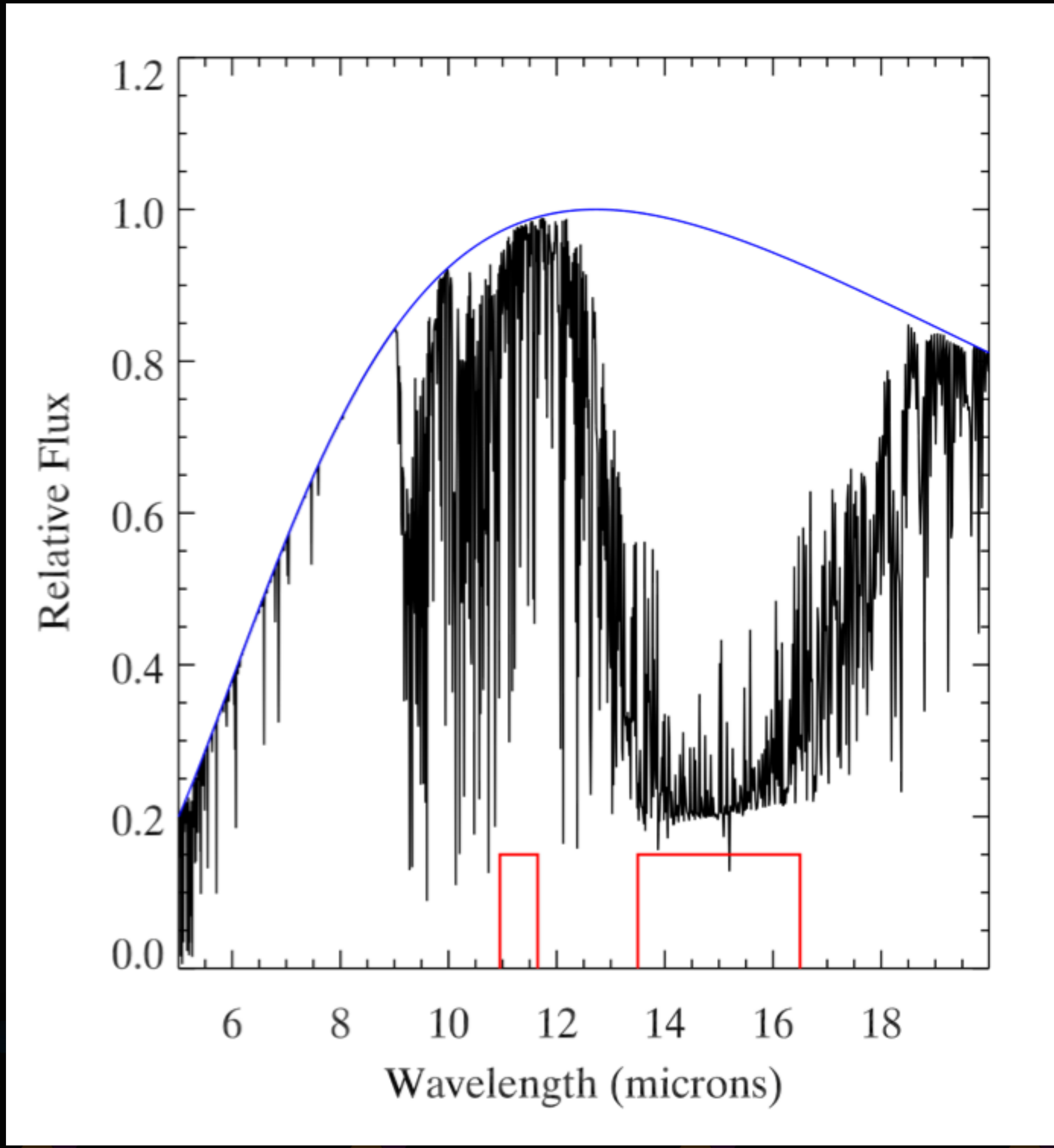
J~5-6 bright limit

MIRI Slitless Low-Resolution Spectroscopy (LRS)
5 - 12+ microns





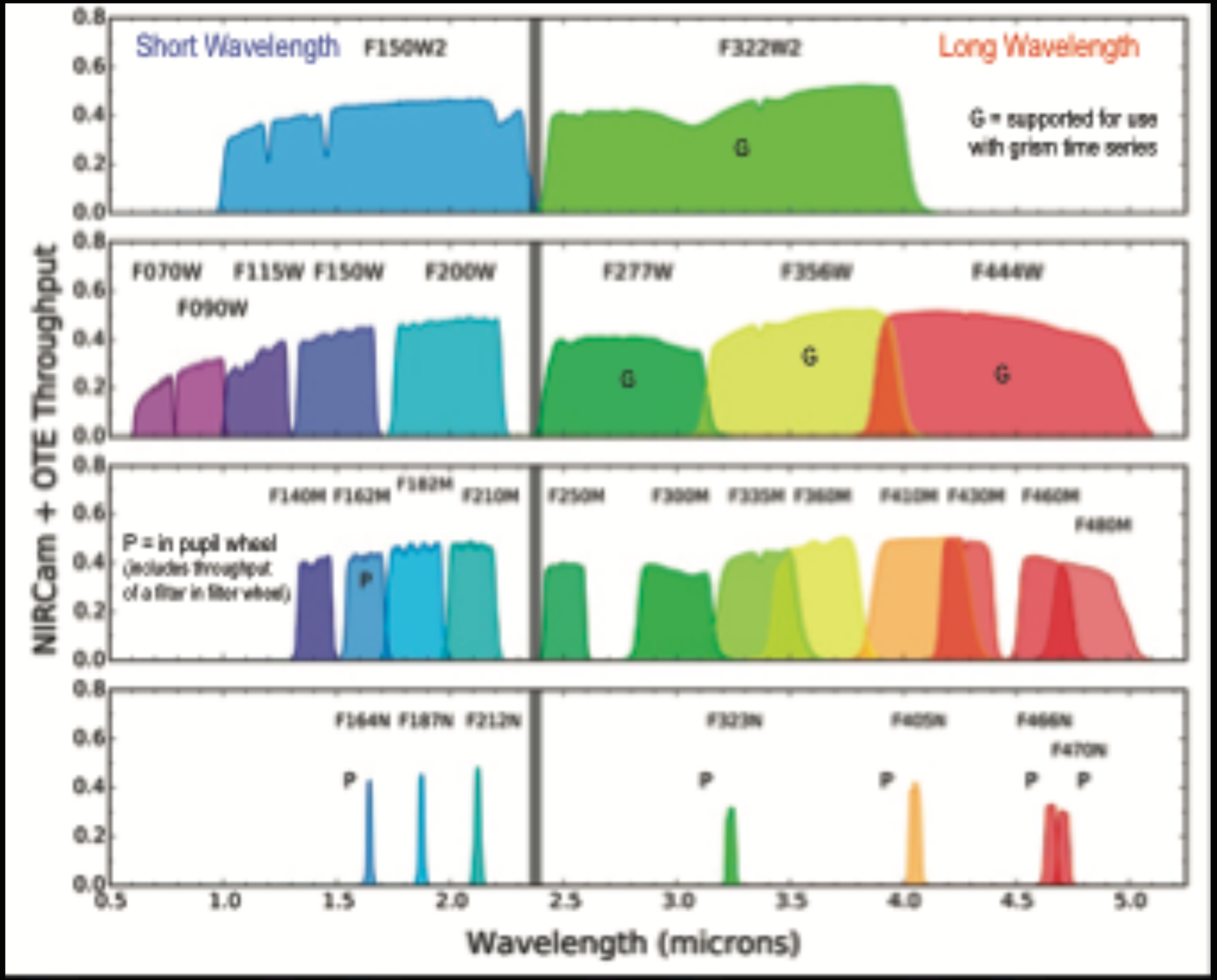
Webb Photometric Modes for Time-Series Observations



Saturation Limits

µm	Jy	M
5.6	0.42	6.1
7.7	0.24	6.0
10.0	0.52	4.7
11.3	2.25	2.8
12.8	0.95	3.5
15.0	1.23	2.9
18.0	2.2	1.9
21.0	2.2	1.5
25.5	6.4	0.0

Glasse+ 2015 G2V

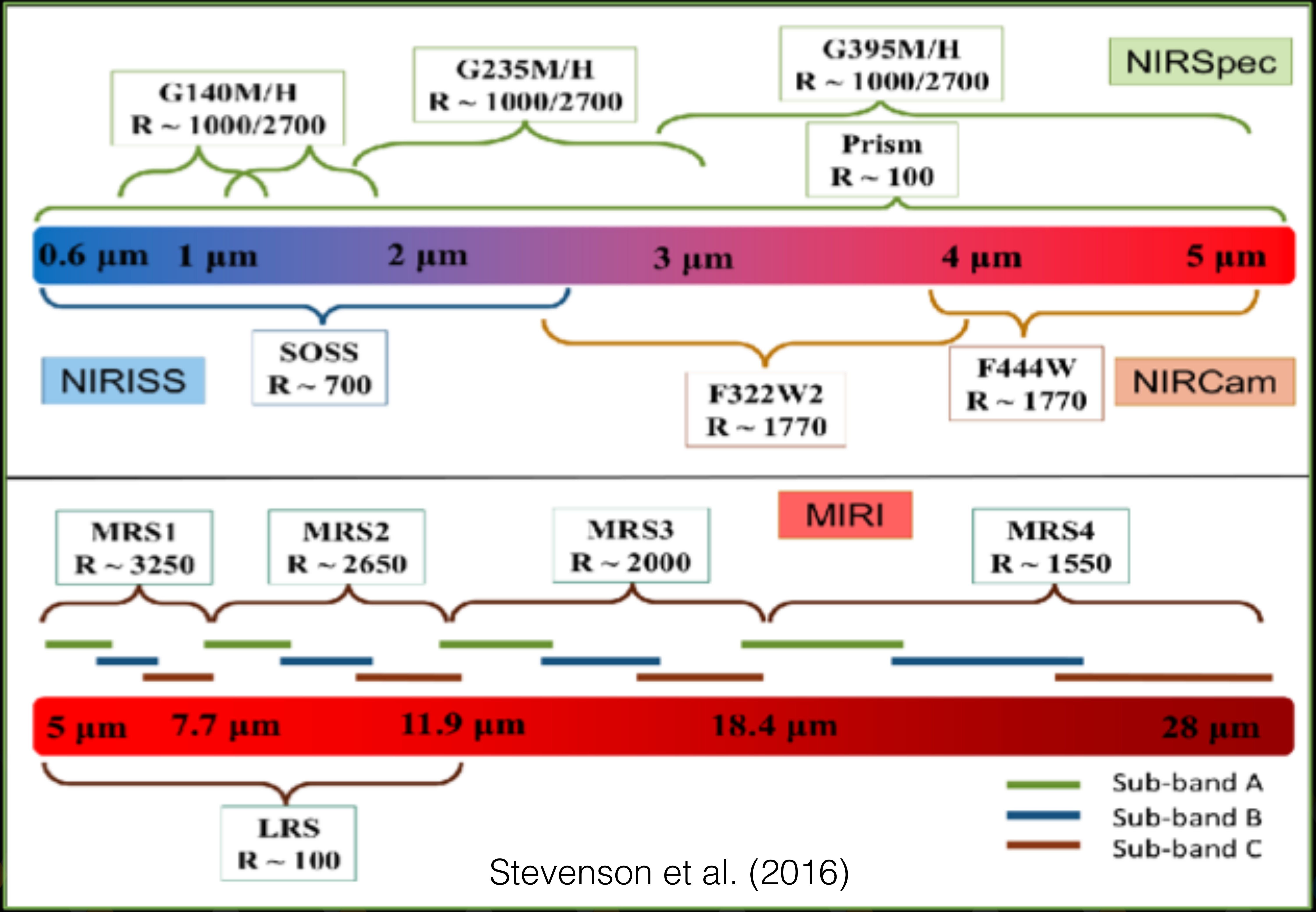


MIRI

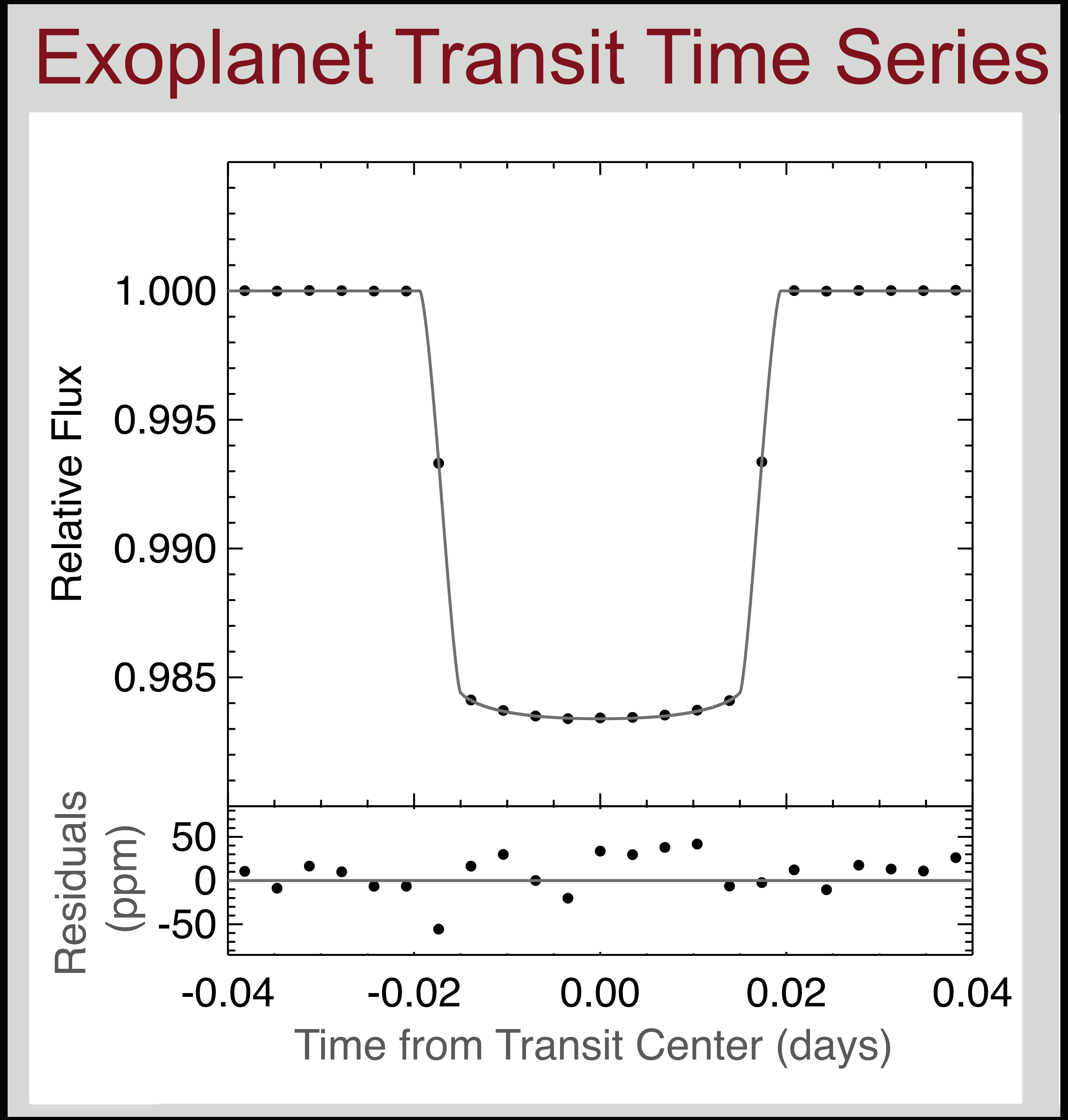
NIRCam

Deming et al. (2009)

Webb High-Precision Time-Series Spectroscopic Modes

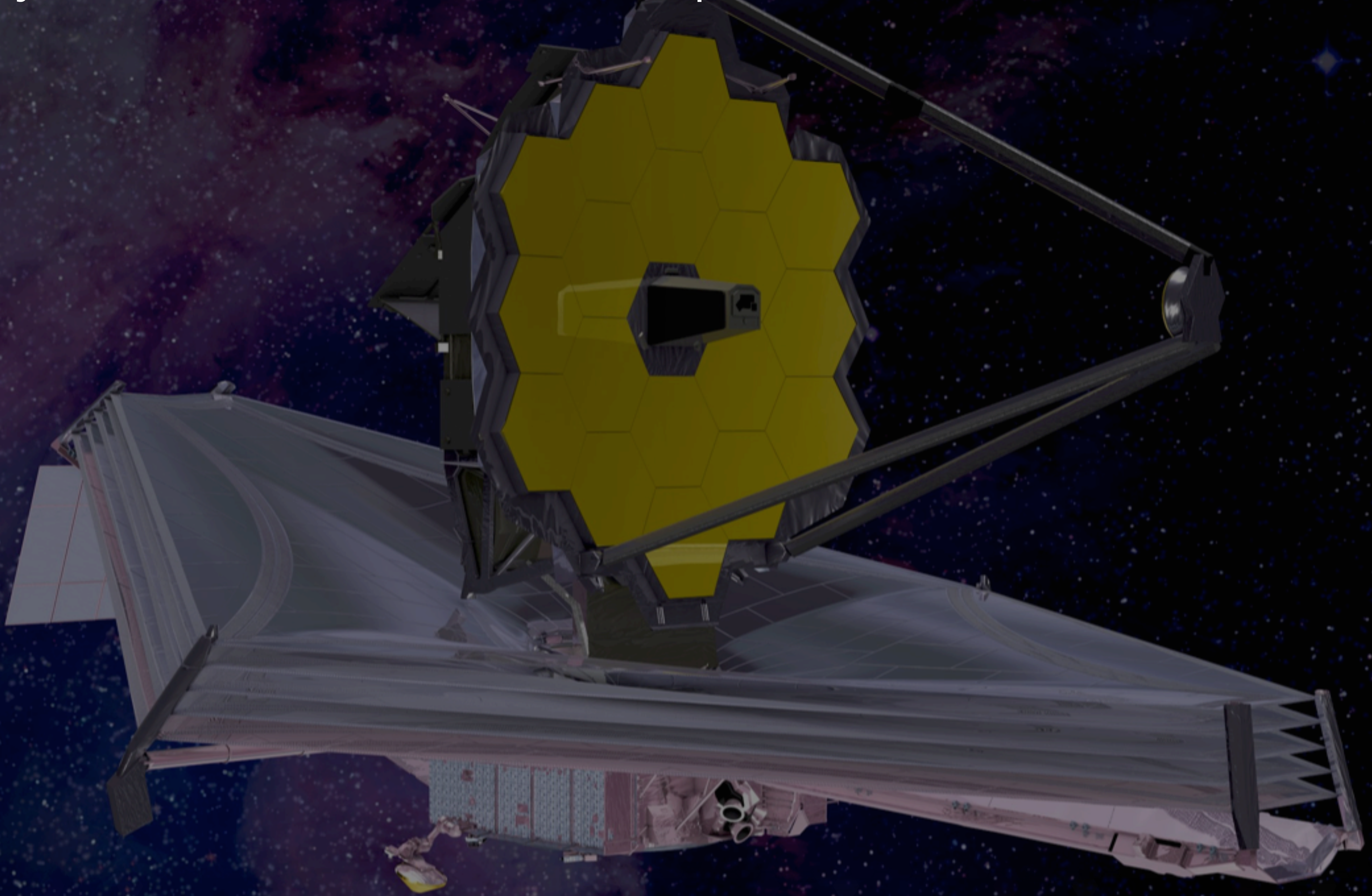


Stevenson et al. (2016)



Single Transit/Eclipse Precisions ~30-100 ppm

Now that you've met JWST's exoplanet modes and features…



Let's talk science!!!!

Infrared spectrum of Jupiter – Circa 1960's

- Danielson (1966)
  - IR reflectance spectrum of Jupiter
- Stratoscope II balloon flight
  - November 1963
  - 84,000 ft
- 0.8 – 3.1 μm, R ~ 100
- Detect CH_4, NH_3, and collision-induced H_2

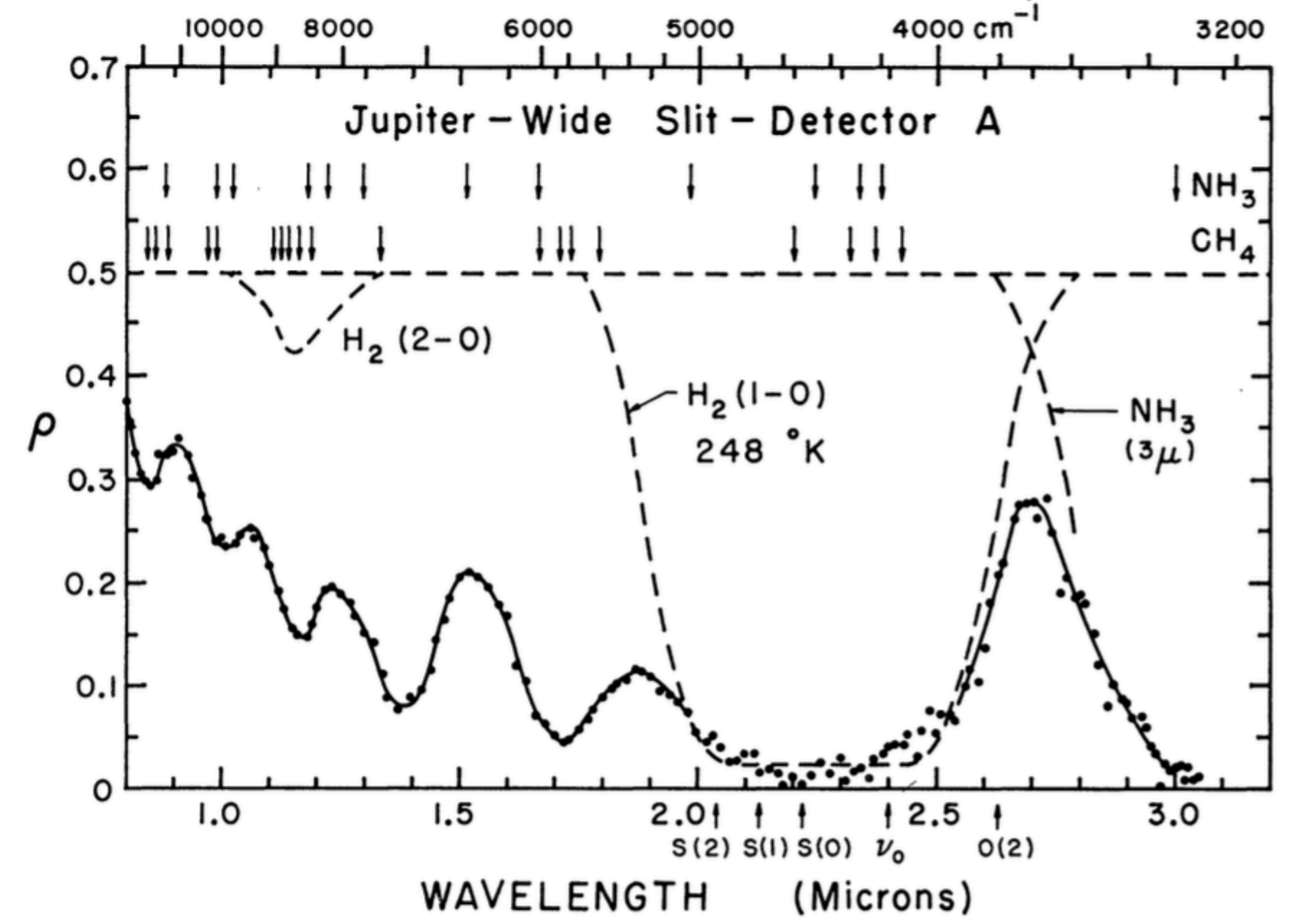
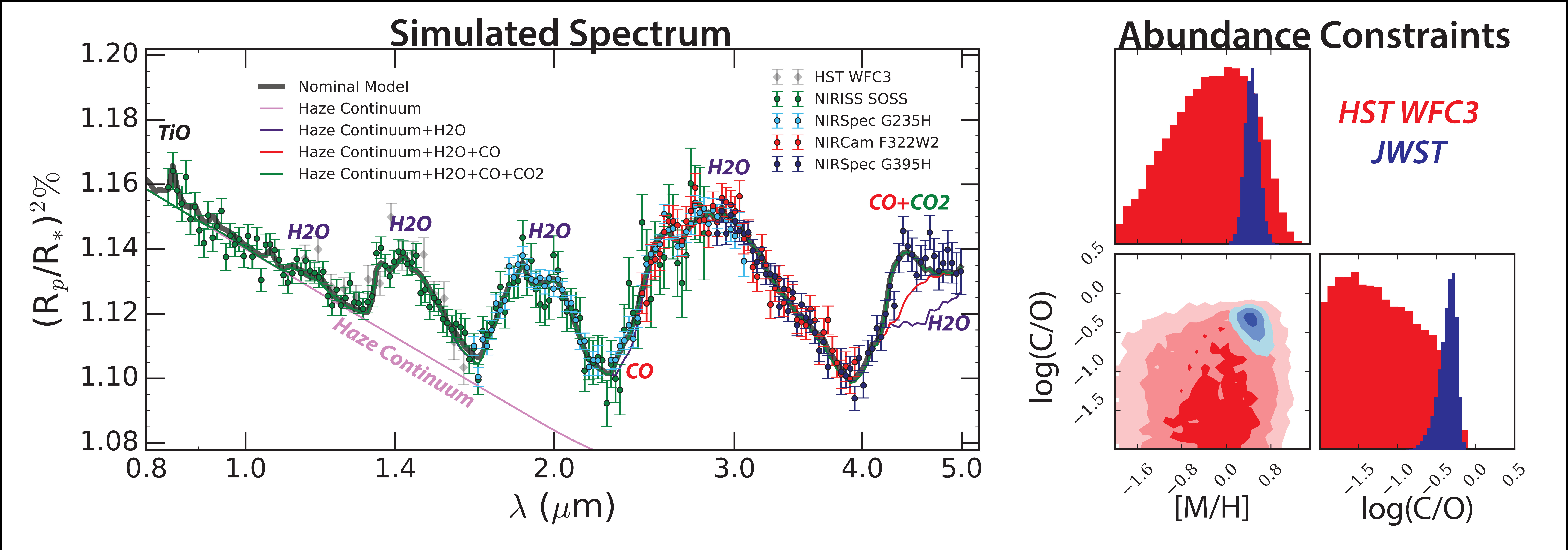


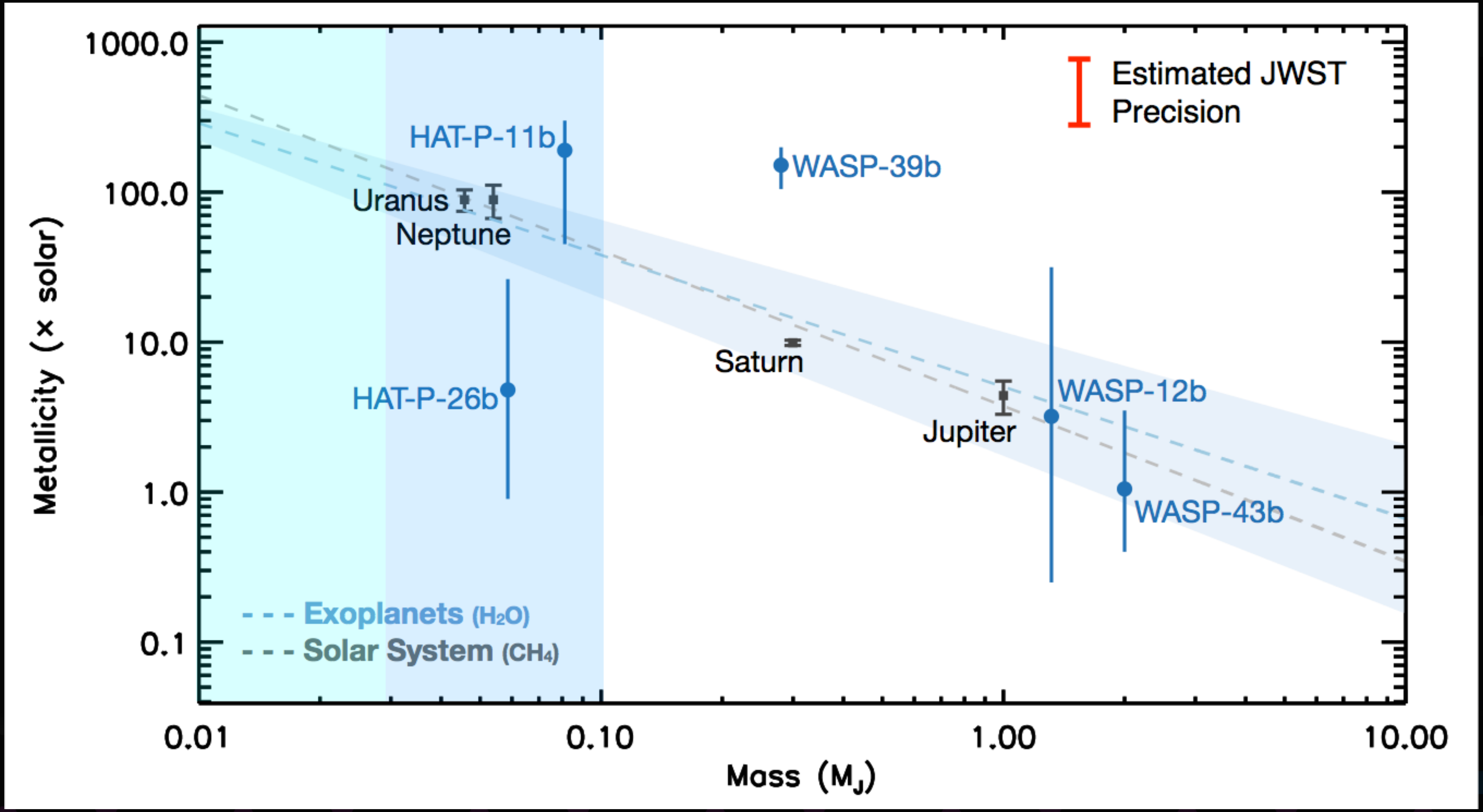
FIG. 2.—The ratio of the observed intensity of Jupiter (as derived from detector A and the wide entrance slit) to the brightness of a perfectly diffusing screen (having an albedo of unity) held normal to the Sun's radiation at Jupiter's distance. The bands of CH_4 and NH_3 which have been observed in the laboratory are shown along with the positions of the lines in the 1–0 band of H_2.

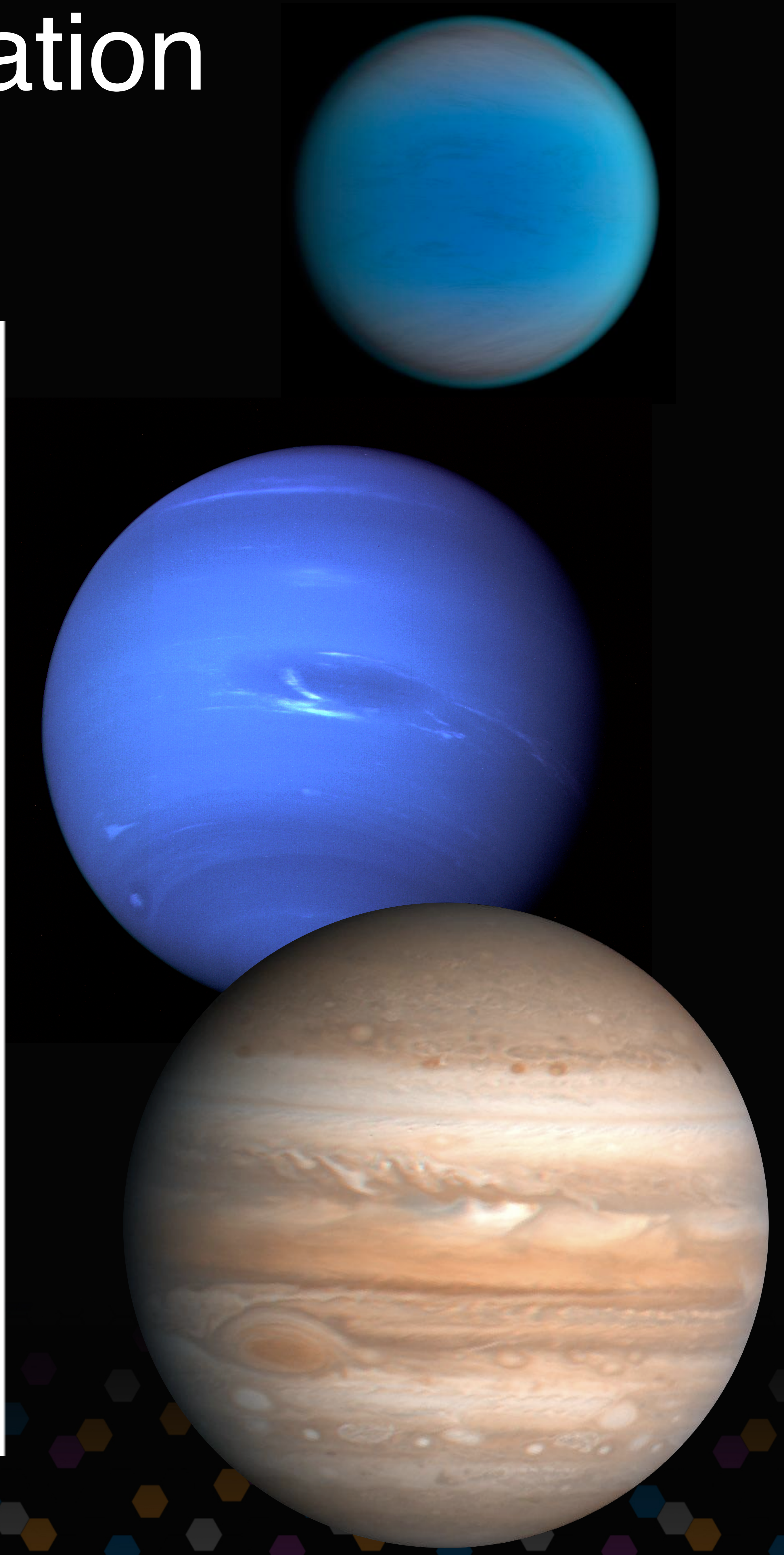
Webb will provide compositional information for a large sample of giant exoplanets



Bean et al. (in prep)

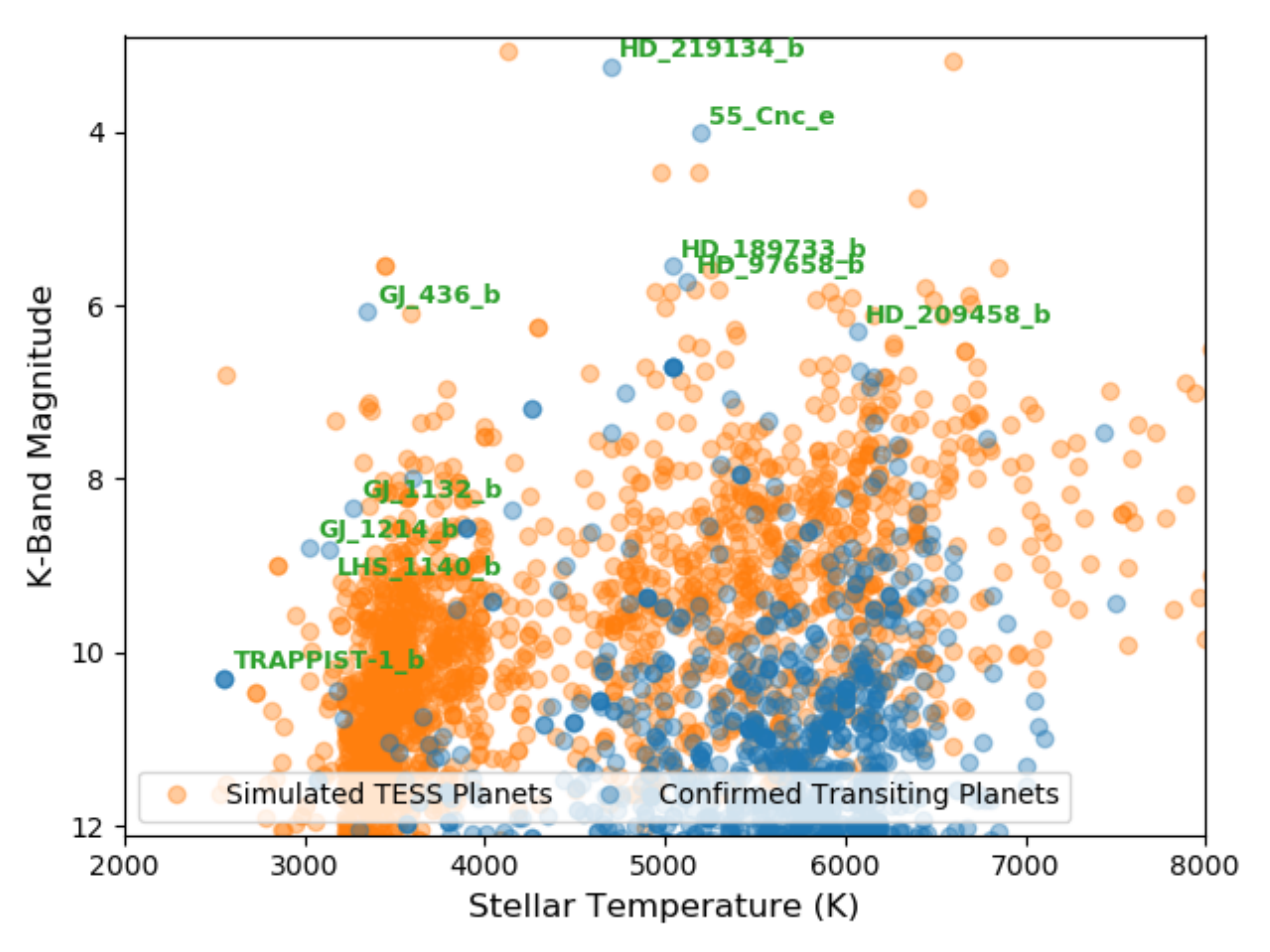
Webb will provide compositional information for a large sample of giant exoplanets

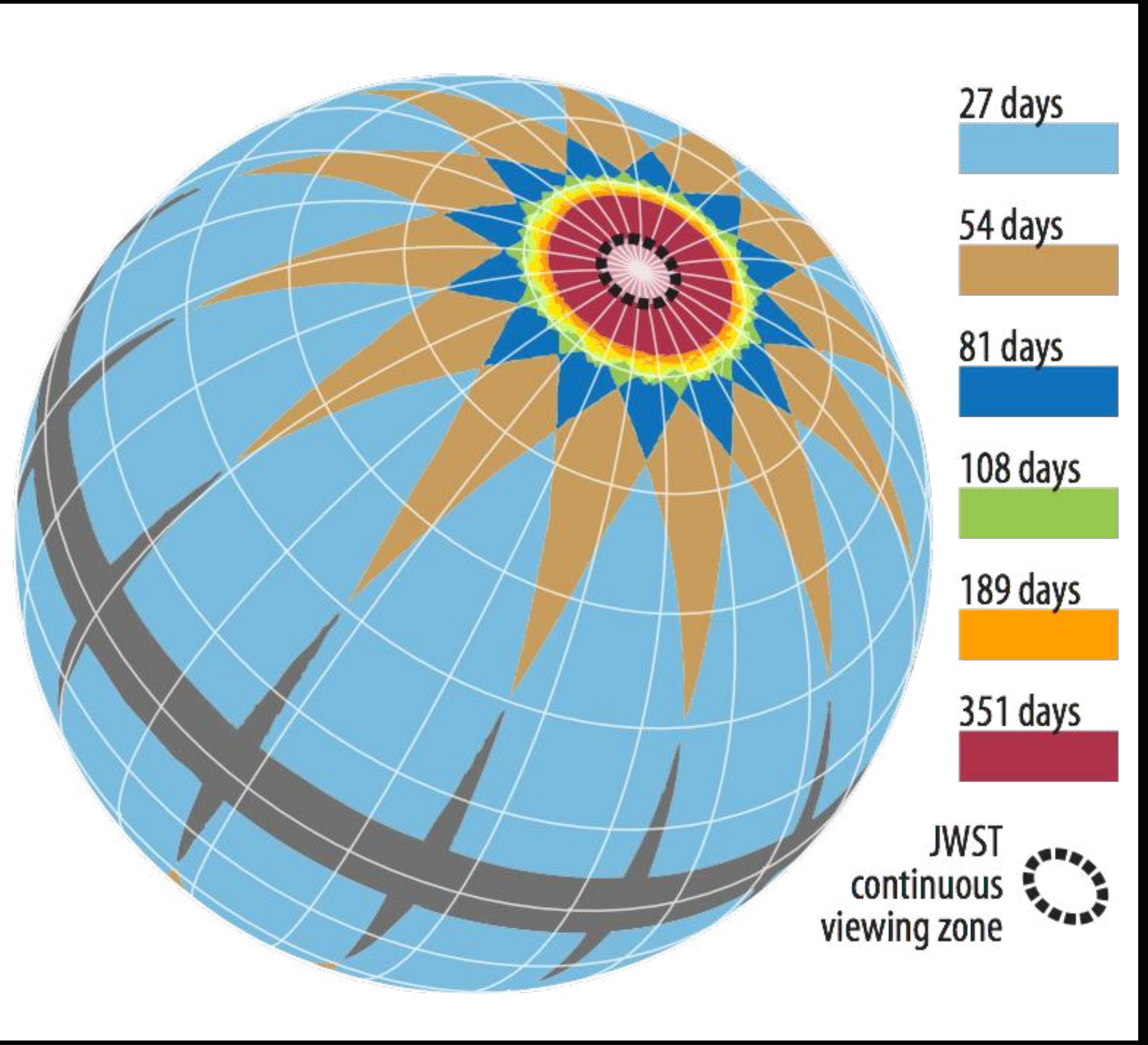


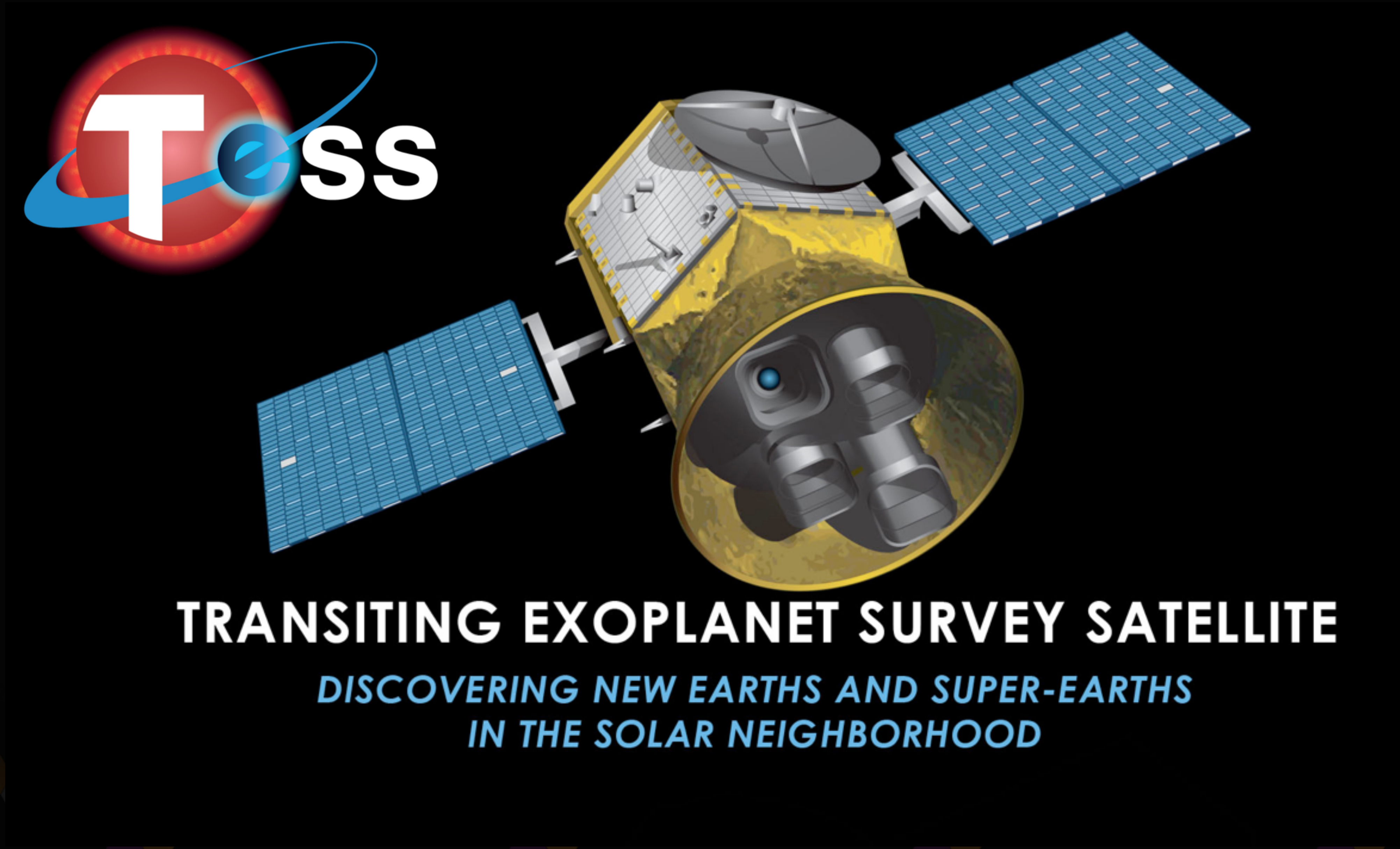


Wakeford et al. (2018)
Greene et al. (2016)

Webb will help to determine the nature of Super-Earths and Mini-Neptunes

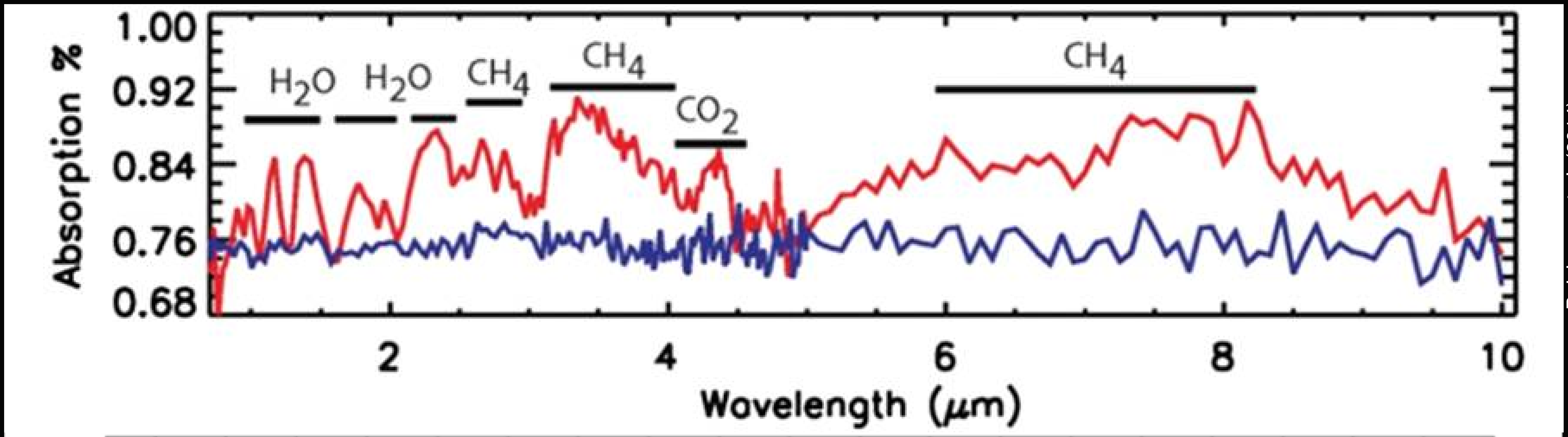


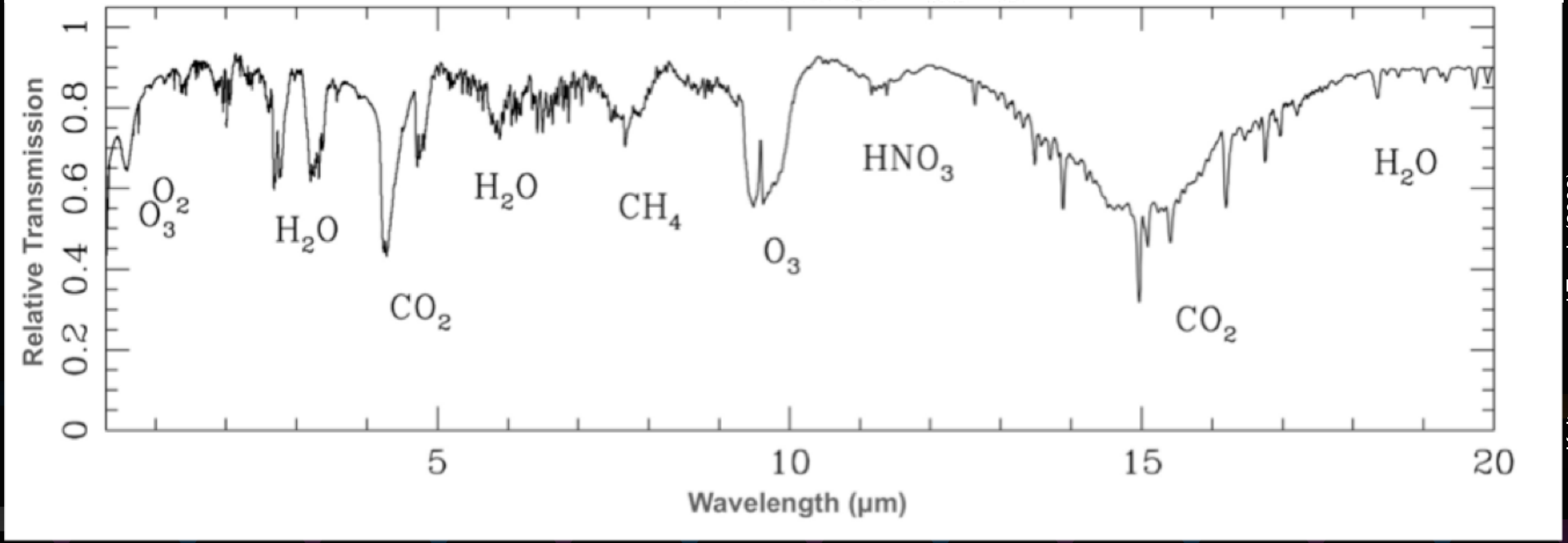


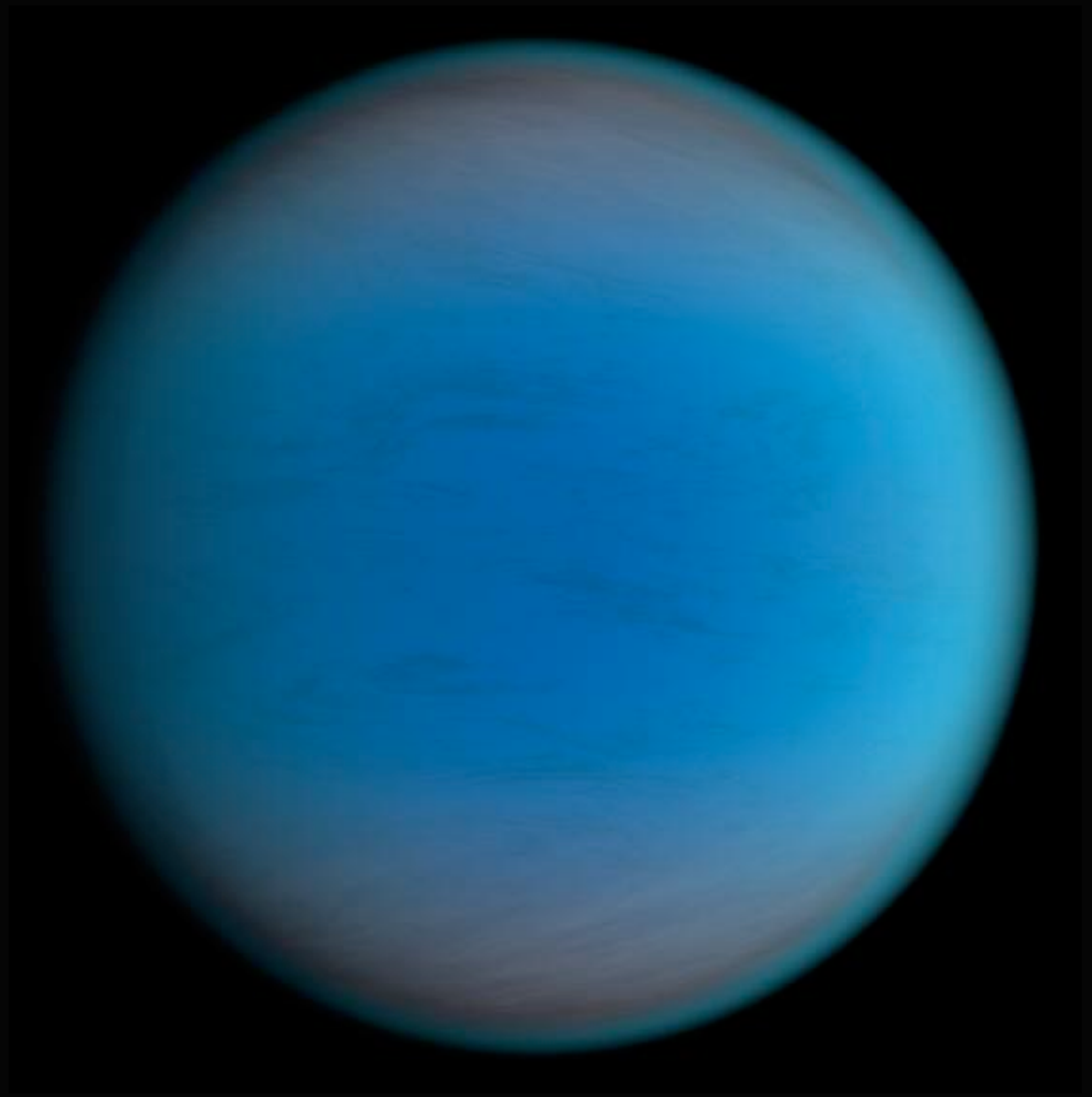


Launch April 16, 2018

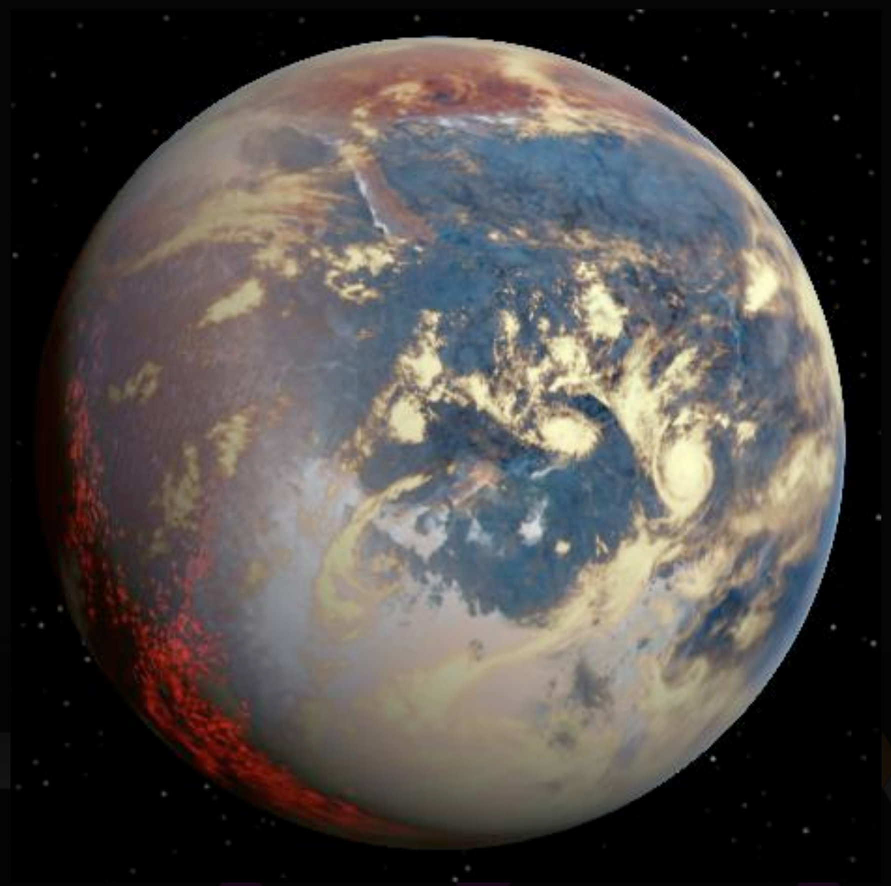
Webb will help to determine the nature of Super-Earths and Mini-Neptunes







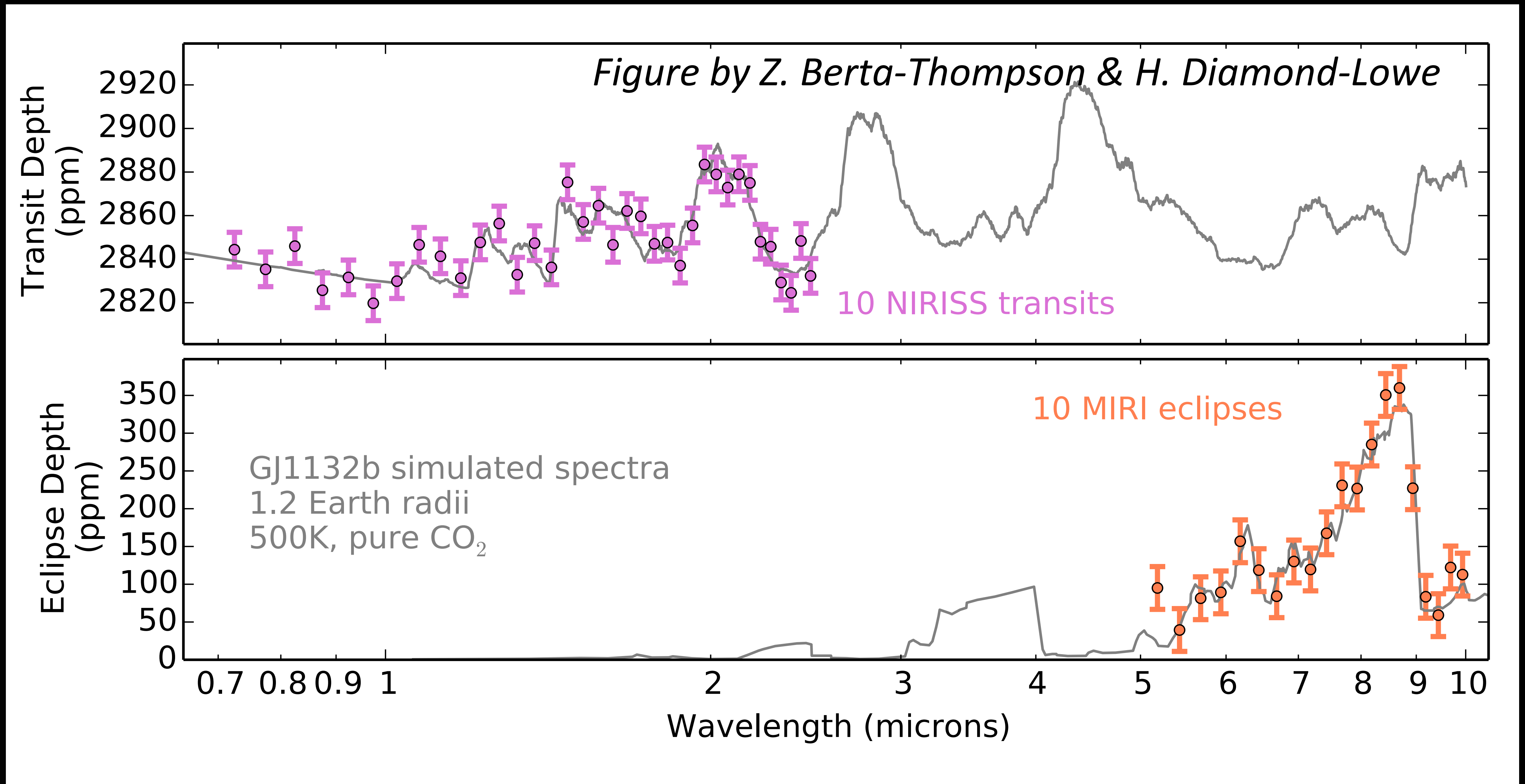
Beichman et al. (2014)

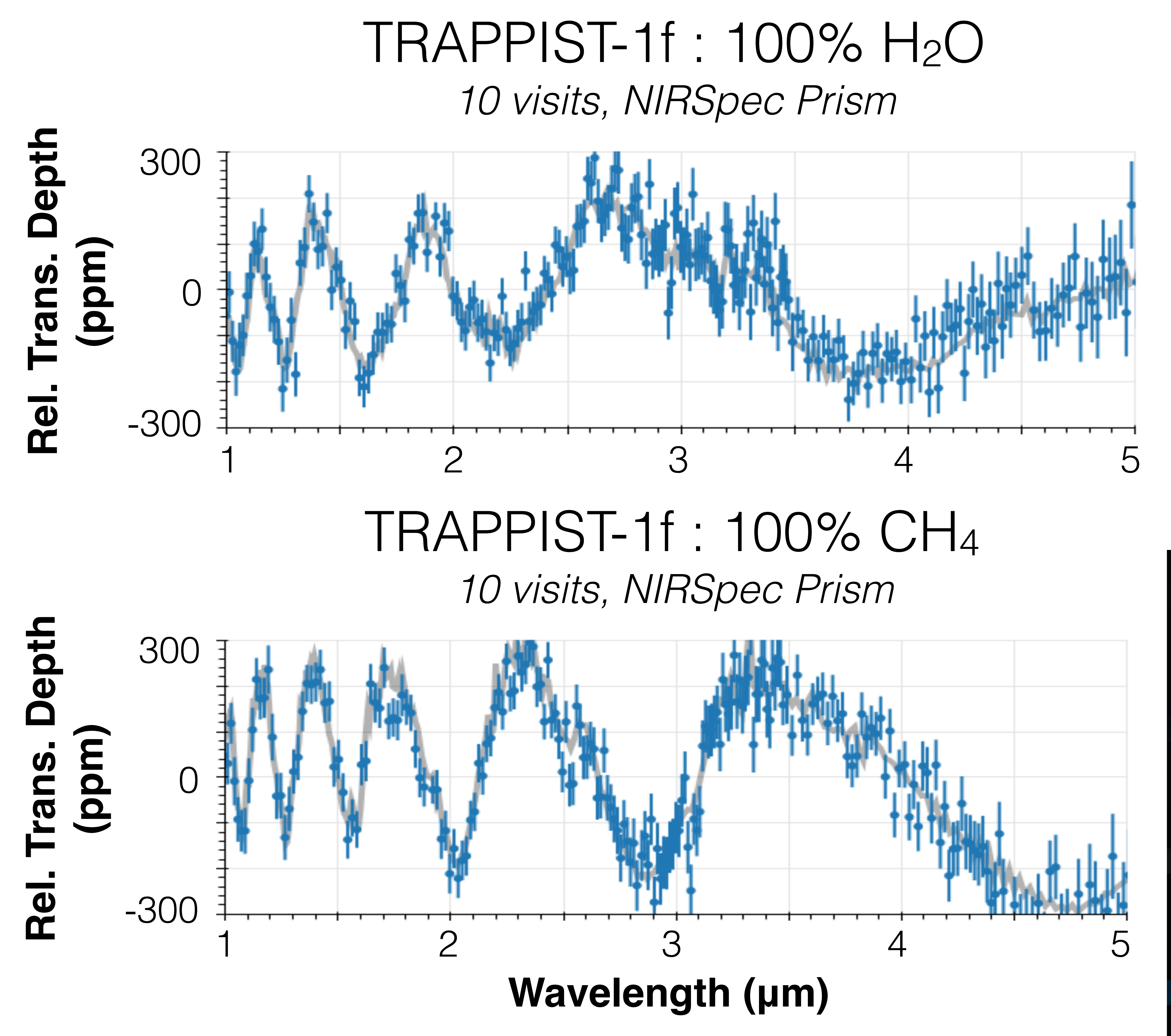


Kaltenegger and Traub (2009)

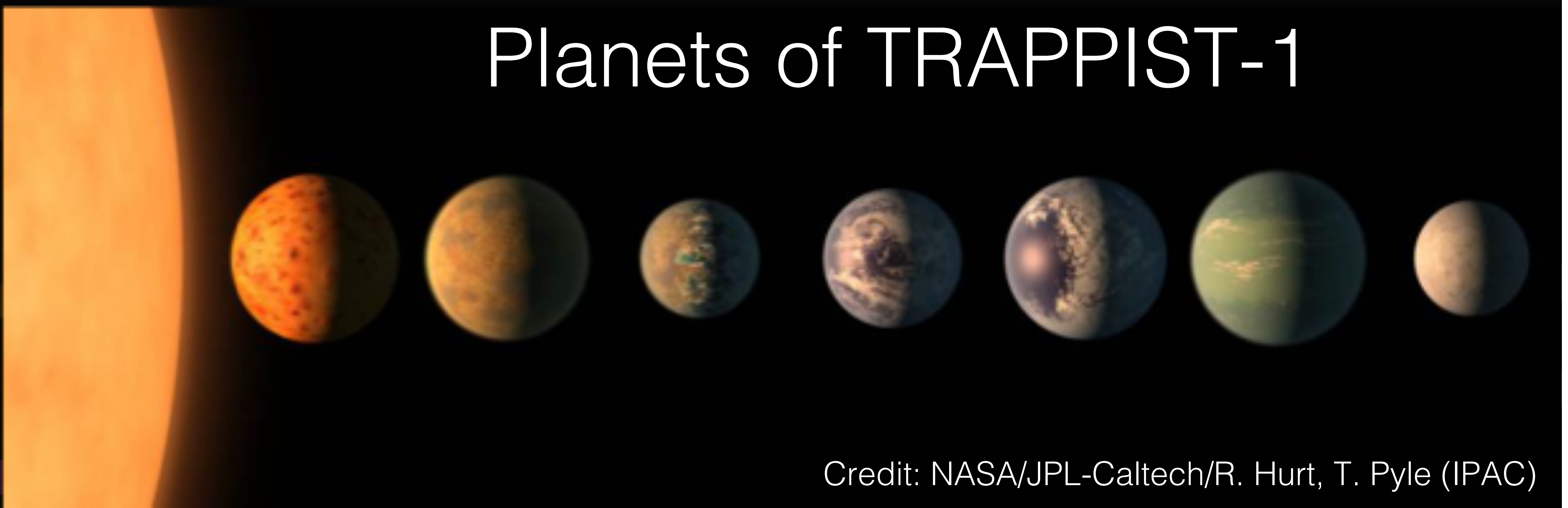
Webb will give us important insights into rocky planet atmospheres beyond our Solar System

Figures from Natasha Batalha using PandExo





The Seven Earth-Sized Planets of TRAPPIST-1



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

Webb will give us important insights into rocky planet atmospheres beyond our Solar System

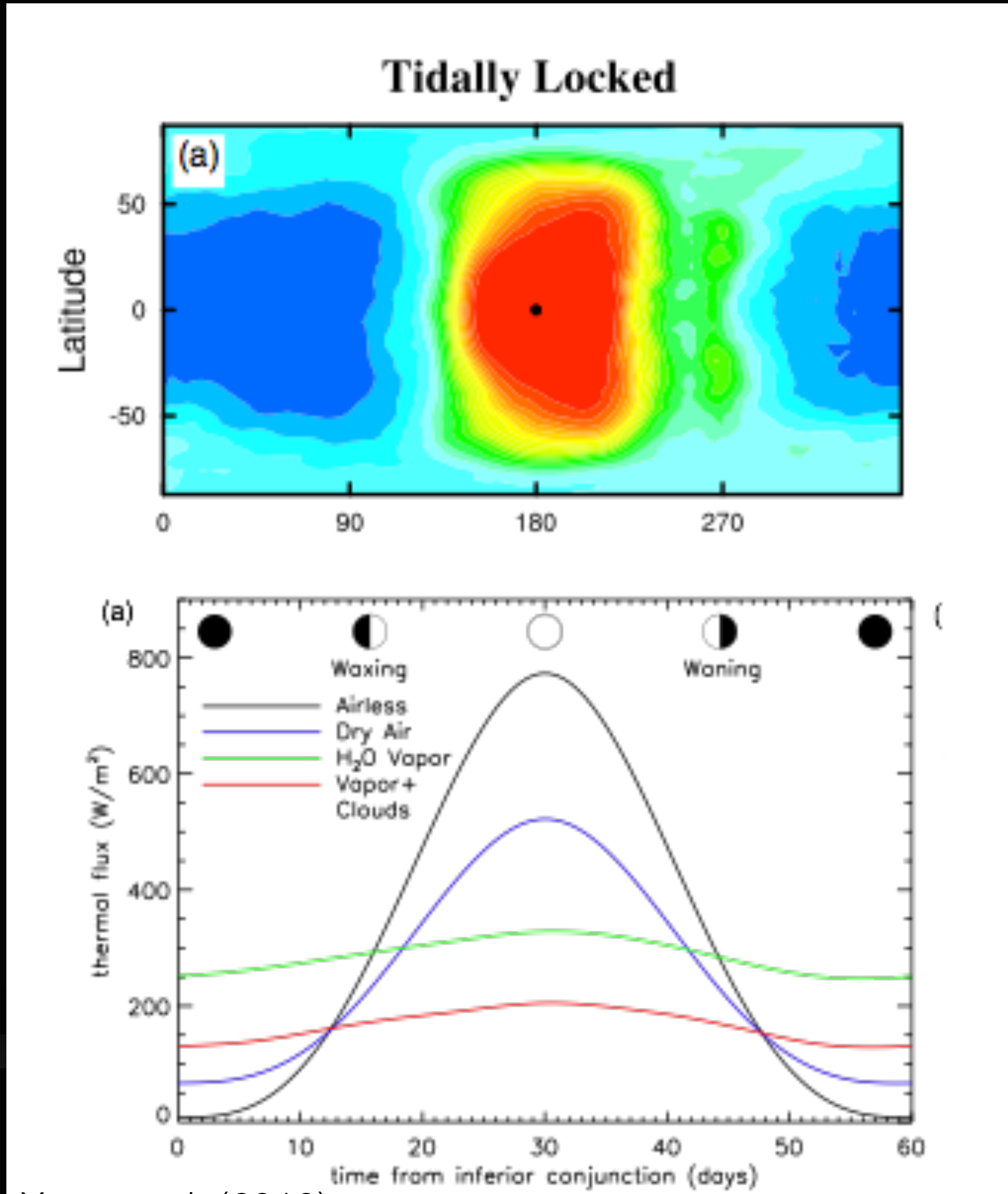
Morley et al. (2017)

Table 1. Number of transits or eclipses required to detect a Venus-like atmosphere[a]

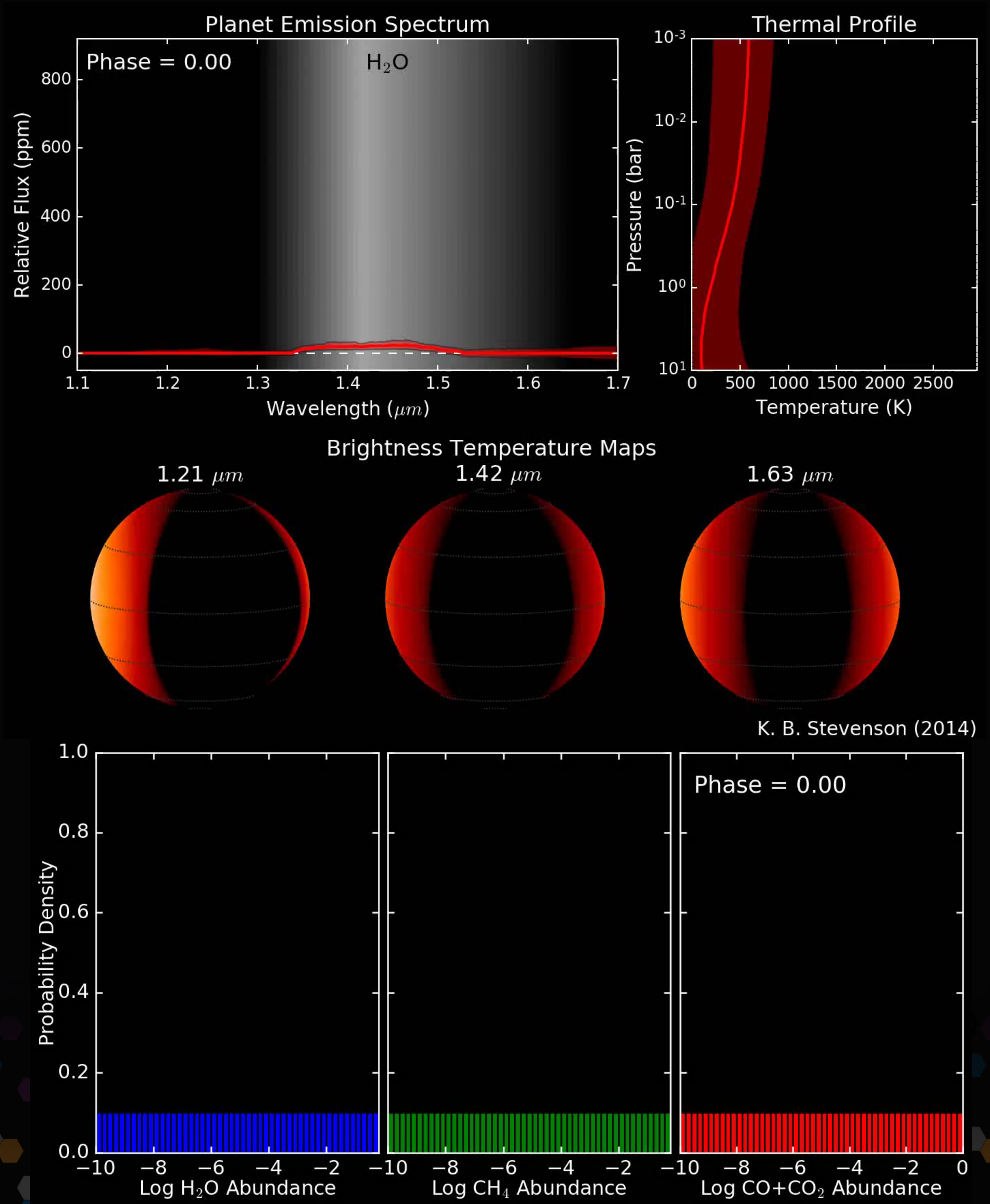
Planet	Emission P = 0.1 bar	Emission P = 1.0 bar	Emission P = 10.0 bar	Transmission P = 0.01 bar	Transmission P = 0.1 bar	Transmission P = 1.0 bar
TRAPPIST-1b	6 (11)	9 (18)	17 (30)	23 (89)	11 (40)	6 (21)
TRAPPIST-1c	19 (37)	29 (58)	48 (92)	–	73 (50)	36 (25)
TRAPPIST-1d	–	–	–	59 (–)	25 (46)	13 (24)
TRAPPIST-1e	–	–	–	15 (–)	6 (66)	4 (71)
TRAPPIST-1f	–	–	–	73 (–)	27 (92)	17 (54)
TRAPPIST-1g	–	–	–	36 (–)	15 (–)	10 (76)
TRAPPIST-1h	–	–	–	16 (–)	6 (90)	4 (56)
GJ 1132b	2 (2)	2 (3)	3 (6)	27 (38)	13 (20)	11 (13)
LHS 1140b	–	–	–	–	– (96)	– (64)

[a] The detection criteria are (1) for transmission spectra, the simulated data must rule out a flat line at 5σ confidence on average, and (2) for emission spectra, the band-integrated secondary eclipse must be detected at 25σ. We base our calculations on models with a Venusian composition, zero albedo, and planet mass equal to the measured values from TTVs or RVs. For the case in parentheses, we use an albedo of 0.3 and planet mass predicted by the theoretical mass/radius relation. The – mark denotes cases where over 100 transits or eclipses are needed.

Webb will allow us to probe the climates of distant worlds



Yang et al. (2016)



K. B. Stevenson (2014)

Webb Is Imperative

- *Webb* is best instrument for atmospheric characterization in the 2020s

- *Webb* will revolutionize exoplanet science
  - From hot Jupiters to temperate Earths
  - Obtain spectra at significantly higher resolutions and at critical wavelengths not previously accessible
  - Provide most precise constraints on atmospheric composition, thermal structure, and climate
  - Better understand planet formation and evolution
  - Put our own solar system into context

- *Webb* will open new doors of scientific inquiry
  - Cycles 1+2: “known unknowns”
  - Cycles 3+: “unknown unknowns”

Backup Slides

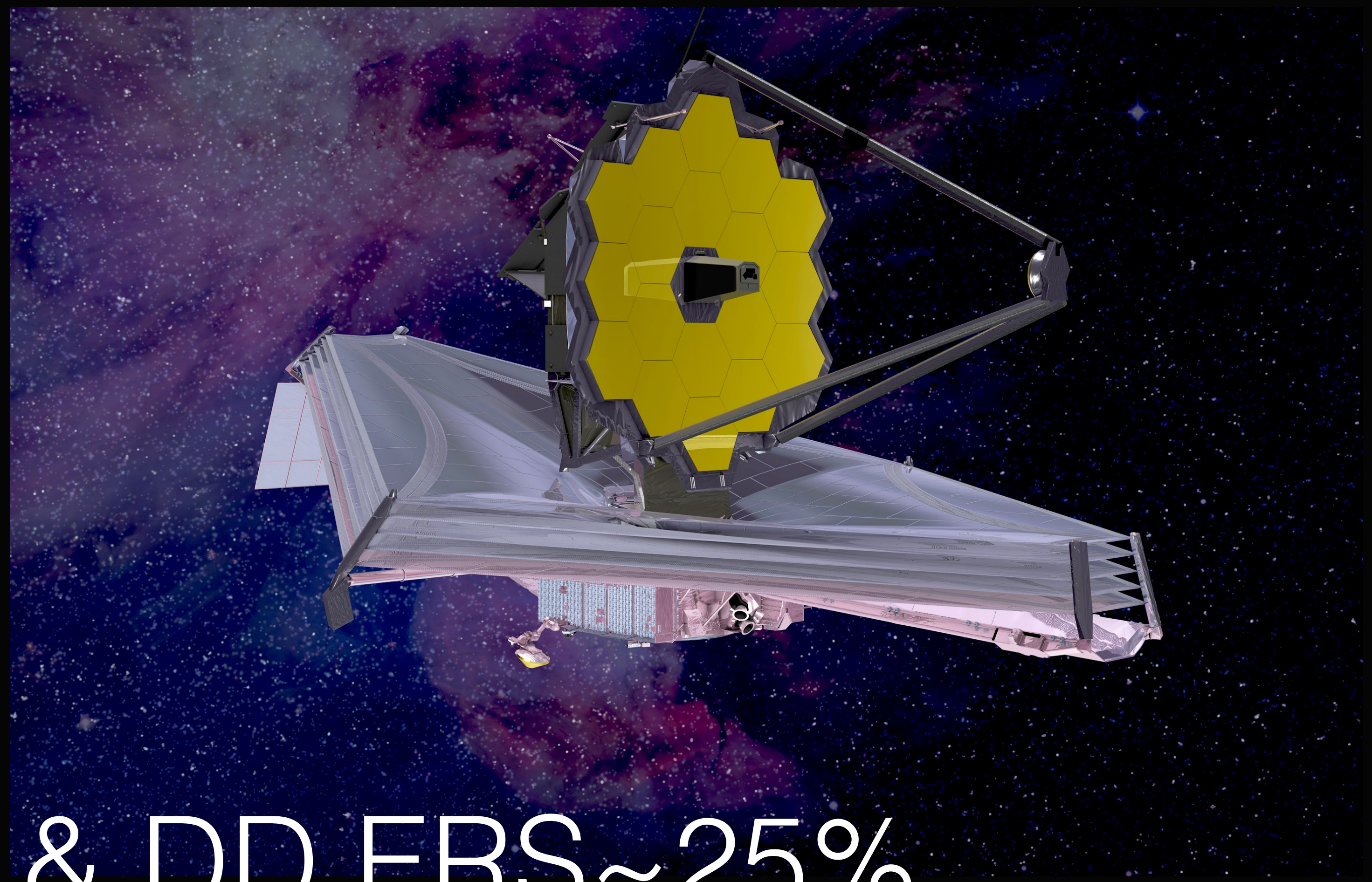
Webb TSO Target Acquisition Strategies

Offset TA and saturation are proven strategies leveraged by *Spitzer* and *Hubble*

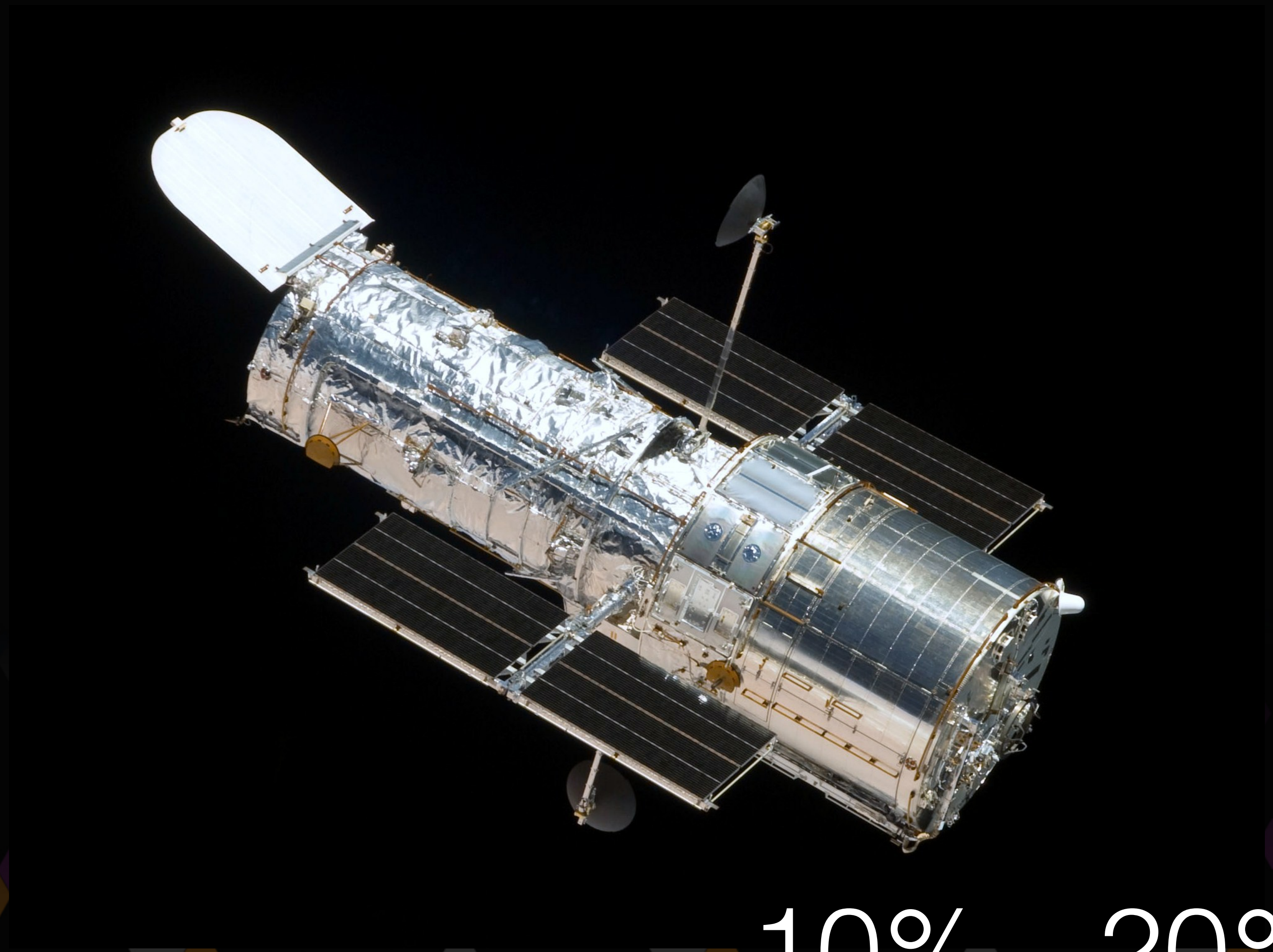
With FGS alone positional errors range from 0.5-1 arcsec (a few pixels)

The Future of Exoplanets with Space-Based General Purpose Observatories is Bright!

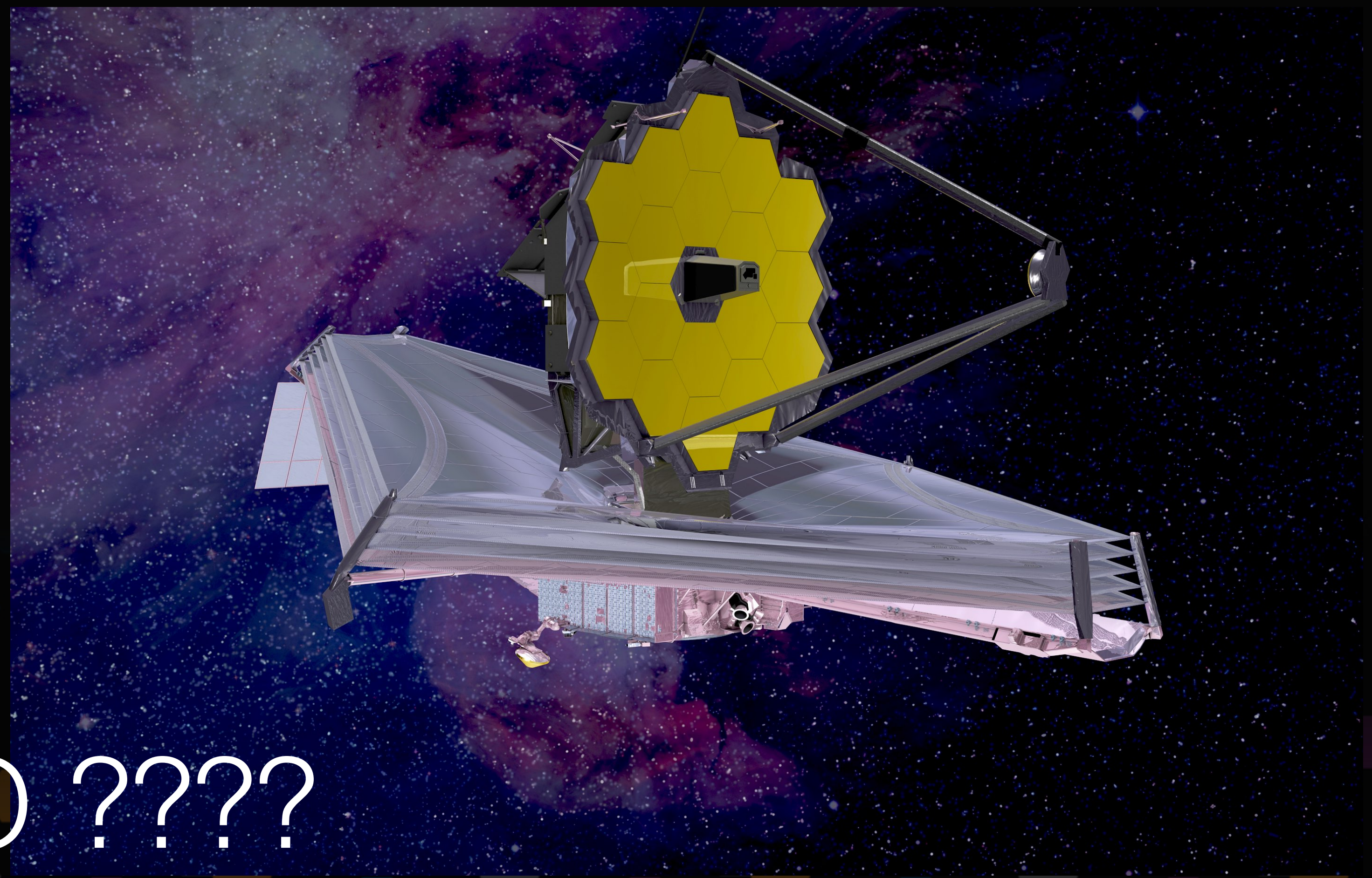
20% - 40%



GTO & DD ERS~25%



10% - 20%



GO ????