TRAPPIST-1 seen by the JWST: First detection of the thermal emission of temperate rocky exoplanets

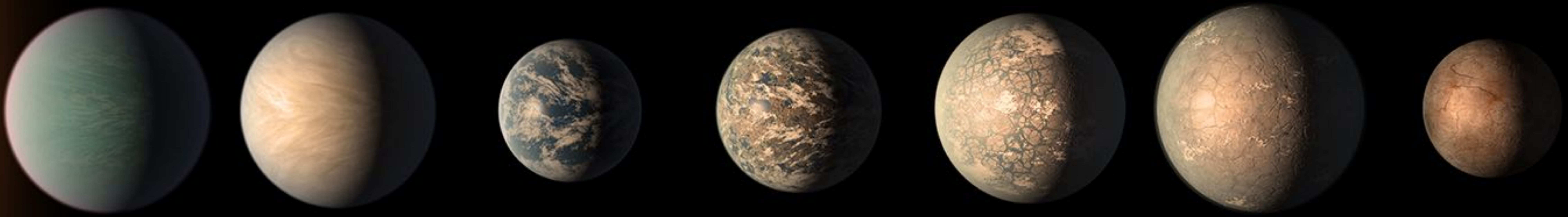
Credit: NASA

Elsa Ducrot

TRAPPIST-1

Credit: NASA

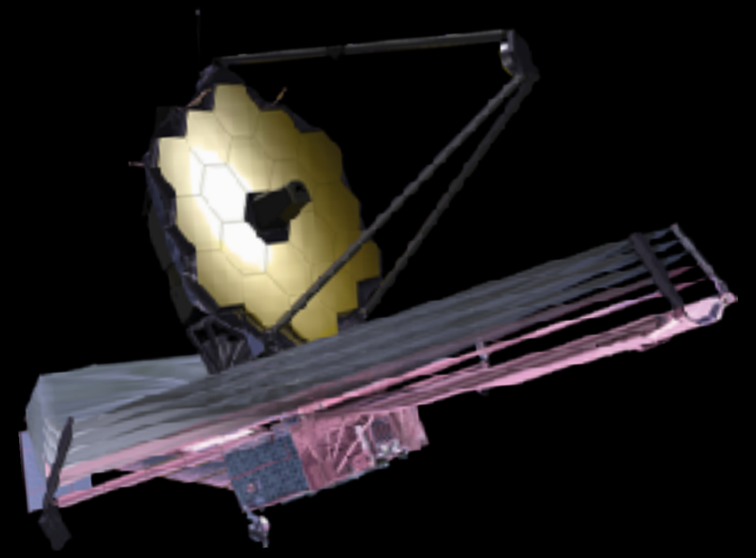
TRAPPIST-1

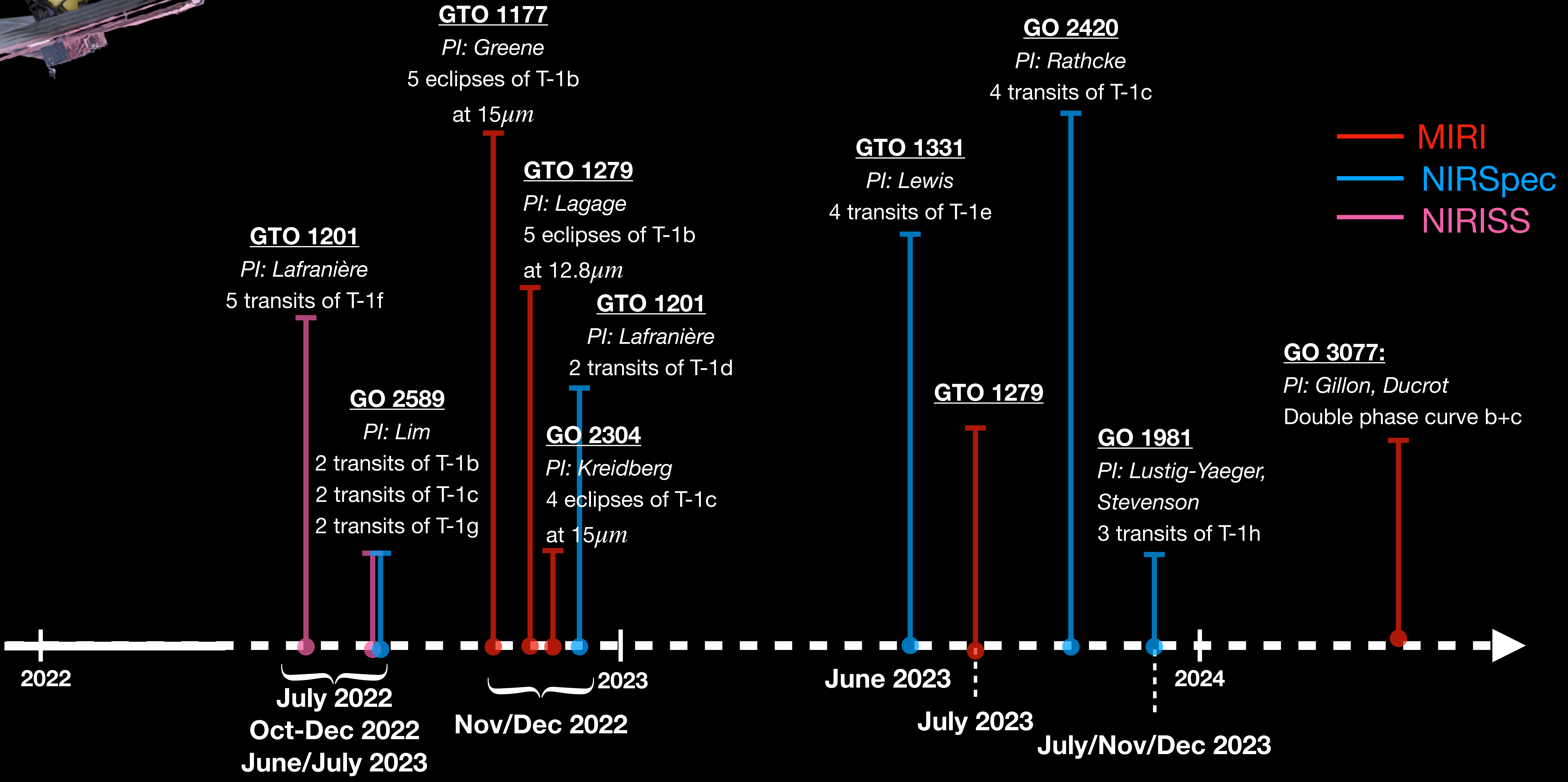


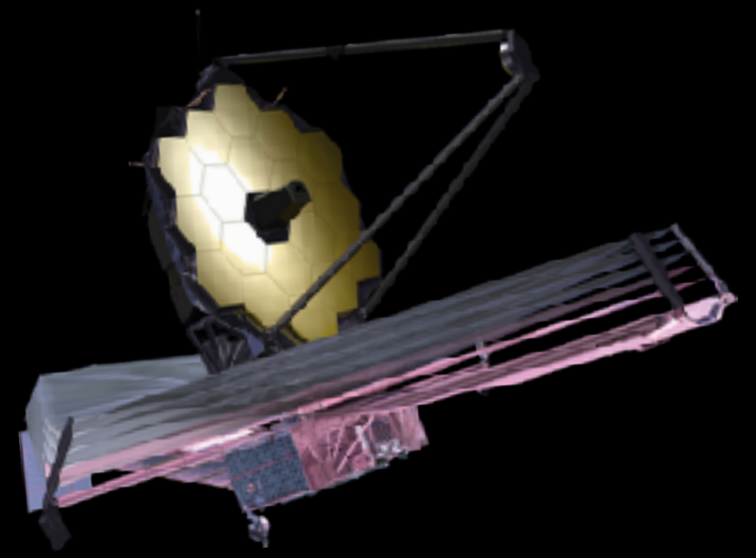
- The star : an old M8V, $T_{eff} \simeq 2500$ K
- $\simeq 9\,\%\ M_{\odot}$, $\simeq 12\,\%\,R_{\odot}$, at 12 pc only
- The planets: 7 Earth-sized planets
- 3 planets within the habitable zone
- periods from 1.51 to 18.76 days
- forming a **chain of three bodies Laplace resonances**
- **r**adii, masses and irradiation similar to the terrestrial planets of the solar system
- Most favorable exoplanets for the first atmospheric characterization of temperate (0.1 — 4 $S_{\oplus}$) rocky worlds (with JWST)

Credit: NASA

TRAPPIST-1 with JWST

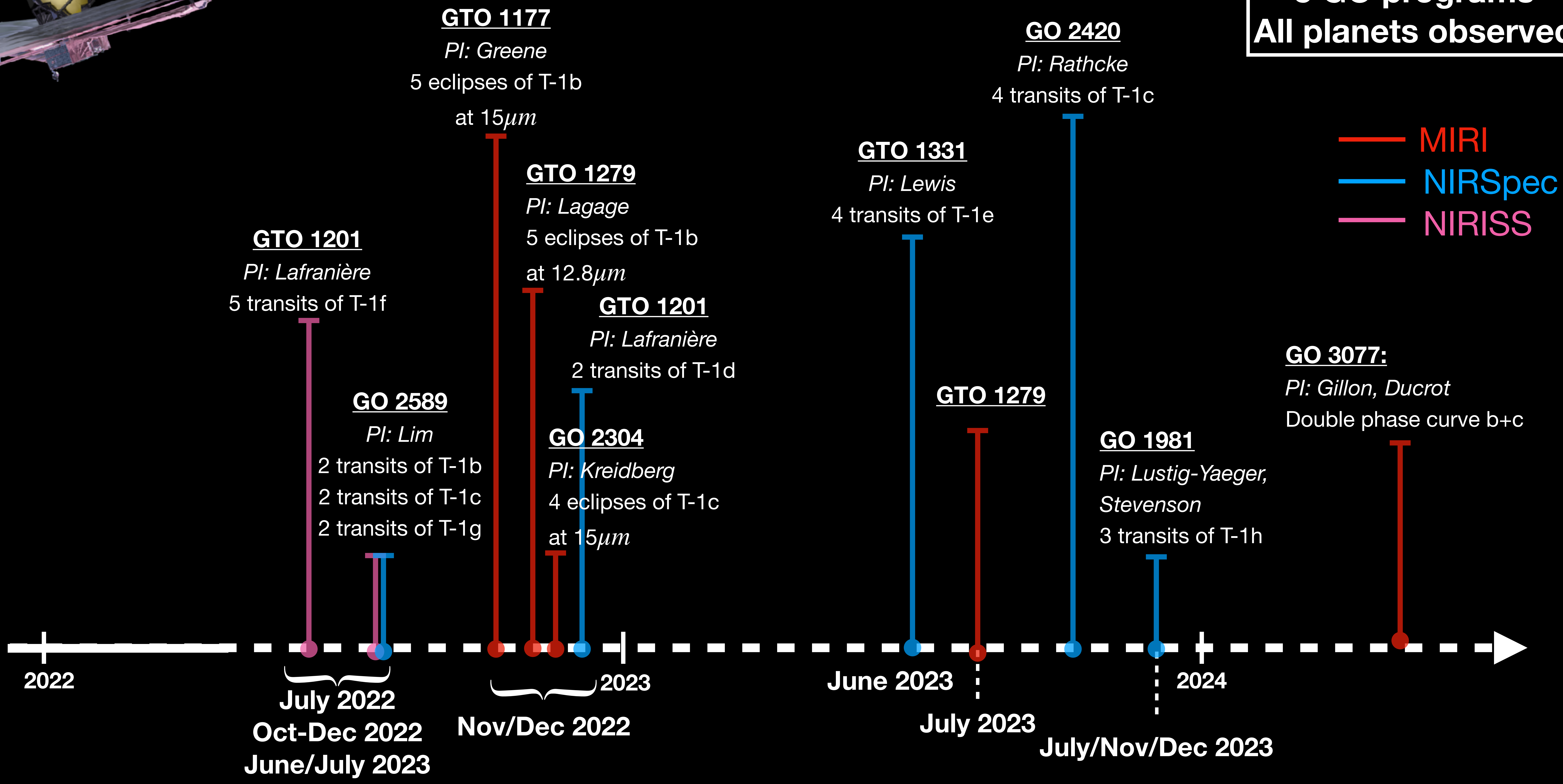




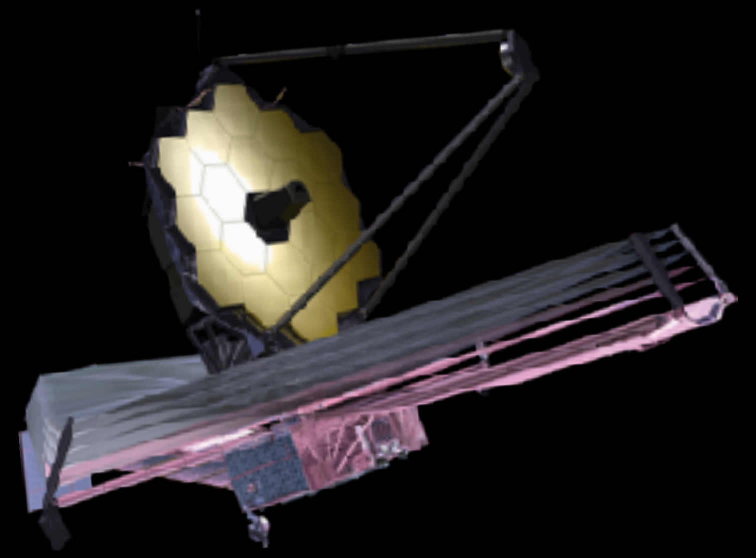


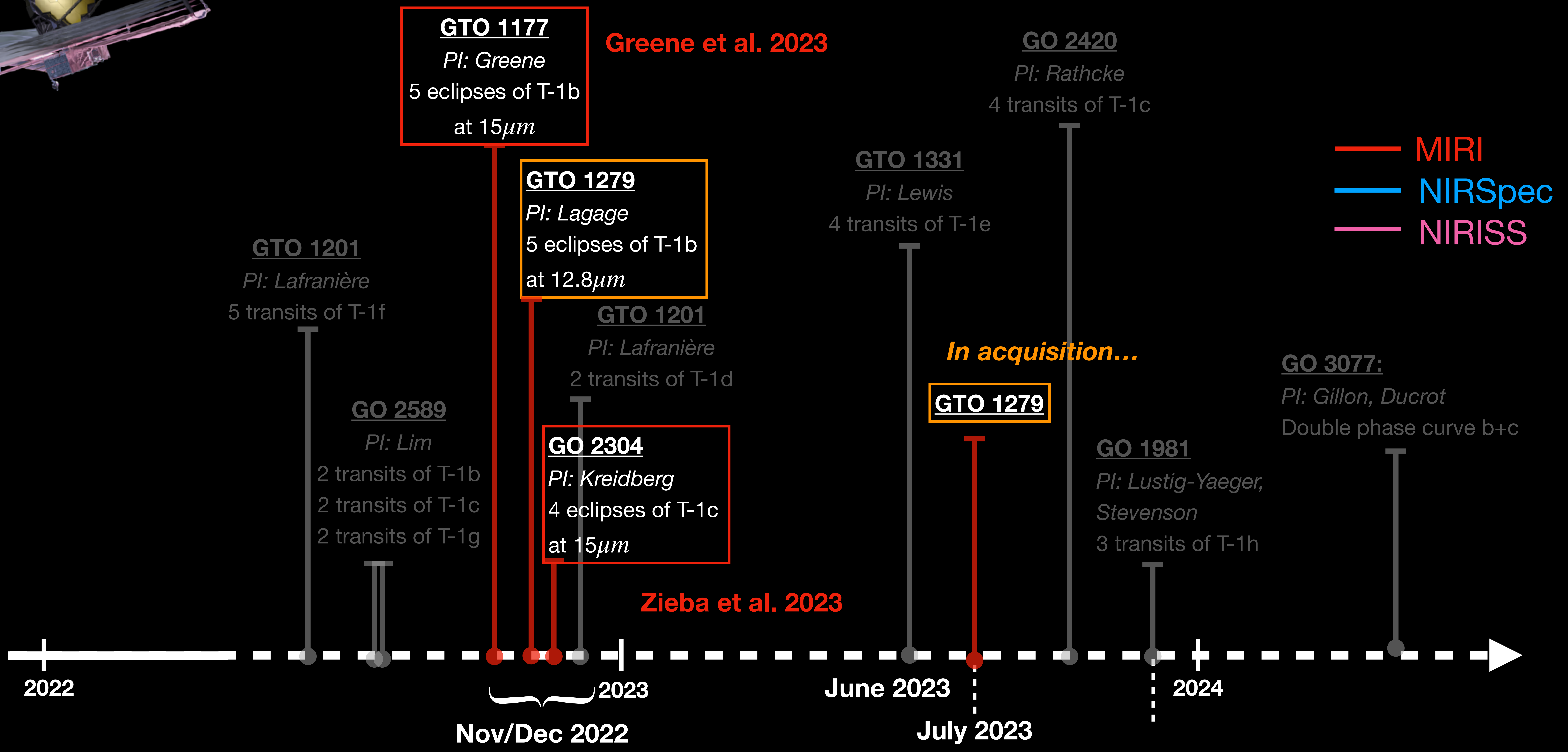
TRAPPIST-1 with JWST

4 programs GTO
5 GO programs
All planets observed

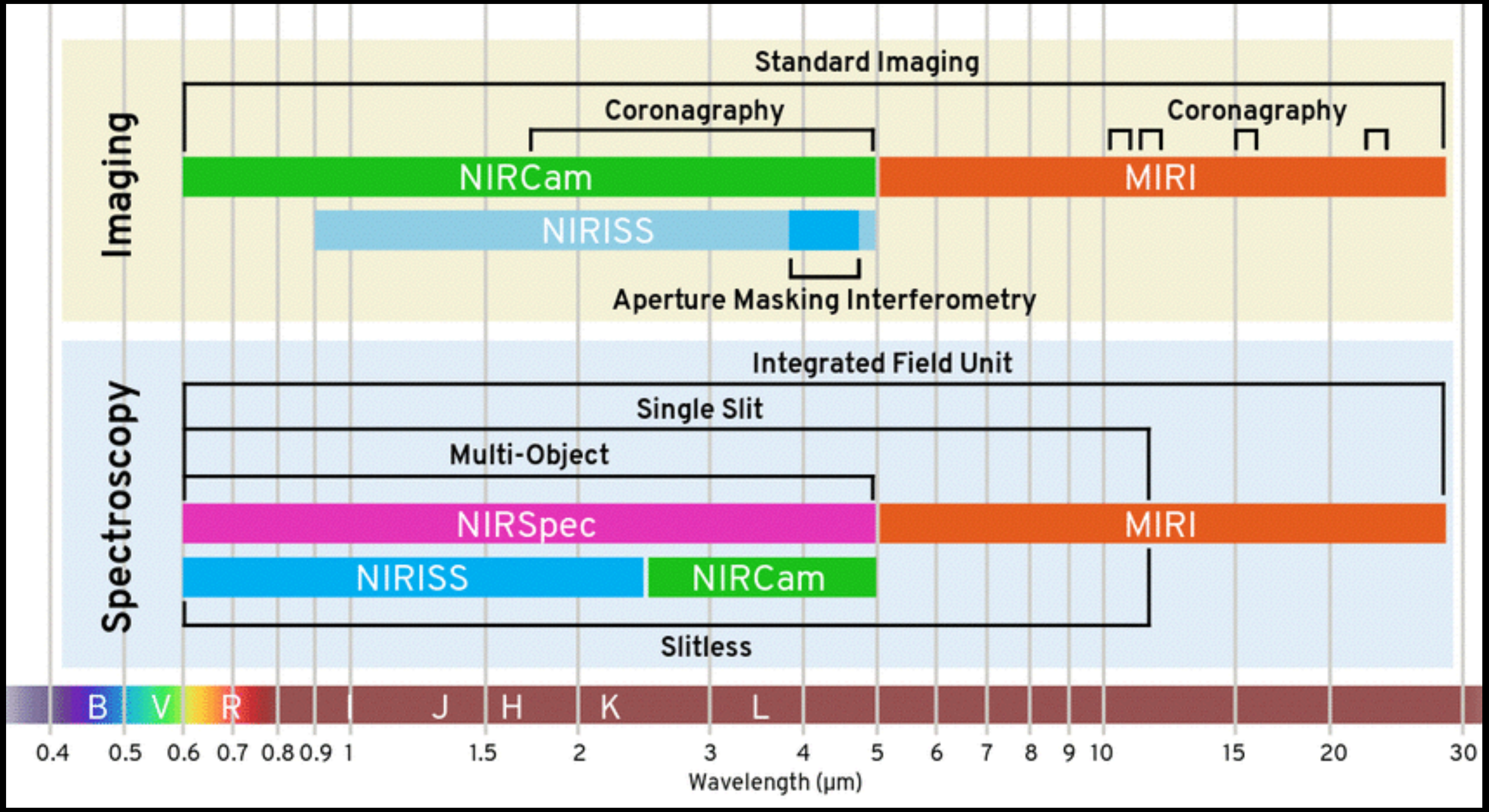


TRAPPIST-1 with JWST





The Mid-Infrared instrument



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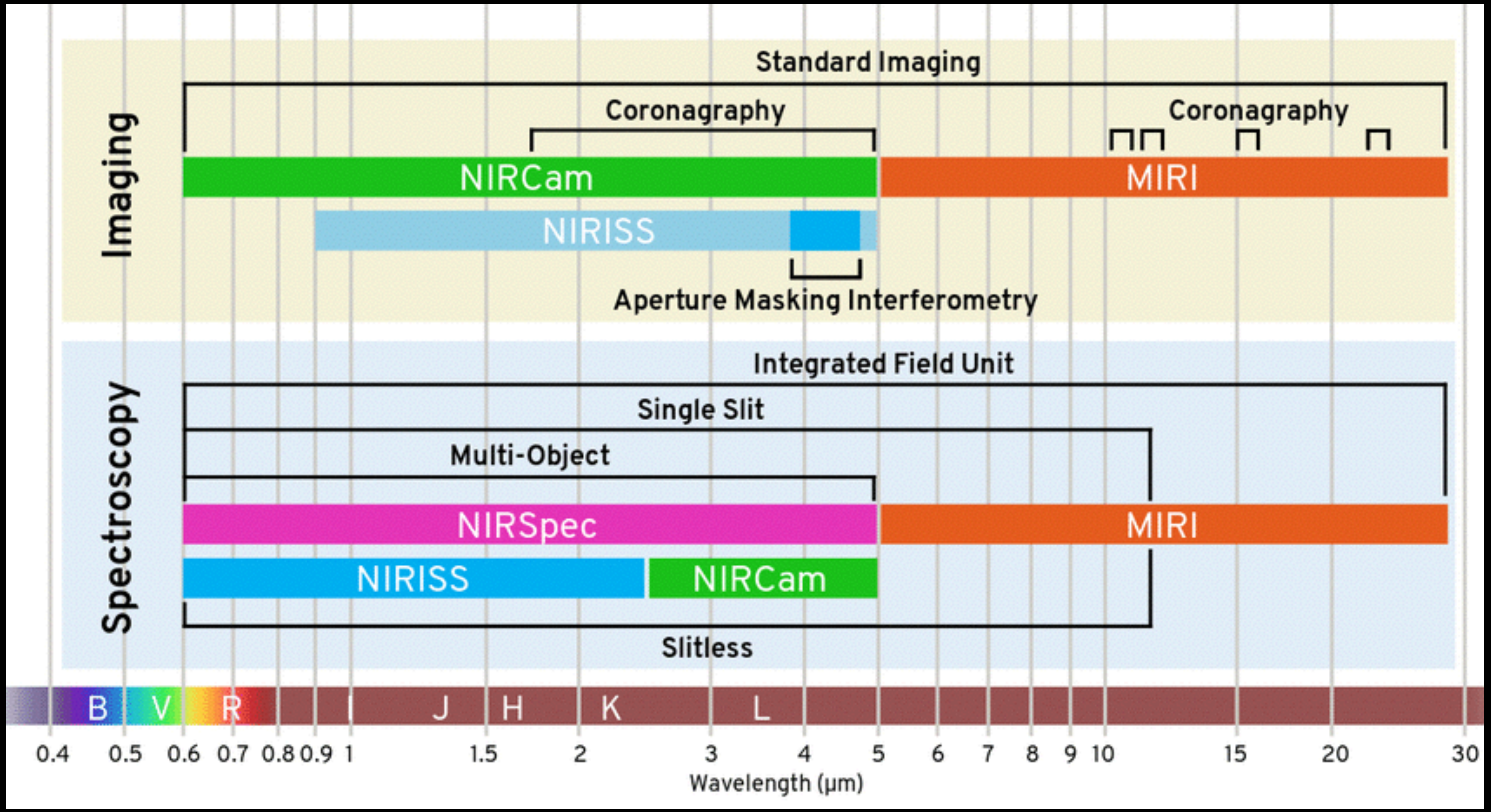

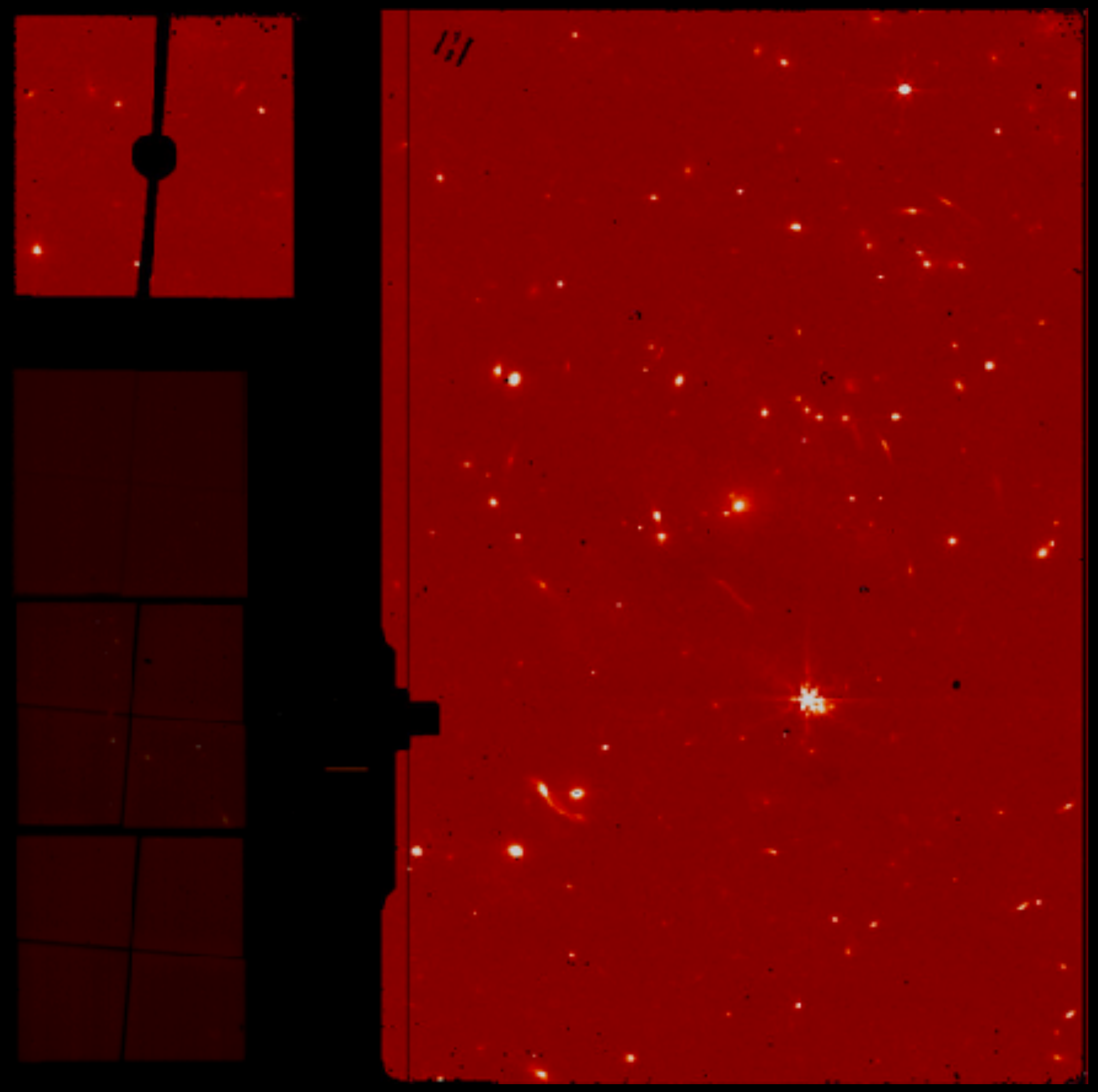

Credit: NASA, CEA, MPIA

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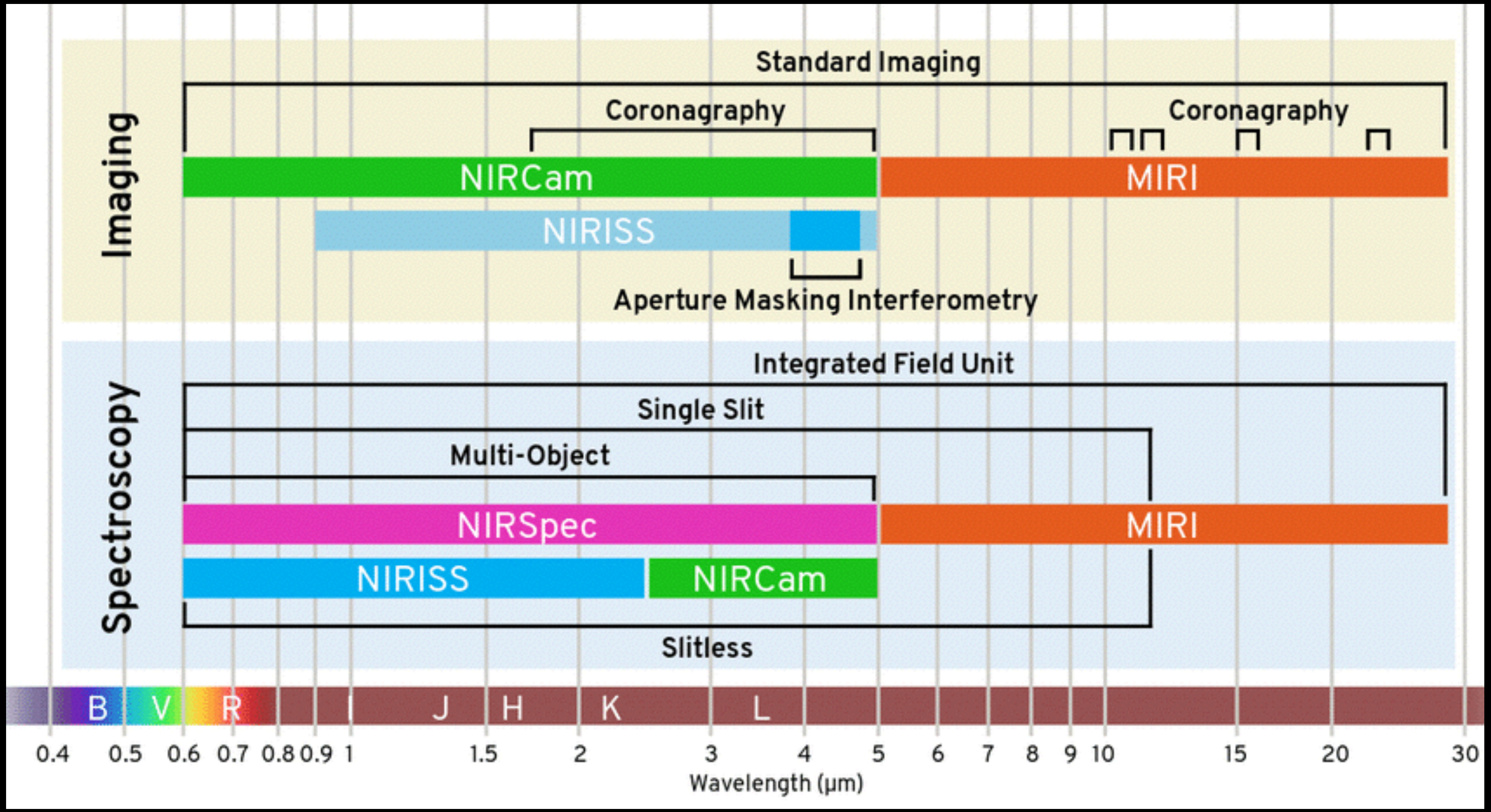
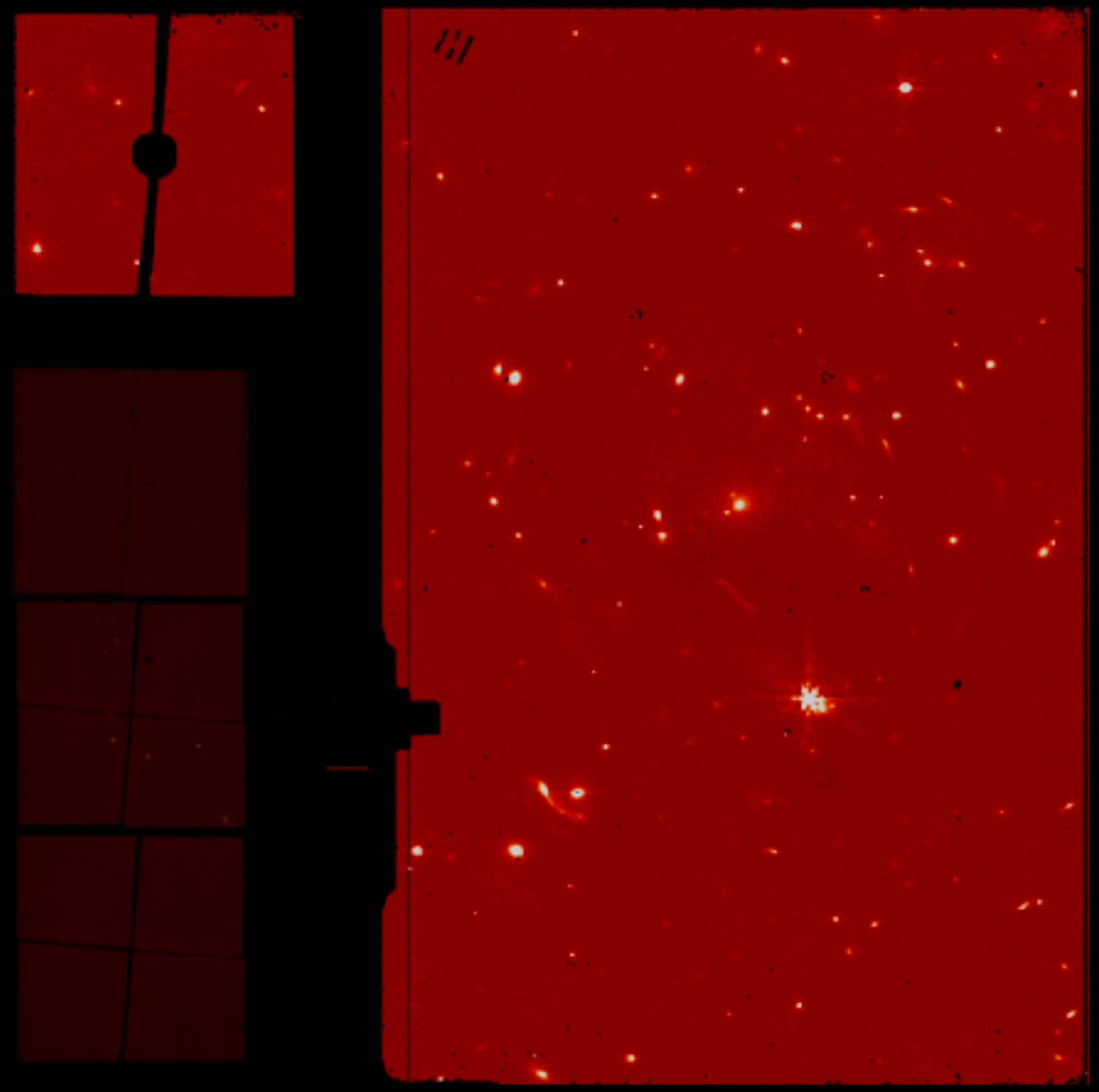


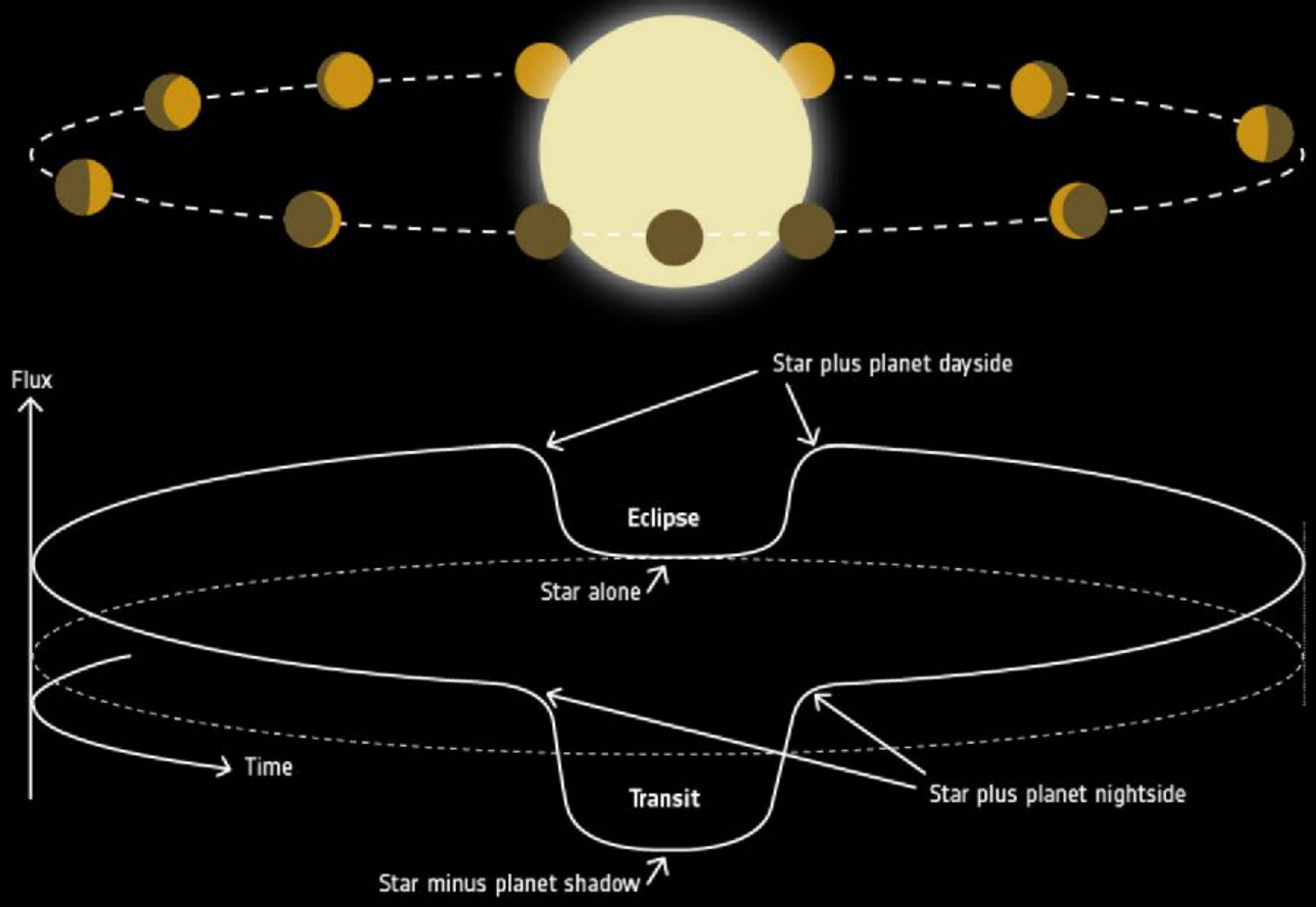


Credit: NASA, CEA, MPIA

- MIRI is the only mid-infrared instrument, it covers the wavelength range of 4.9 to 28.8 μm
- MIRI has 3 modes: MRS, LRS, imaging + one Lyot and three 4-quadrant phase mask coronagraphs
- MIRI's imager has 9 broad-band filters. This is the mode used to observe TRAPPIST-1 b/c in emission


TRAPPIST-1 b

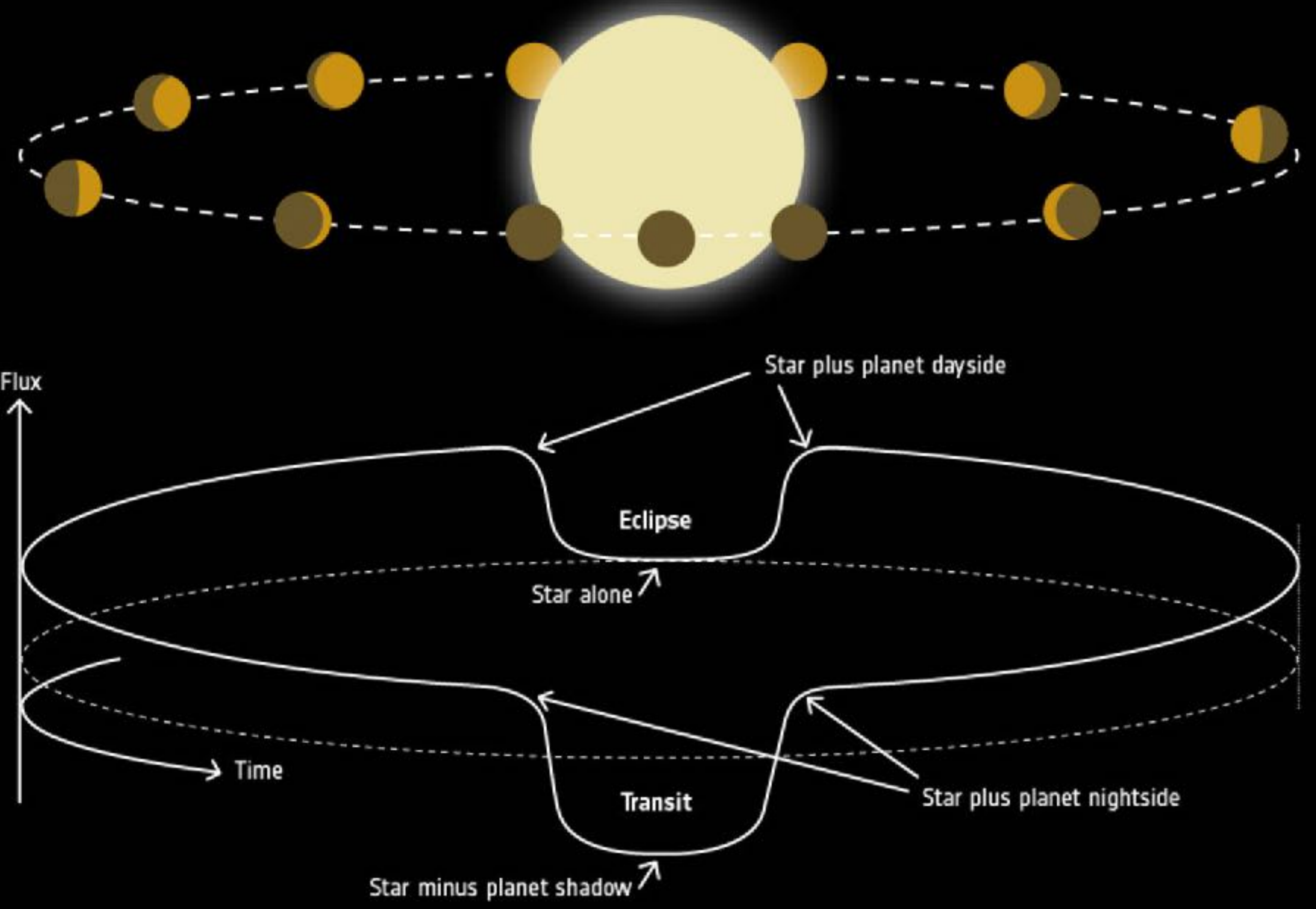
Secondary eclipses observations



- With eclipses we can derive the brightness temperature of the dayside of the planet
- Not impacted by stellar contamination !

Credit: ESA

Secondary eclipses observations



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Motivation of the observations of TRAPPIST-1 b:

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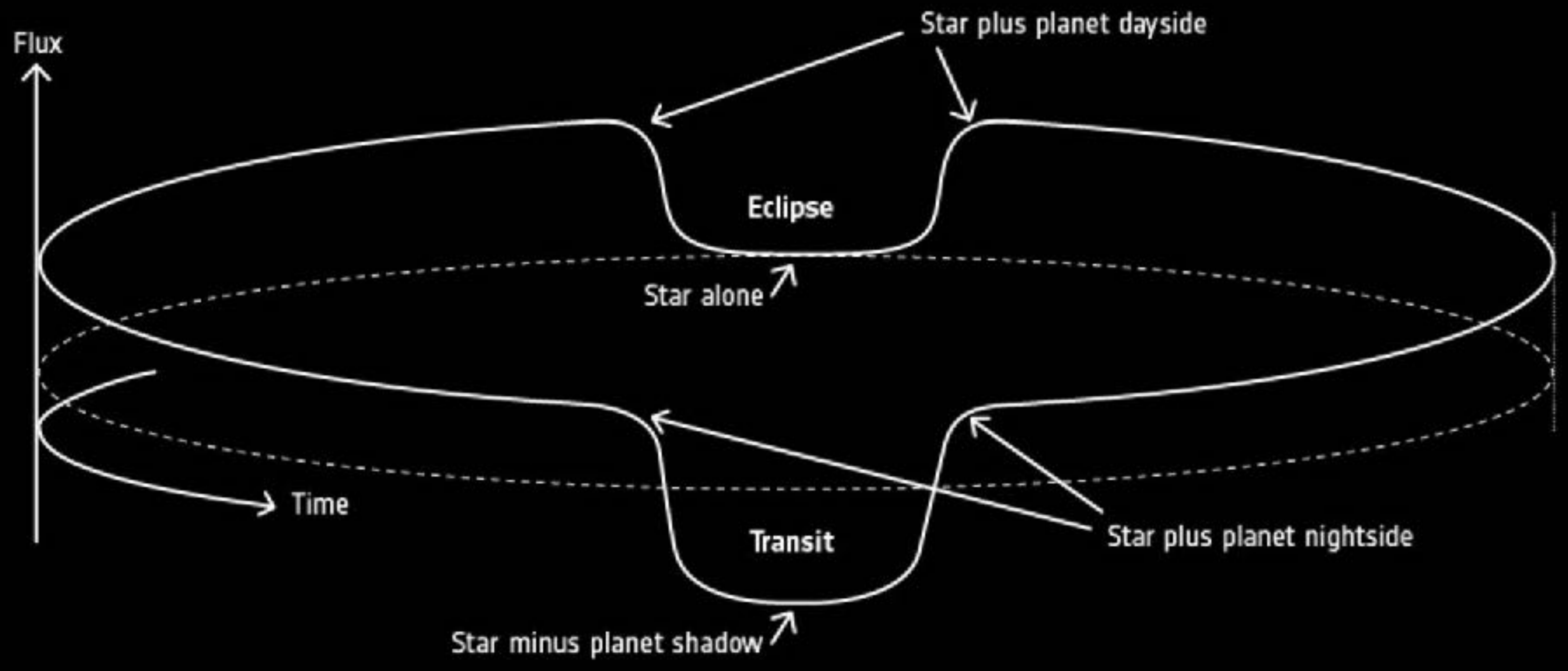

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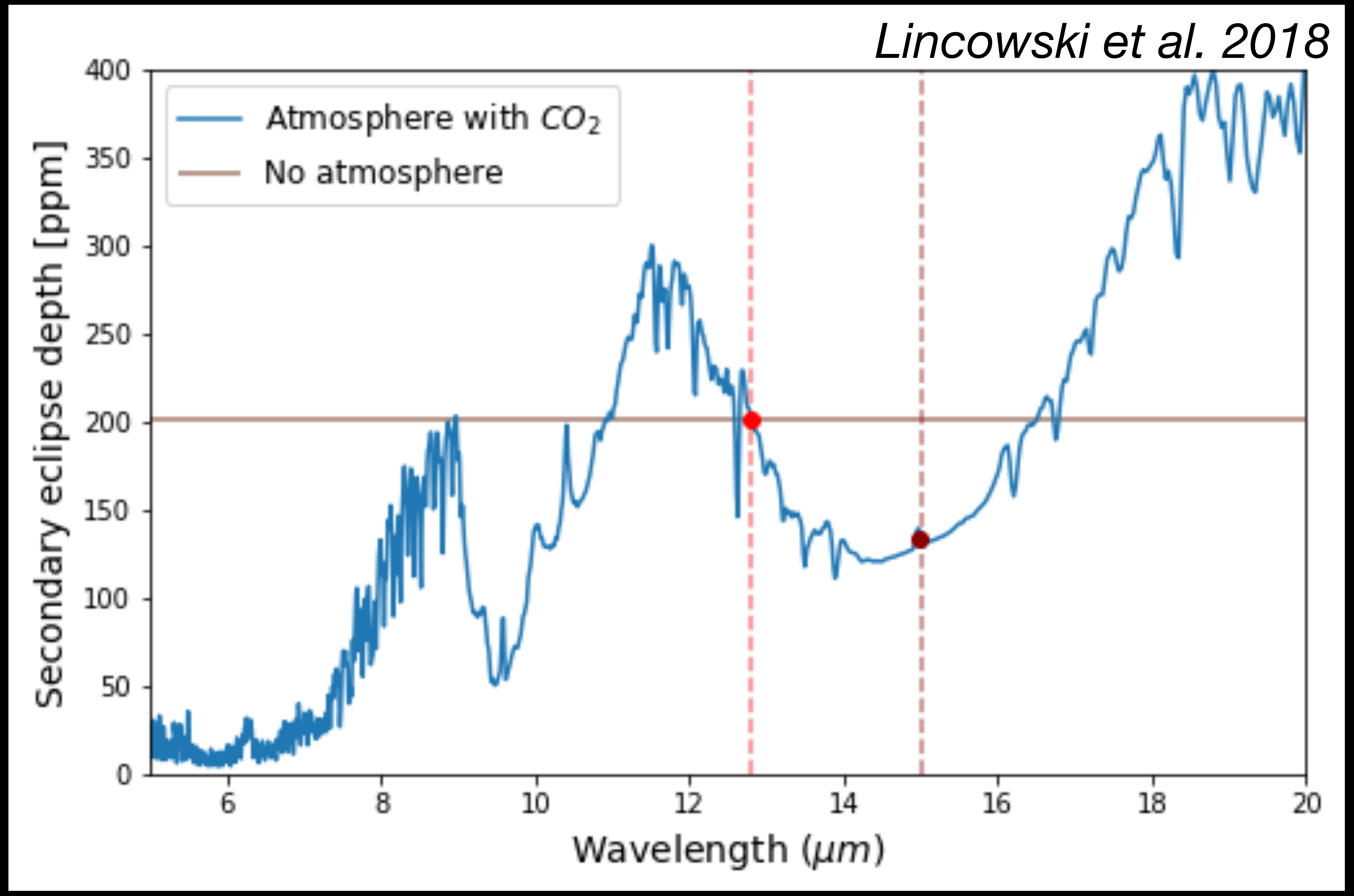

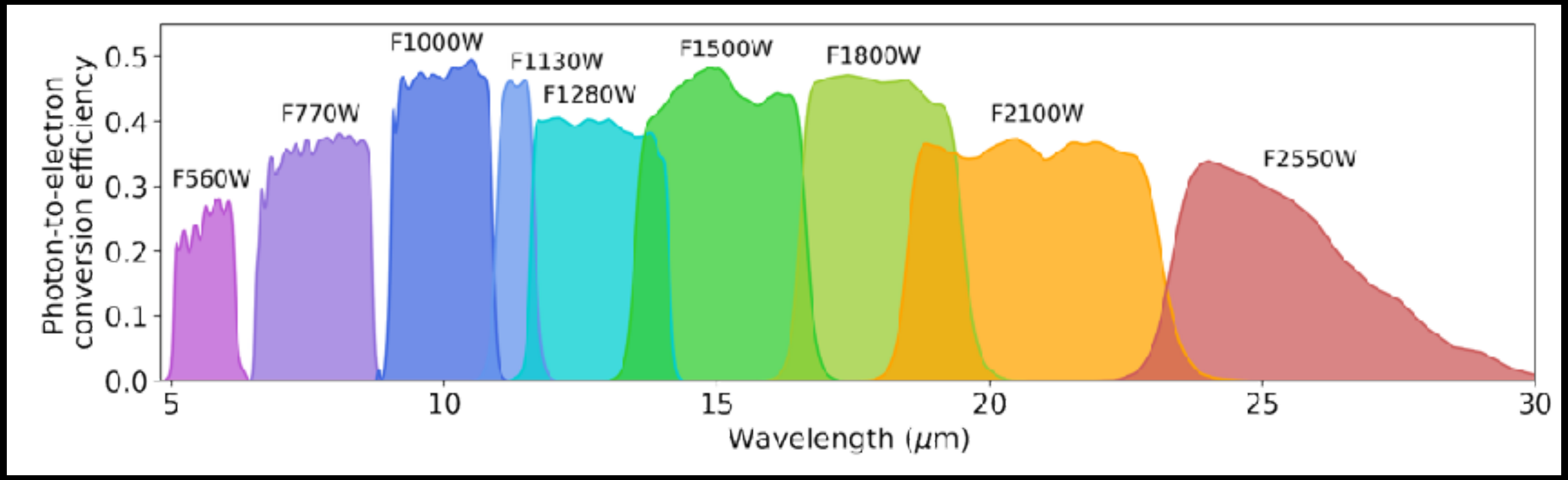

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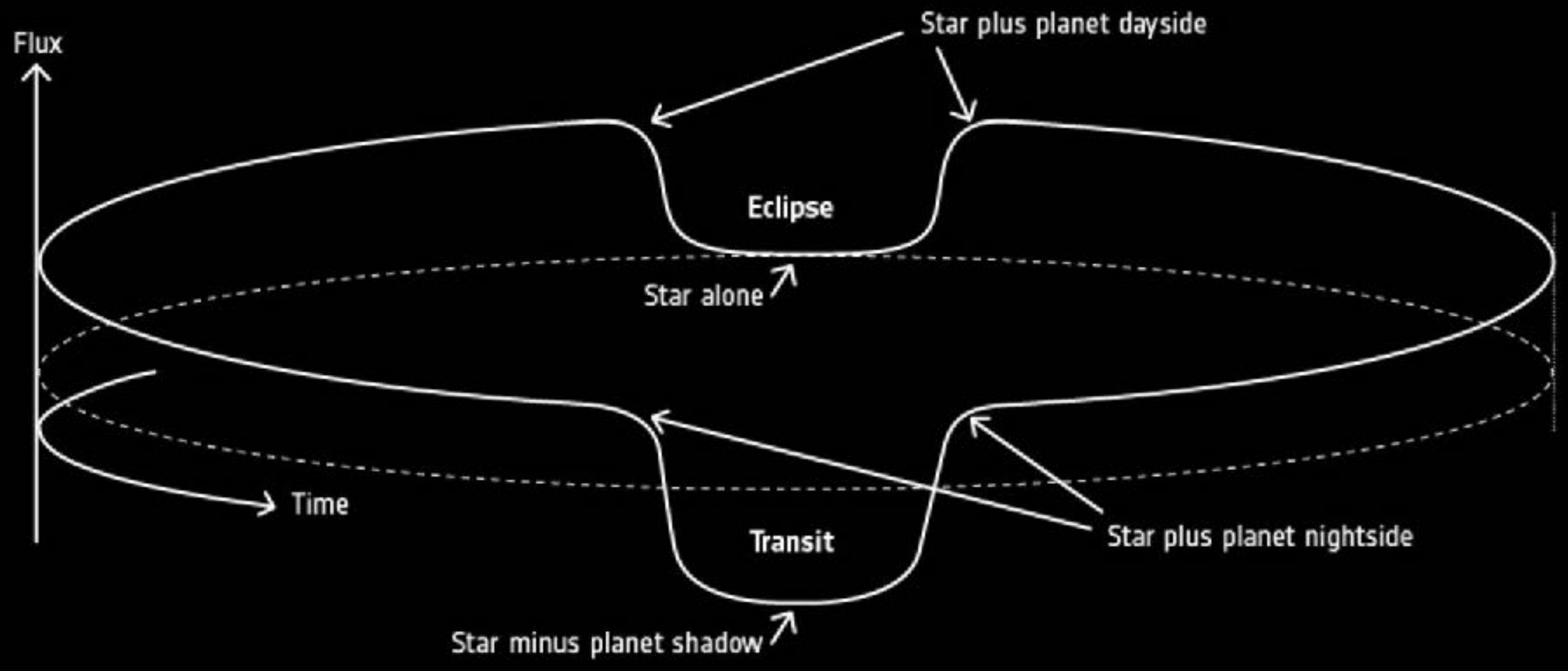

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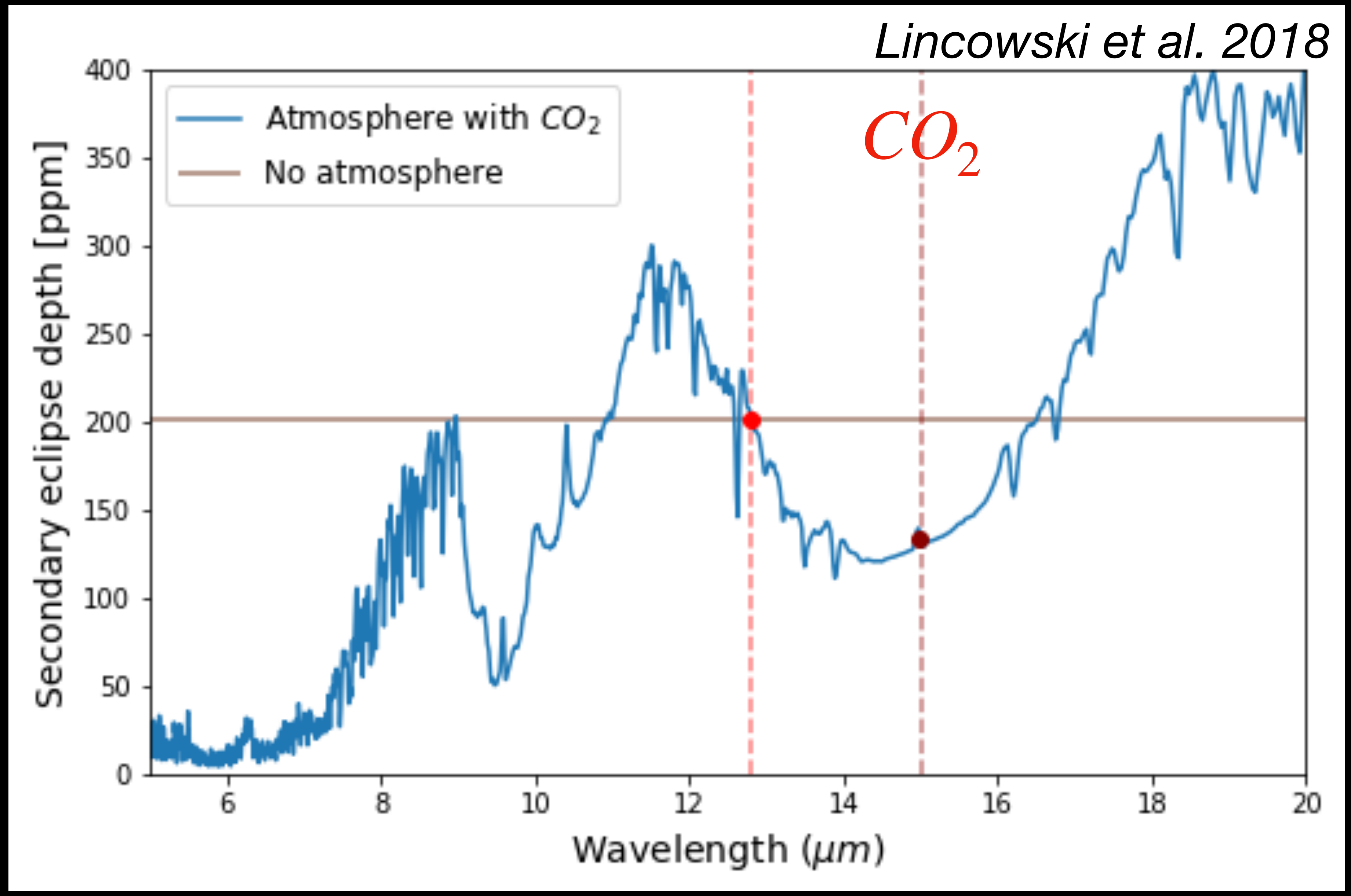

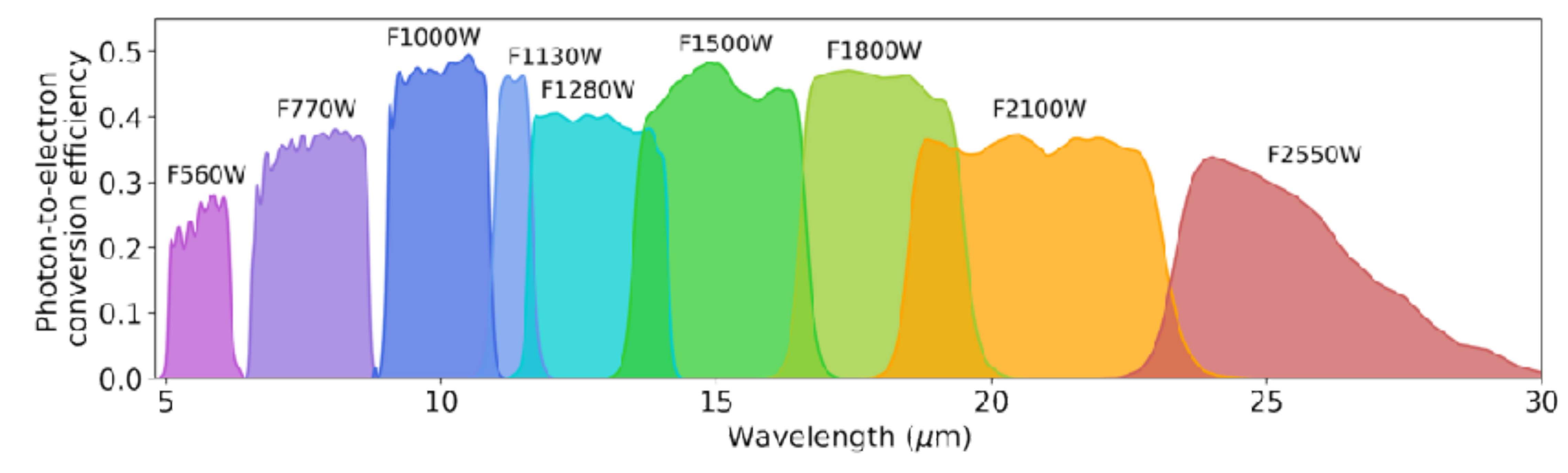

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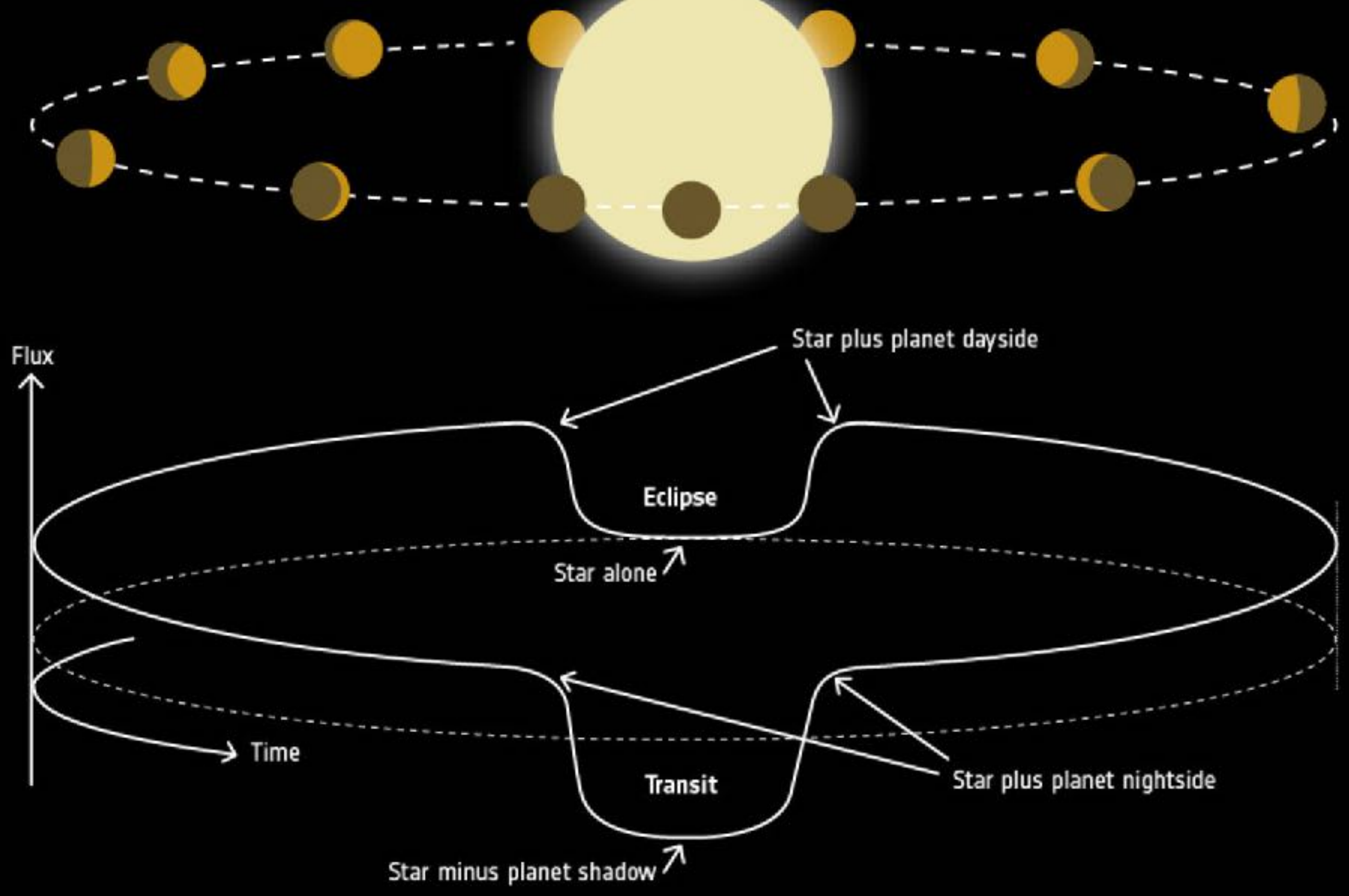

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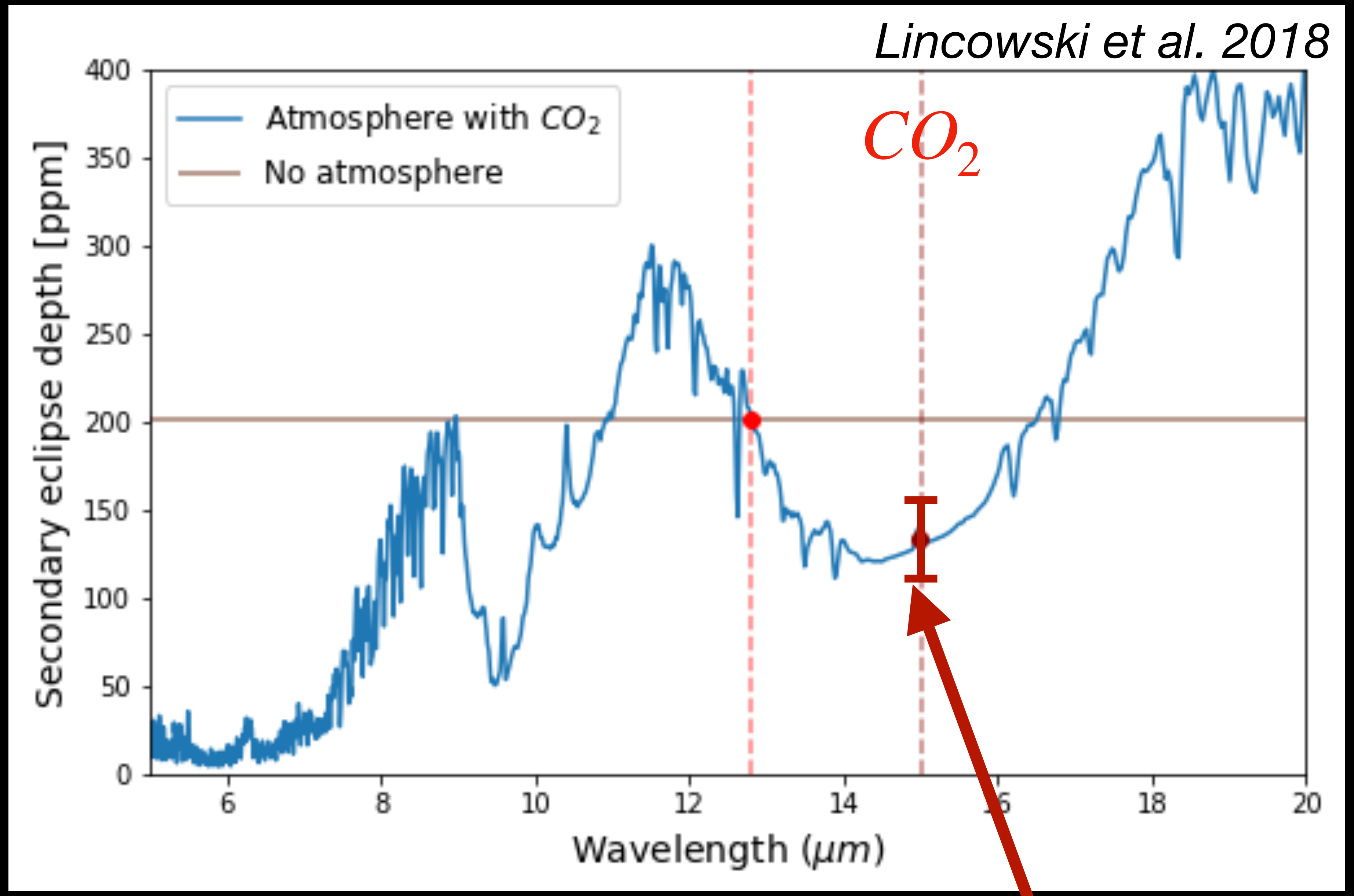
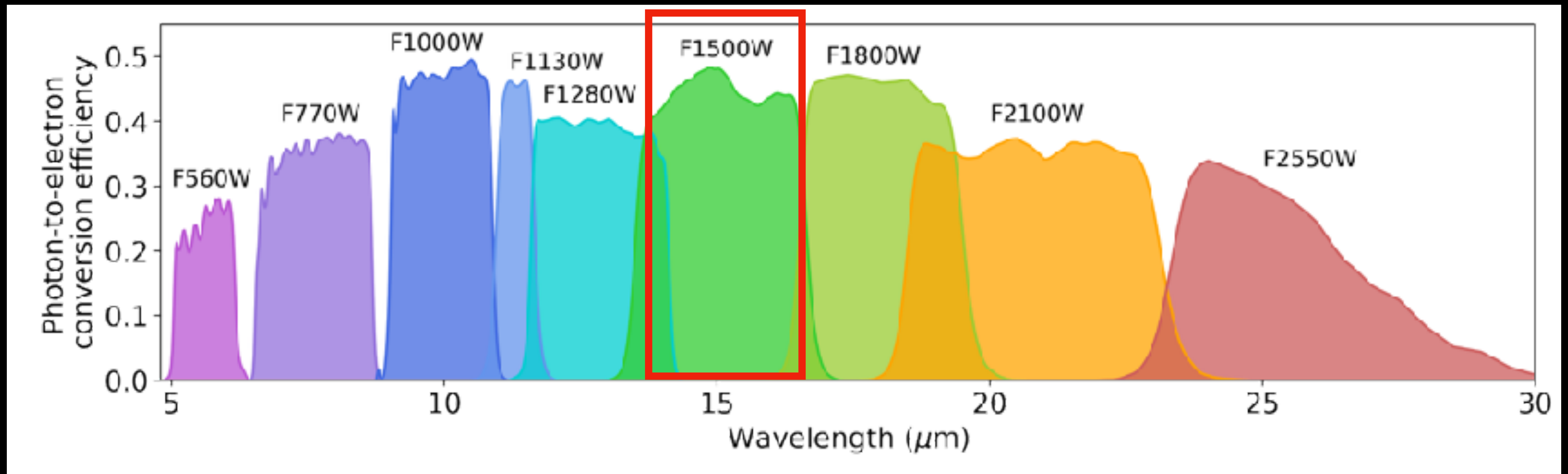
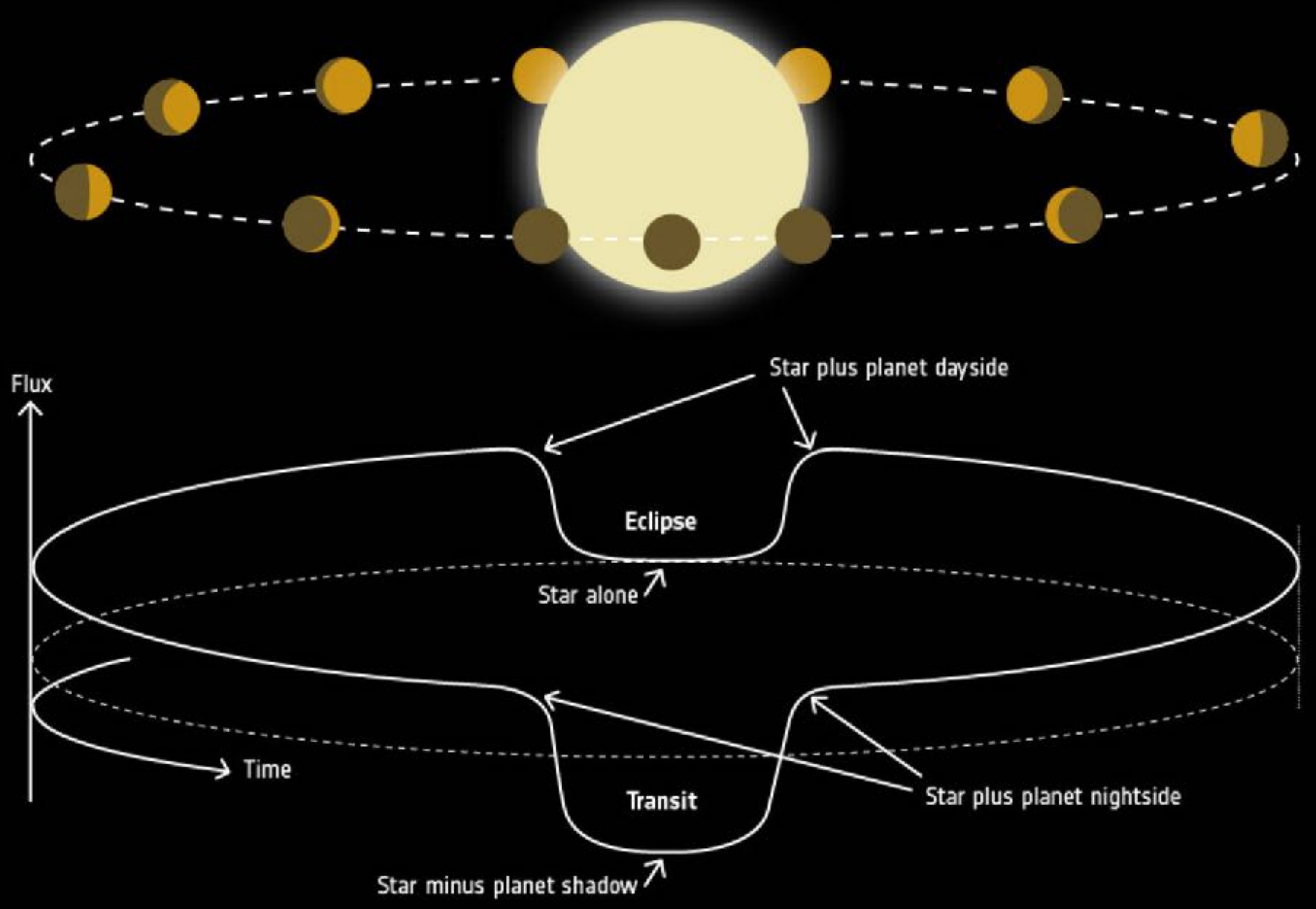


GTO 1177 - NASA Ames



Secondary eclipses observations



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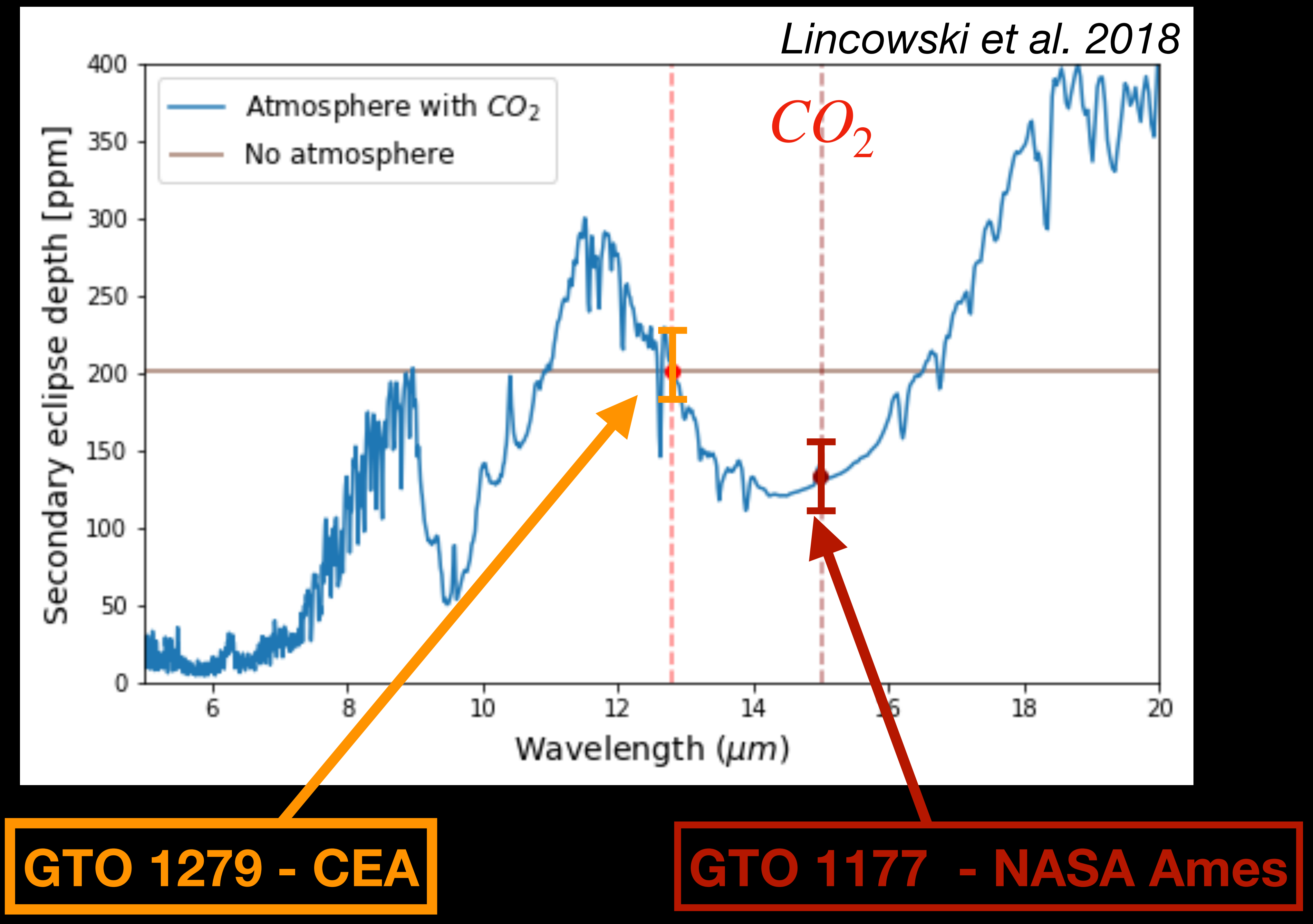
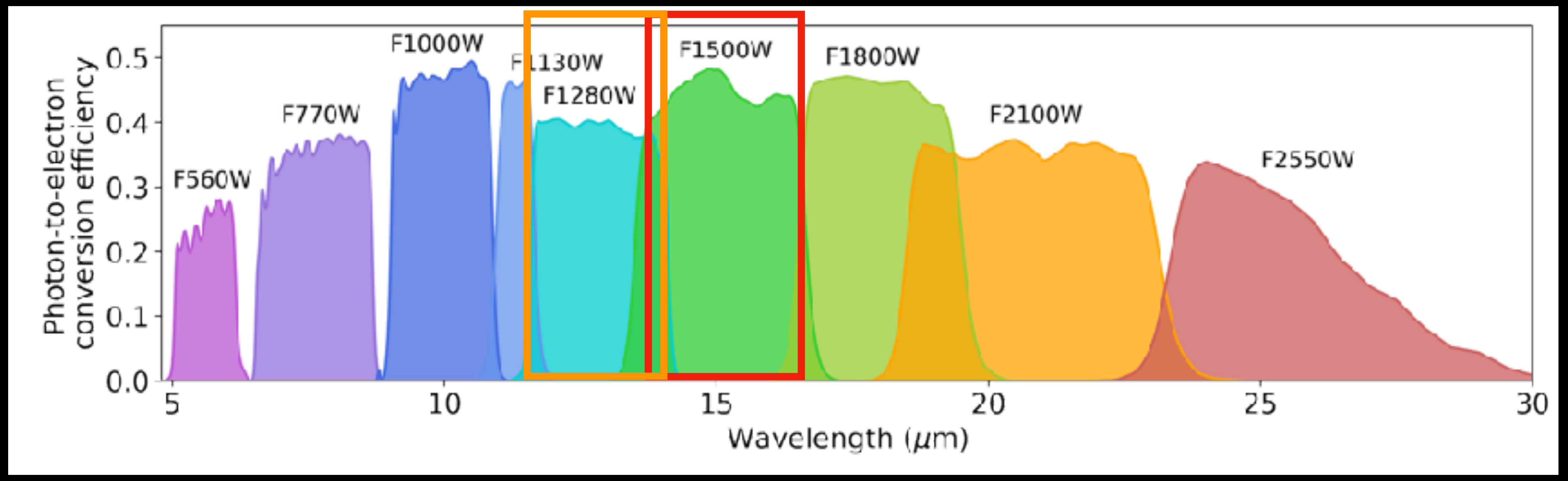
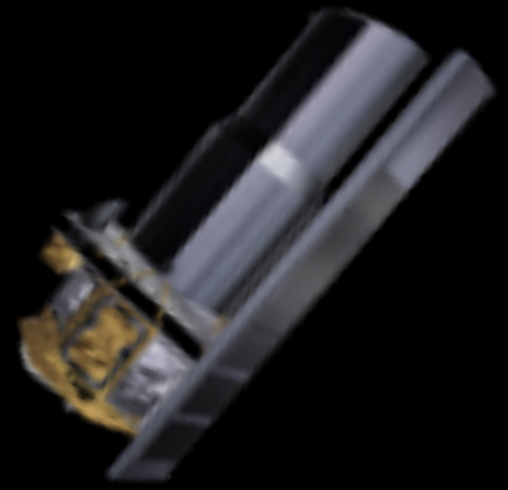
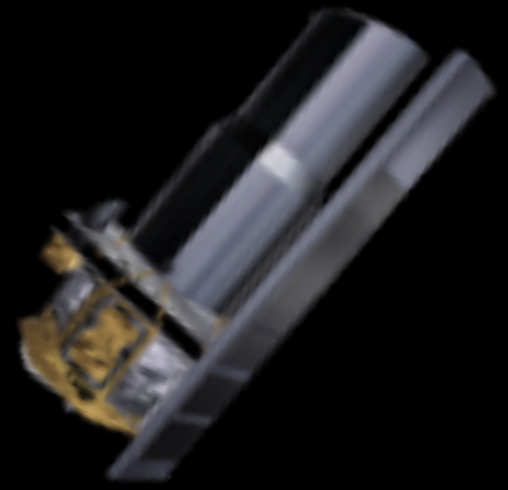






Results from Spitzer at $4.5\mu m$

	Trappist-1b	Trappist-1c
# Occultations targeted	28	9
Brightness temperature (K) upper limit	768	842



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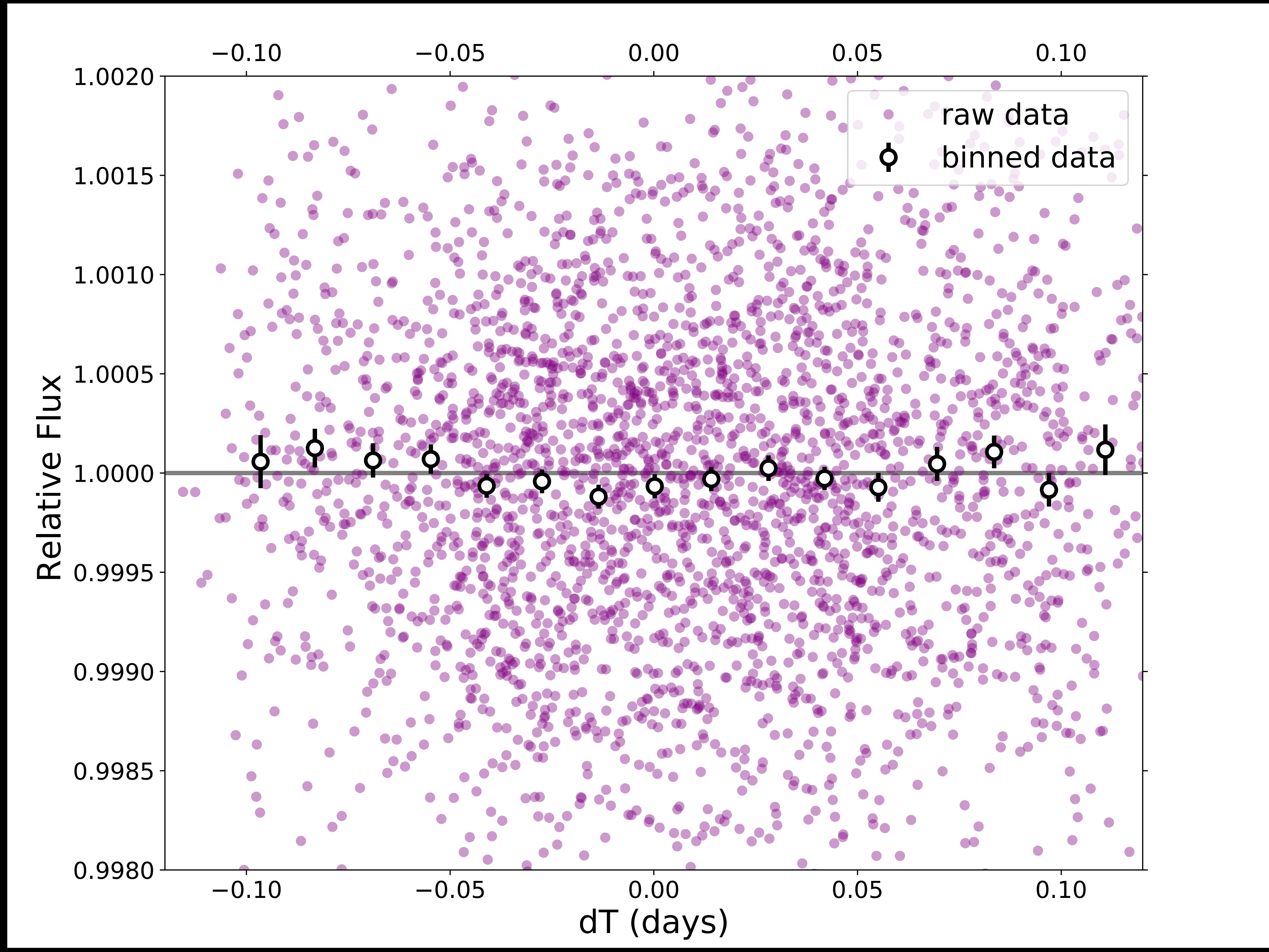
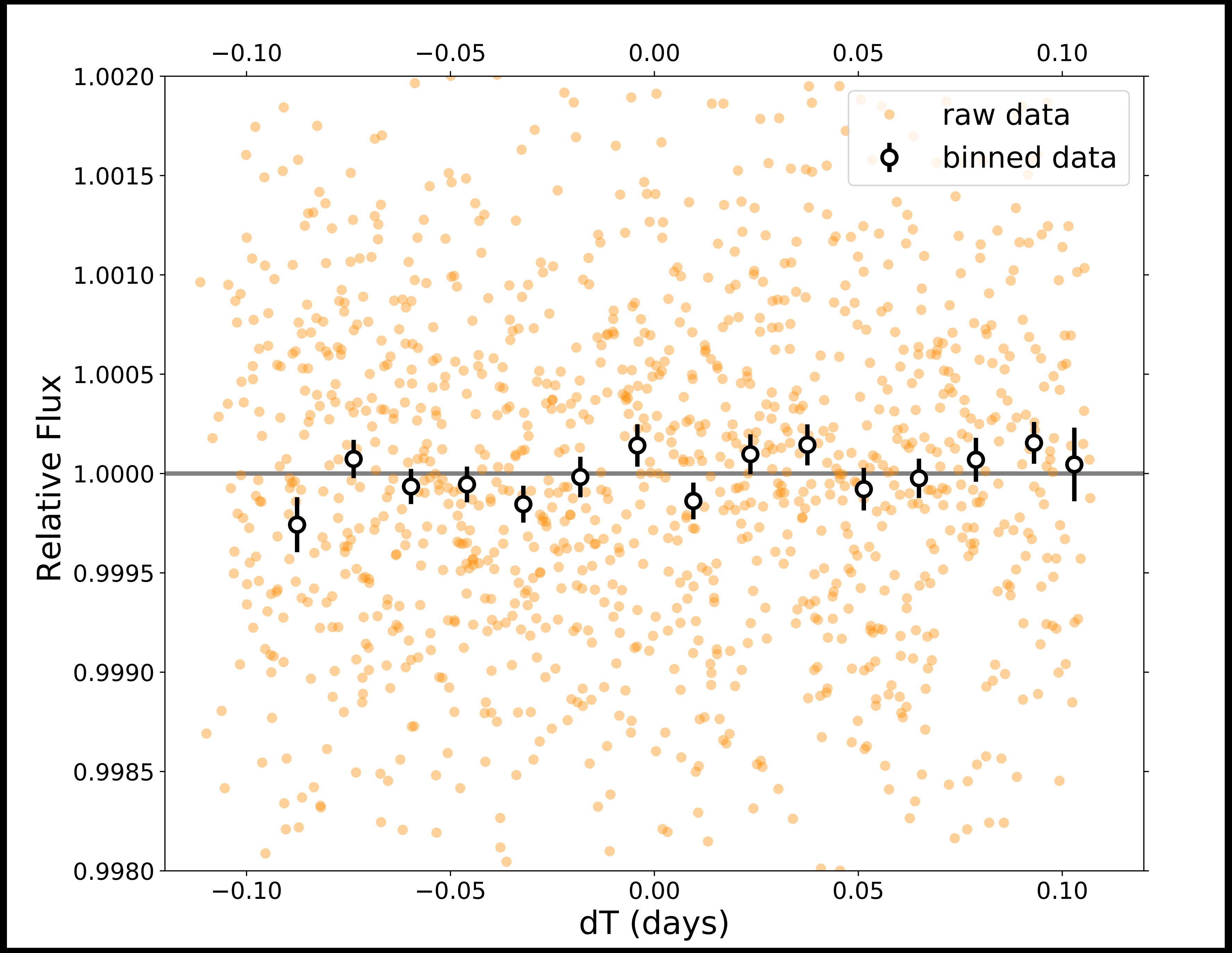
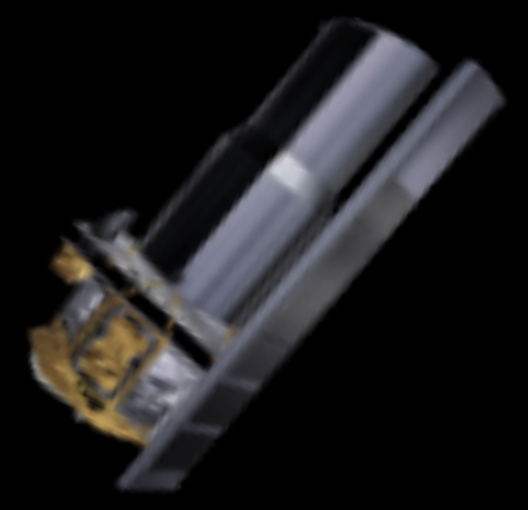
Ducrot +2020



Phase folded light curve for TRAPPIST-1 b



Phase folded light curve for TRAPPIST-1 c

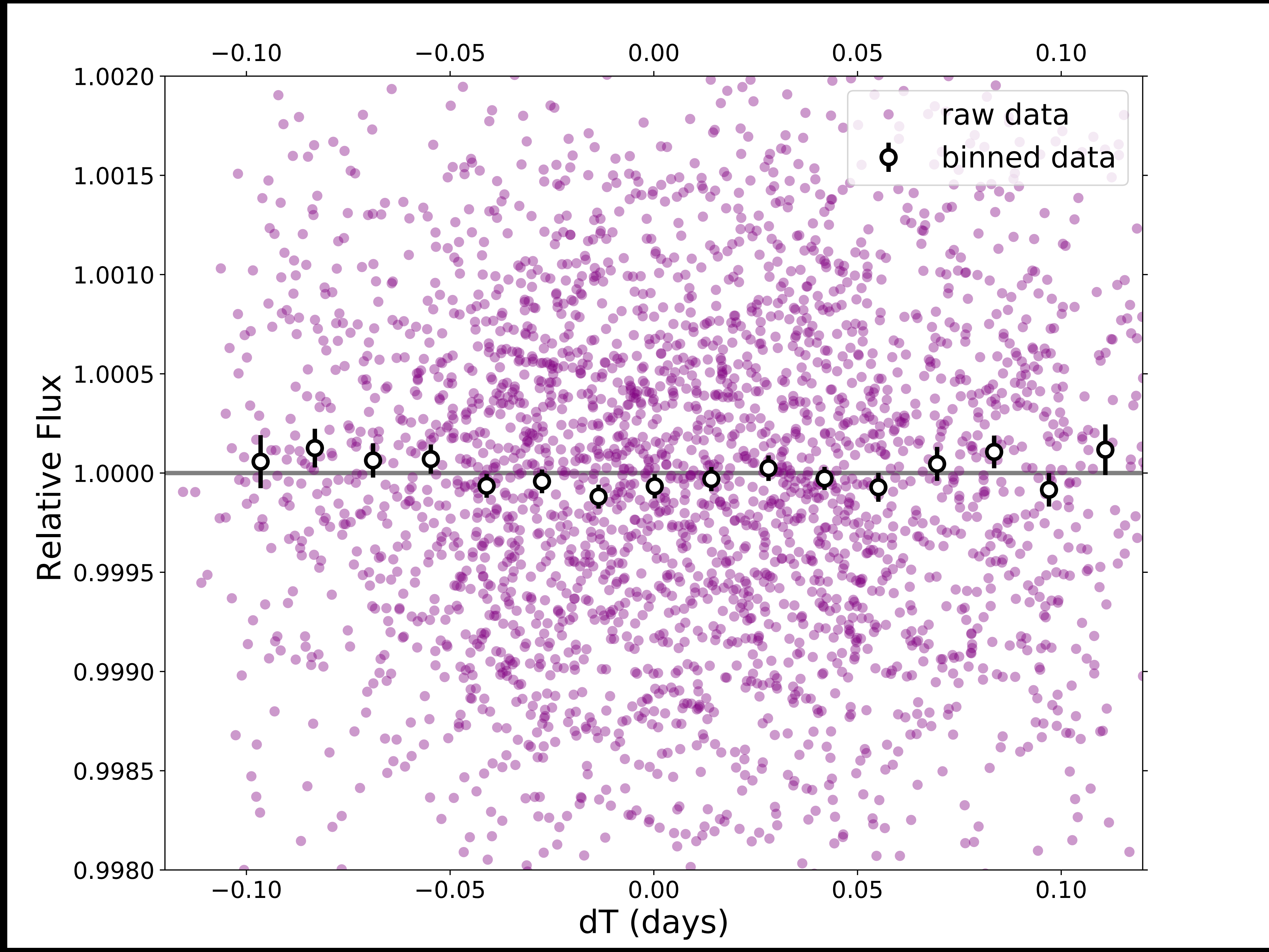


Results from Spitzer at $4.5\mu m$

	Trappist-1b	Trappist-1c
# Occultations targeted	28	9
Brightness temperature (K) upper limit	768	842

- No secondary eclipse of TRAPPIST-1 b detected in Spitzer data at $4.5\mu m$ even **when stacking 28 occultations** !
- What about JWST ?

Ducrot +2020



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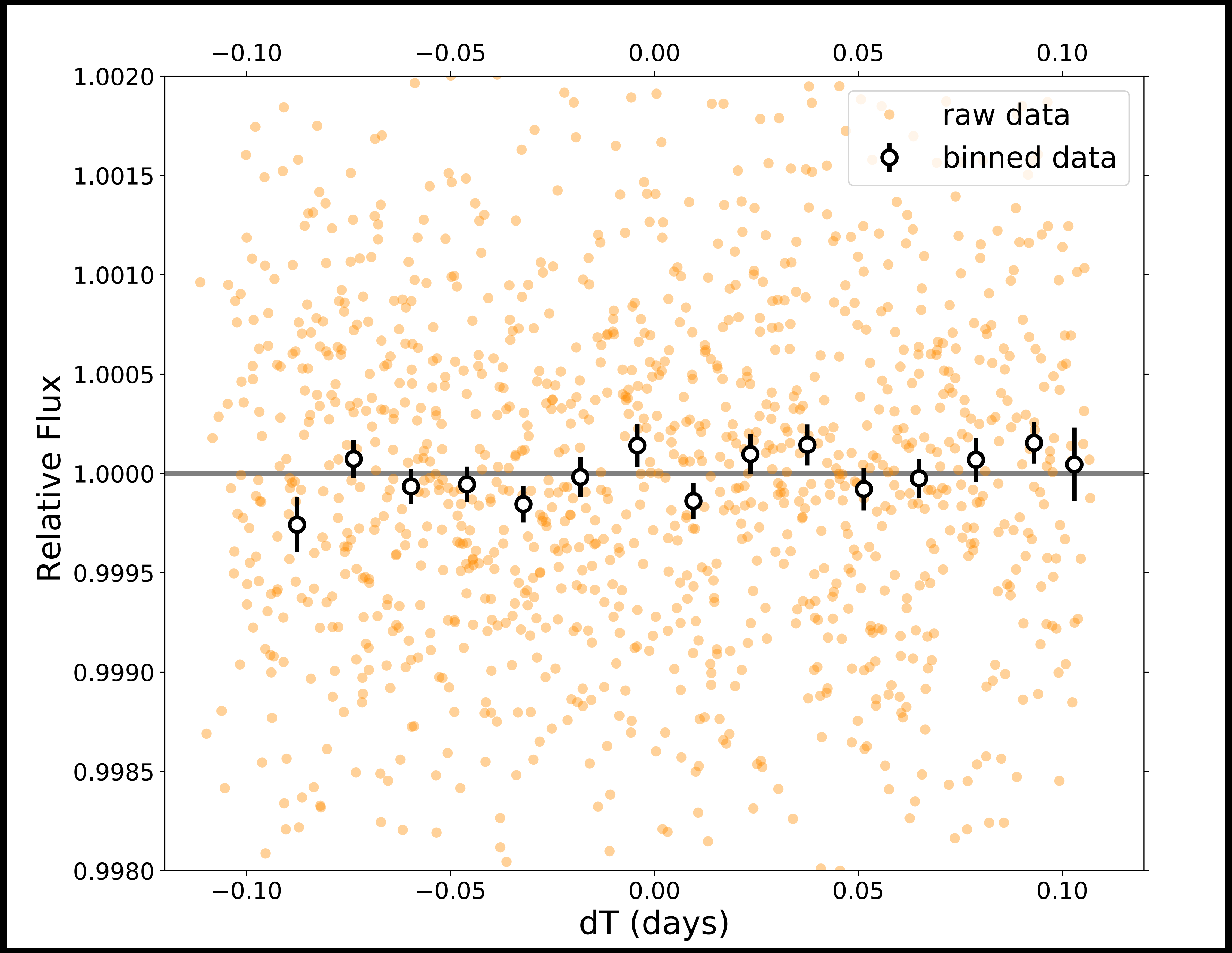
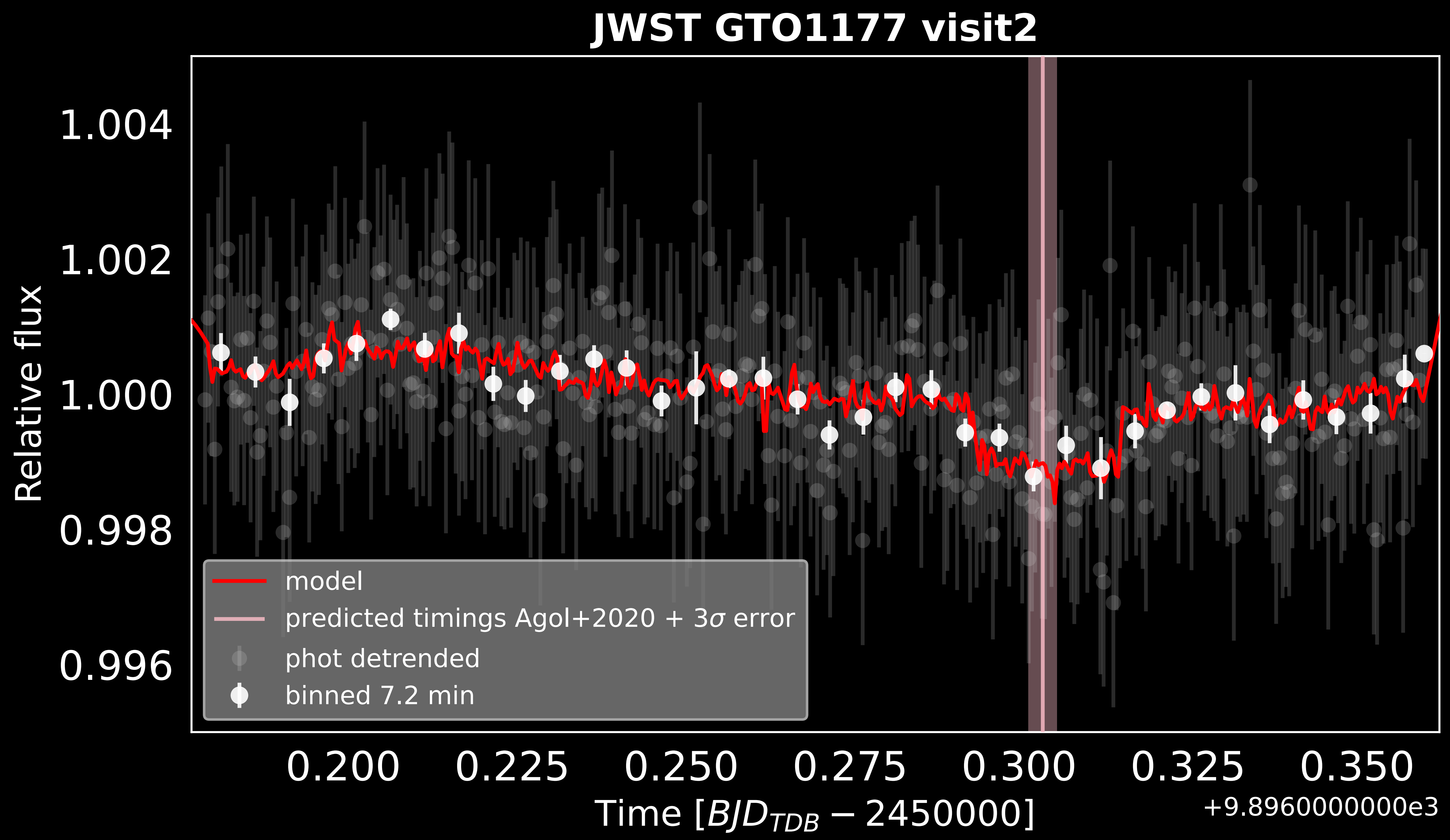
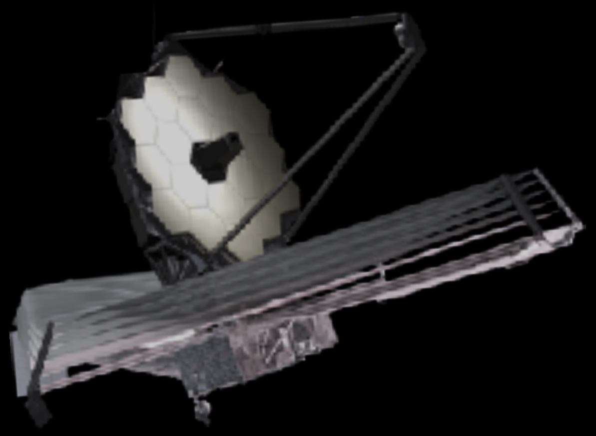


Phase folded light curve for TRAPPIST-1 c

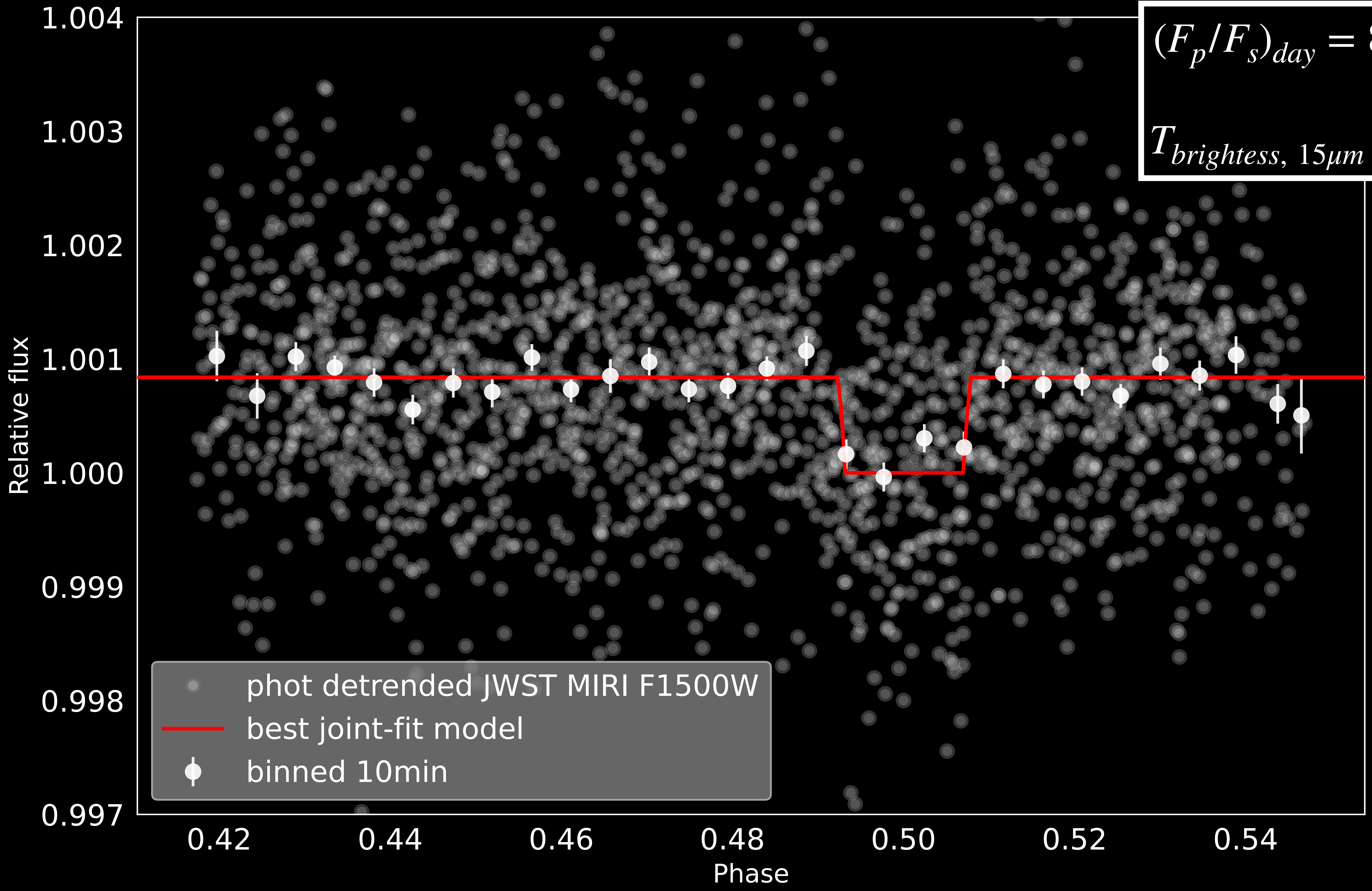
Observations with the JWST



The secondary eclipse of TRAPPIST-1 b is **visible by eye in one single visit at 15 microns**!



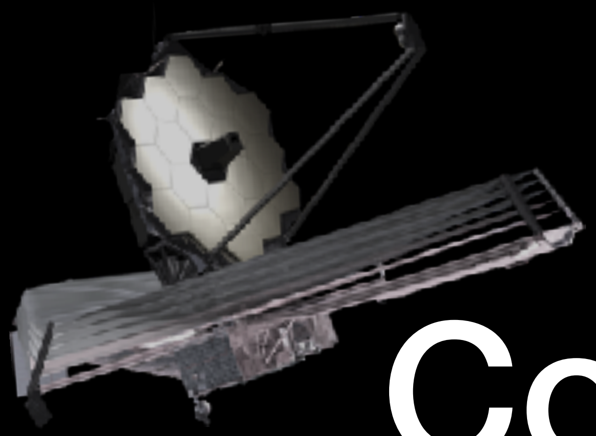
Joint fit of the 5 visits



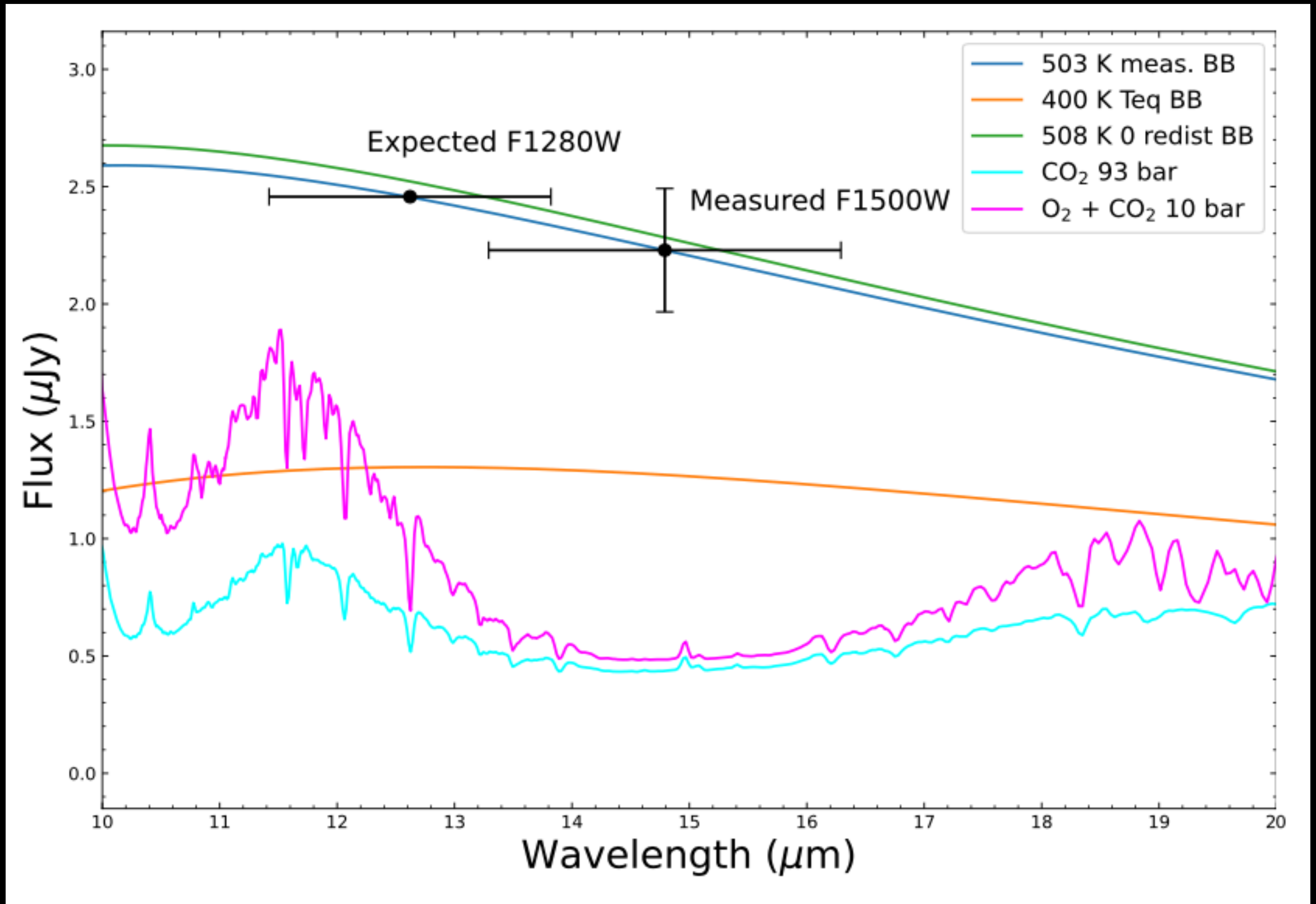
$$(F_p/F_s)_{day} = 861 \pm 99\ ppm$$

$$T_{brightess,\ 15\mu m} = 503 \pm 26\ K$$

Greene et al. 2023



Comparison with possible atmospheric scenarios



Greene et al. 2023

- Measured temperature consistent with a blackbody but **this is only one point**
- CO_2 rich atmosphere is likely rejected
- We must wait for the remaining 4 visits at 12.8 microns to know more

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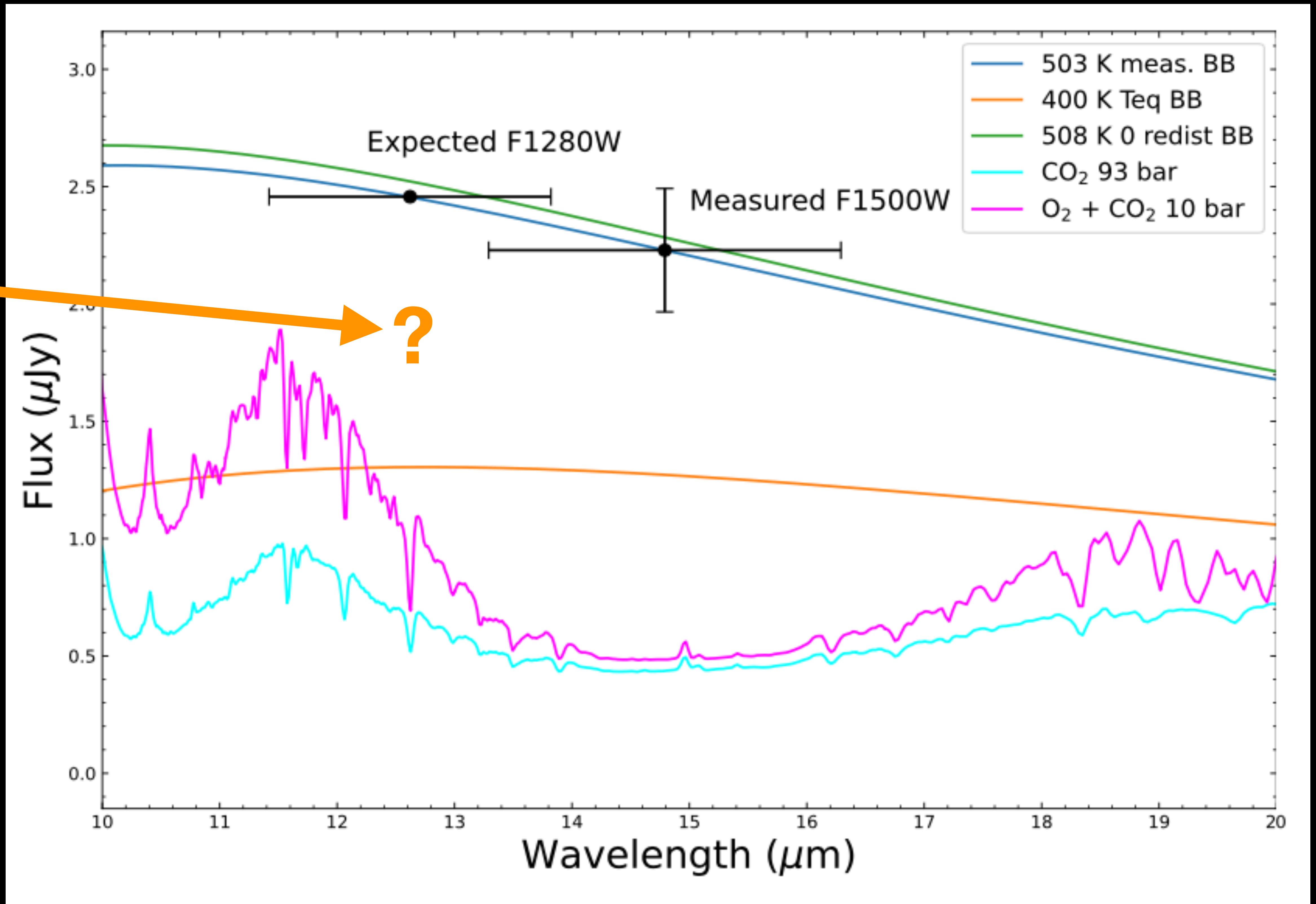

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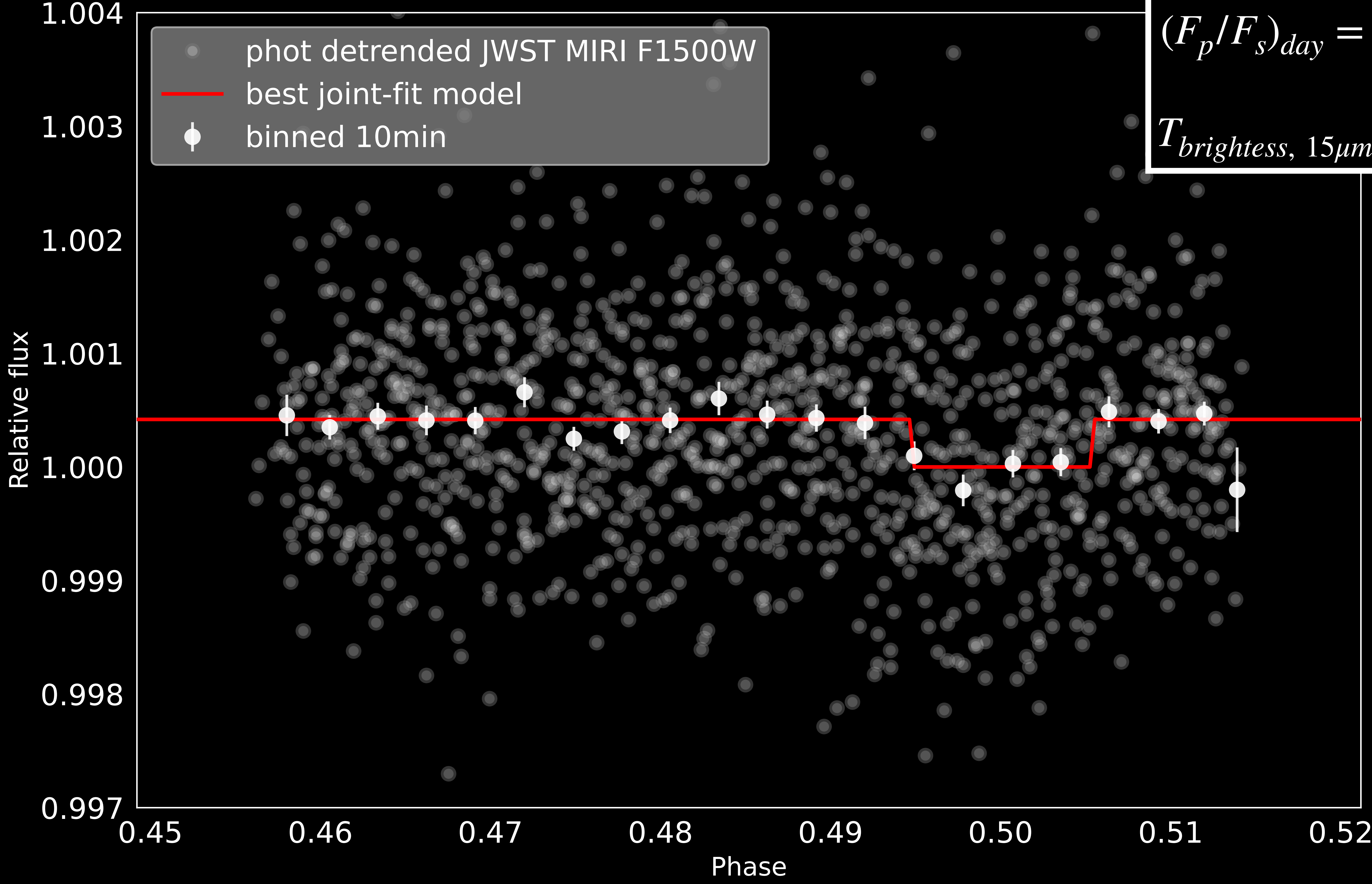
TRAPPIST-1 c

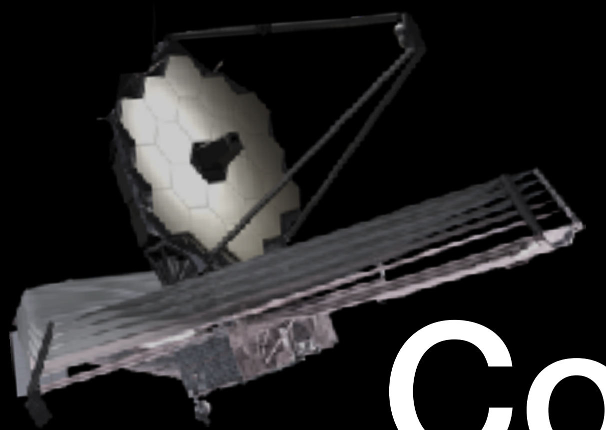
Joint fit of the 4 visits



$$(F_p/F_s)_{day} = 421 \pm 94\ ppm$$

$$T_{brightess,\ 15\mu m} = 380 \pm 31\ K$$

Zieba et al. 2023



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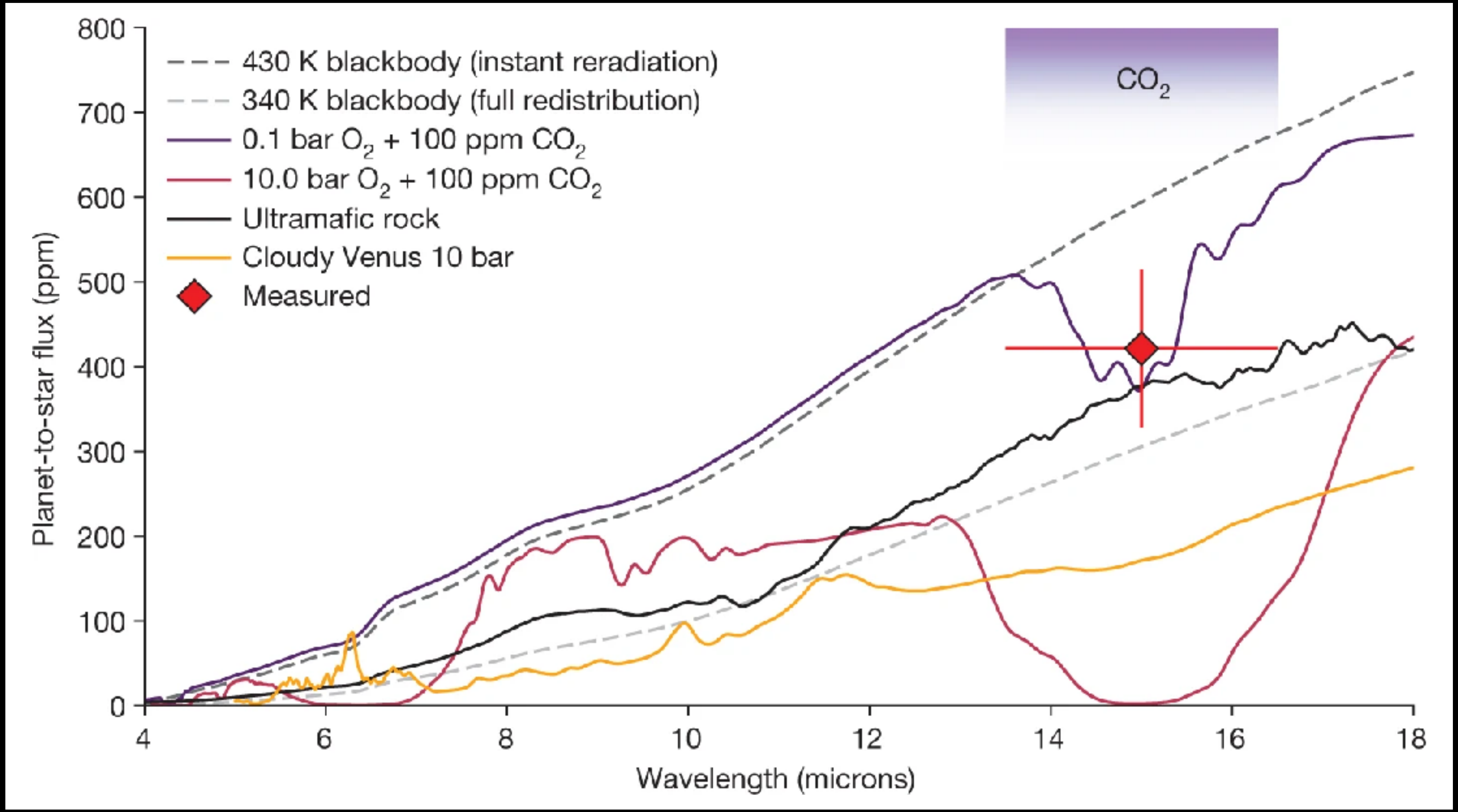
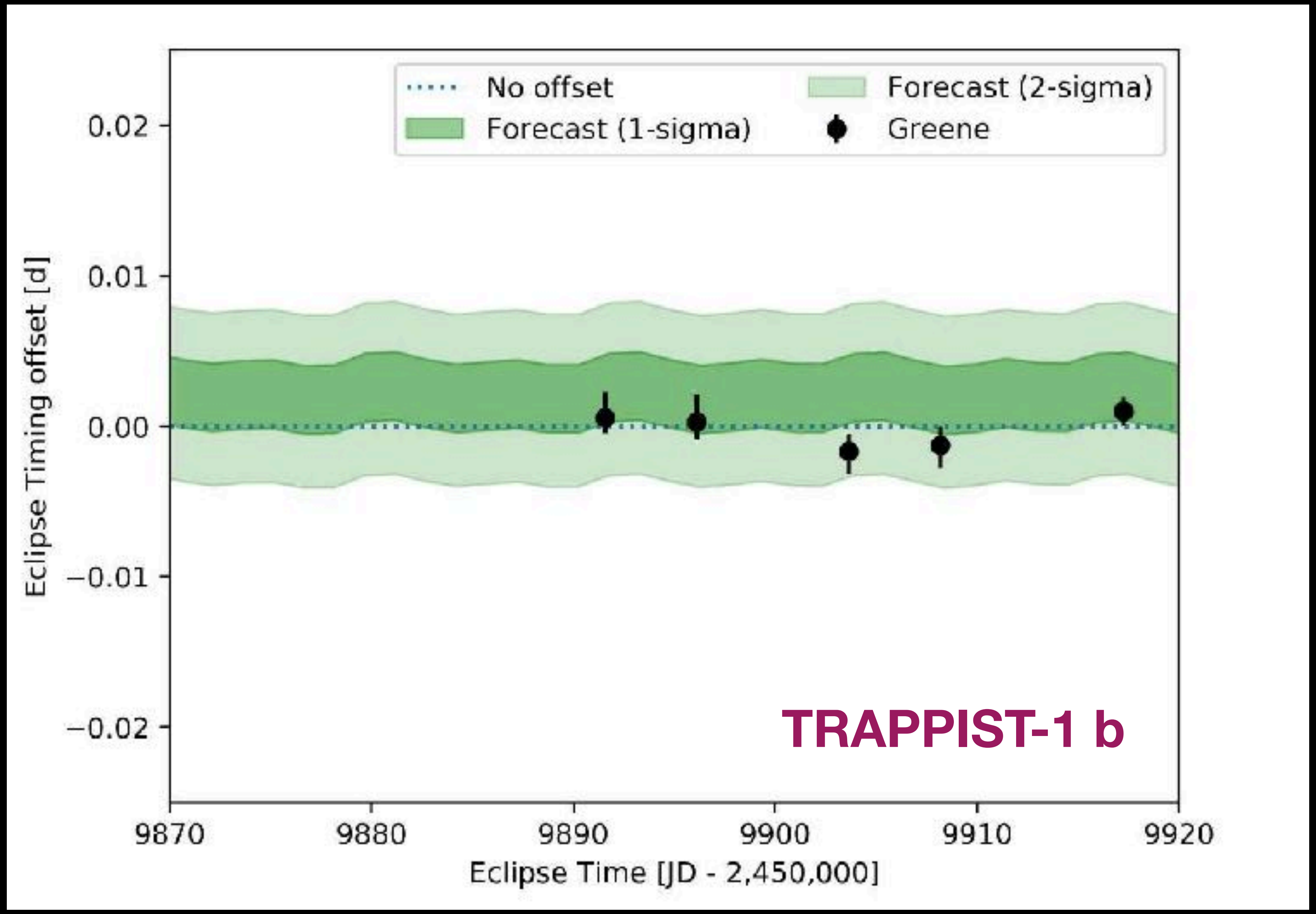


Zieba et al. 2023

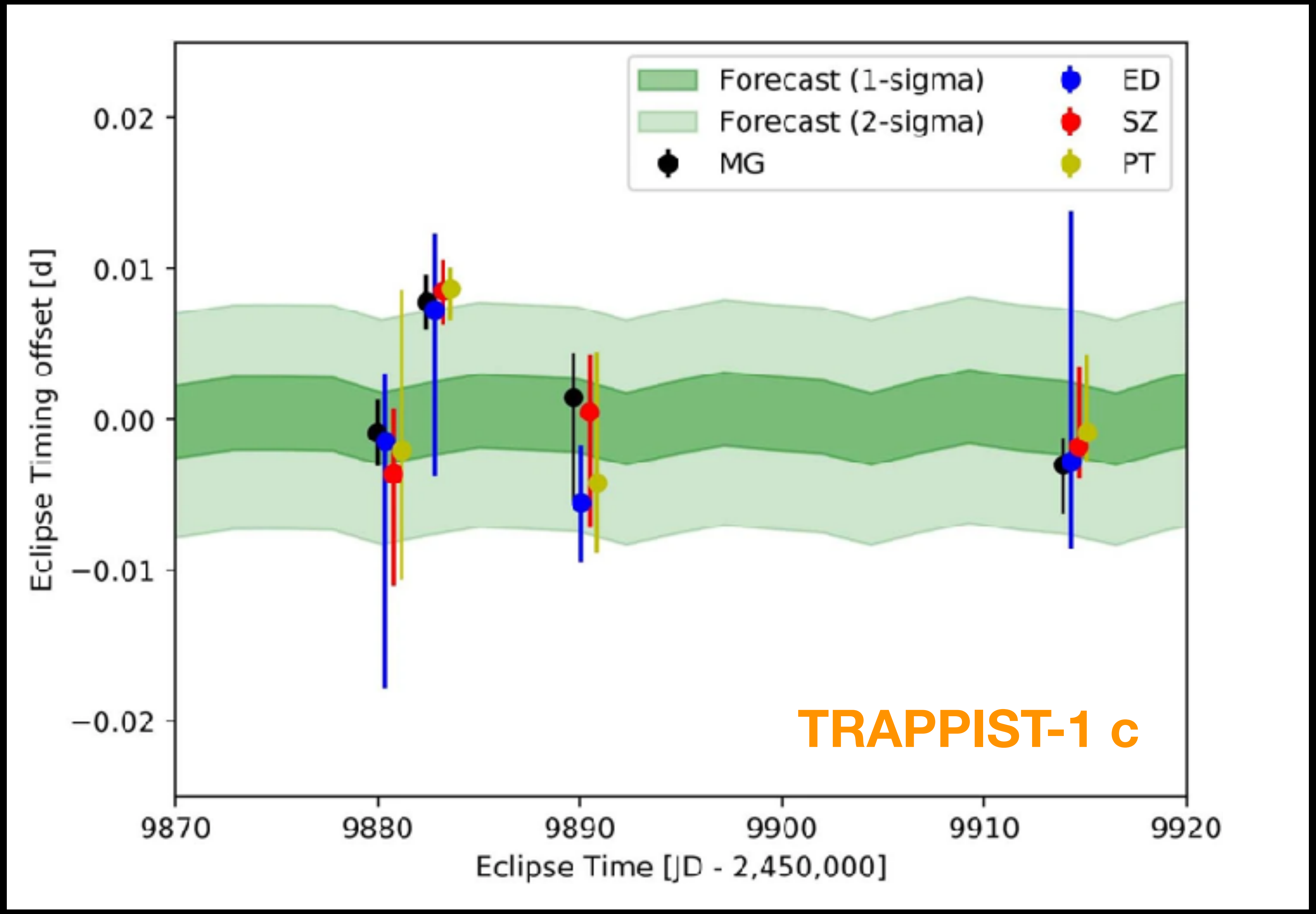
- Cloudy and cloud-free Venus-like atmospheres are disfavoured at 2.6σ and 3.0σ
- The measured depth can rule out all thick atmospheres with surface pressures $P_{surf} \geq 100$bar
- The measurement is consistent with an unweathered ultramafic rock or a thin cloud-free O2/CO2 atmosphere

Eclipse timings

Figure made by Eric Agol (University of Washington)



Zieba et al. 2023



- Eclipse timings can be used to constrain the eccentricities of the planets
- In total we have 10 eclipse timings of TRAPPIST-1 b and 4 of TRAPPIST-1c
- <u>Next step:</u> Include these eclipse timings in dynamical models (TTV analysis) to better constrain the eccentricities of these two inner planets.

What else could be done?

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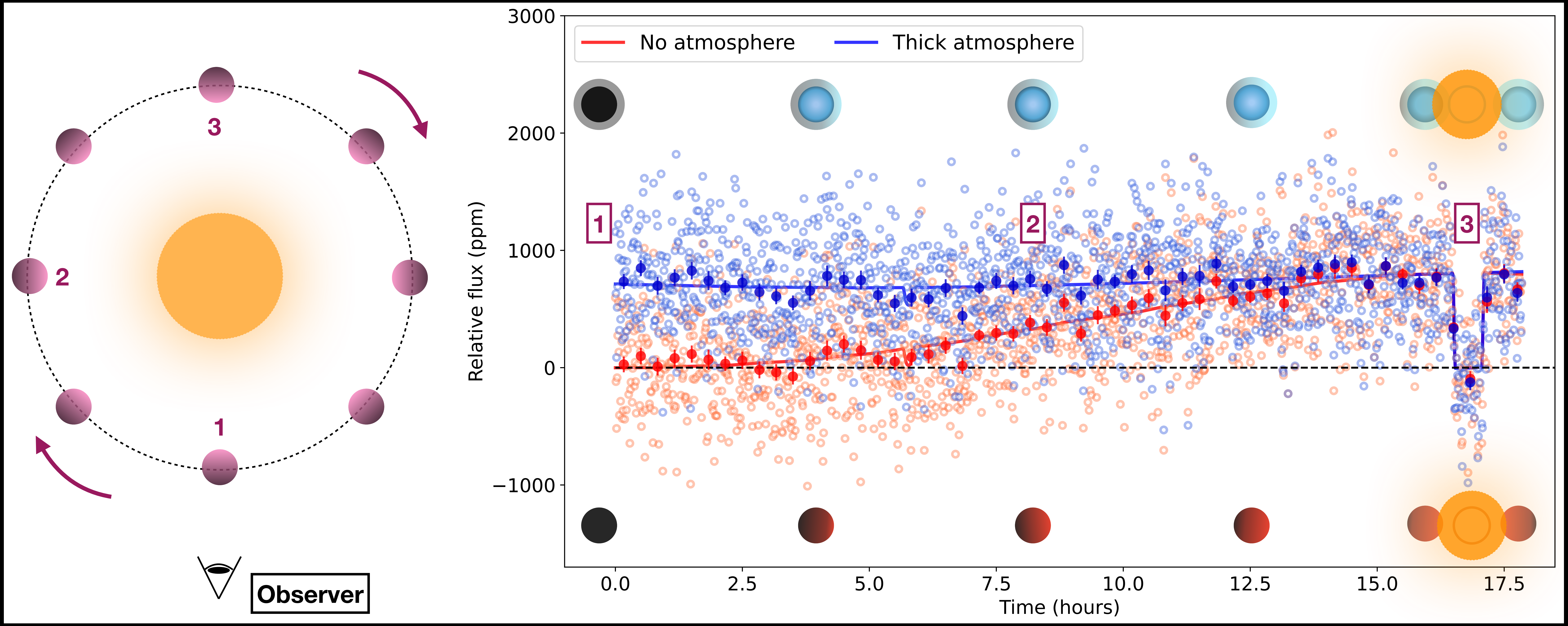

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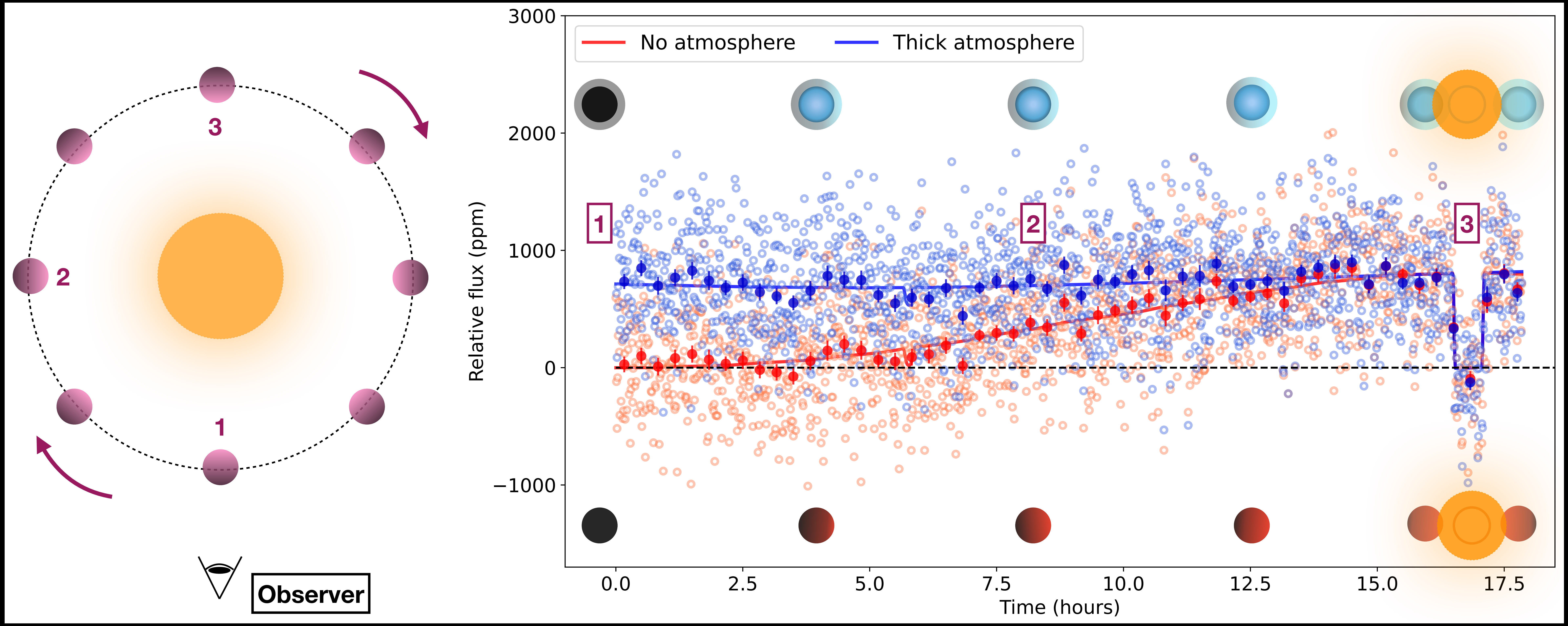
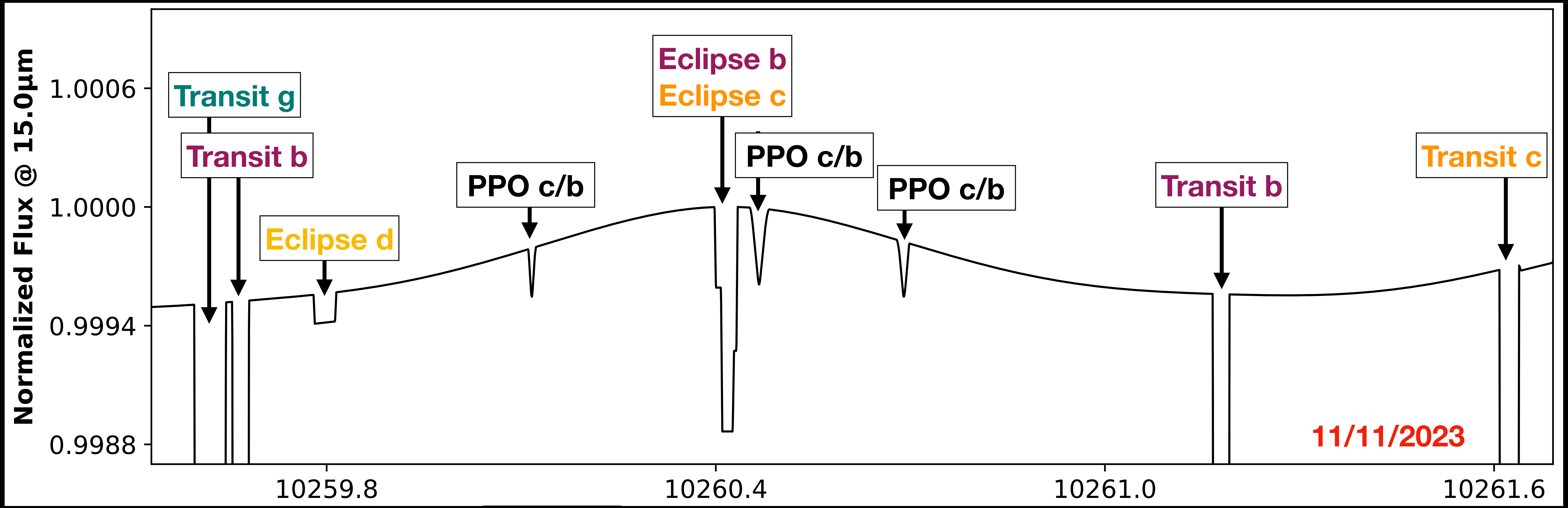


- A full (or partial) phase curve at 15 μm of these planets could help us confirm the presence/absence of an atmosphere if redistribution of heat is observed or not

Two birds one stone

Two birds one stone



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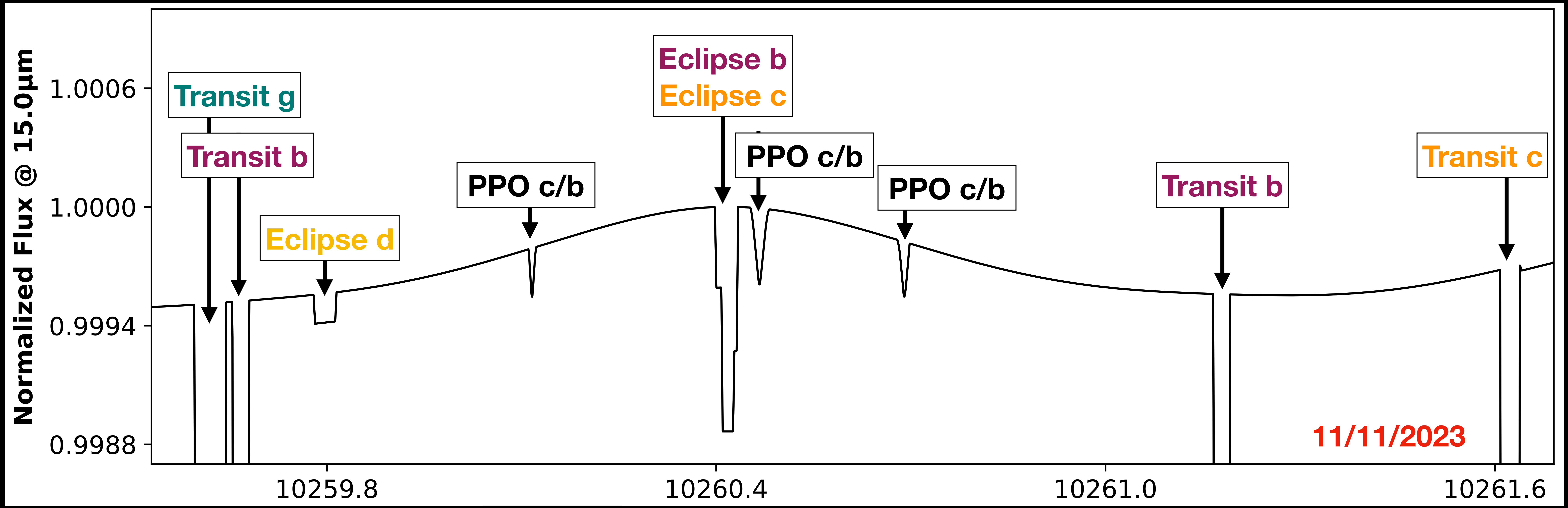

- A double phase curve of b+c with MIRI FW1500 has been granted (GO 3077)
- From this phase curve we will reveal whether any or both of the planet have an atmosphere
- The system is extremely coplanar, planet-planet occultation must happen all the time
- Planet-planet occultation can also help constrain the nightside temperature of TRAPPIST-1 b or c

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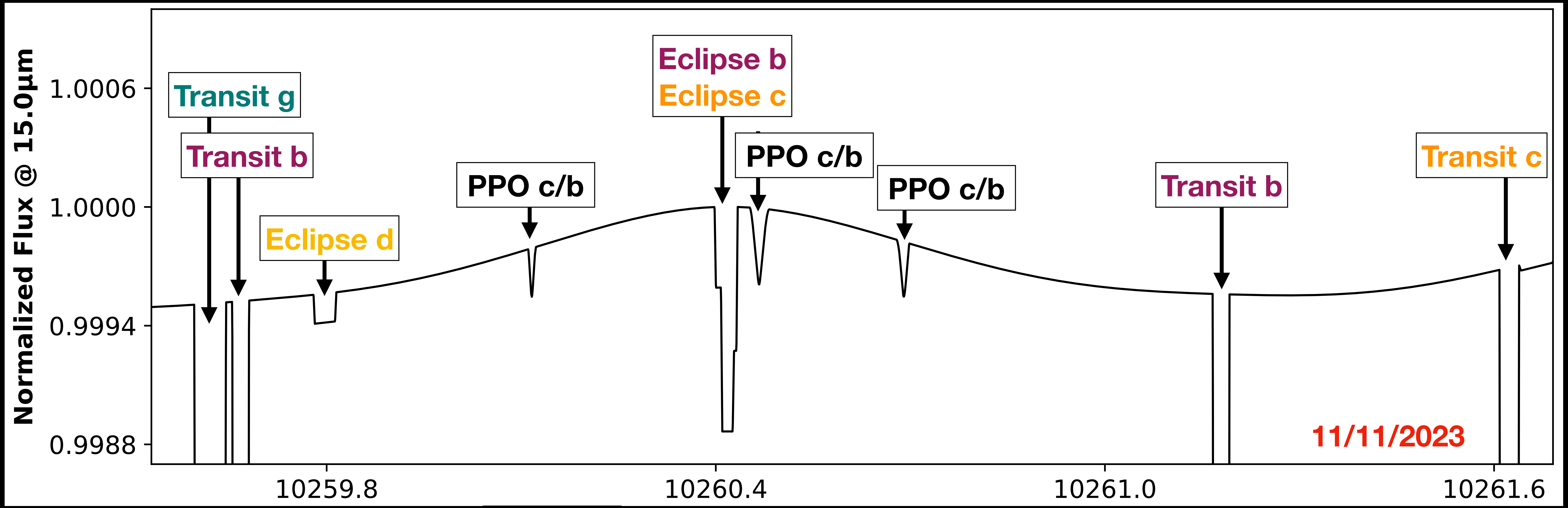

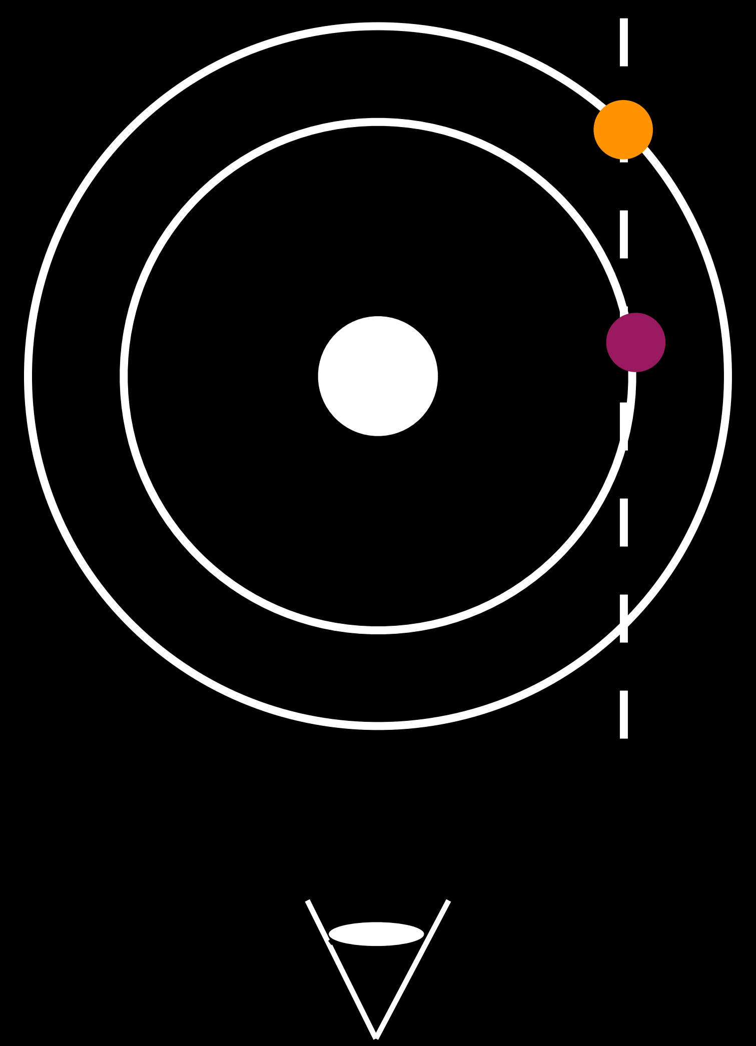

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Conclusion

- The secondary eclipses of TRAPPIST-1 b and c are detected at $15\mu m$ with the JWST **at 8.7 sigma,** and **4.4 sigma** in only 5 and 4 visits respectively. This is the **first times we detect the thermal emission of a rocky temperate planets**

- For TRAPPIST-1 b, the mesured brightness temperature is consistent with a blackbody with no heat redistribution.

- For TRAPPIST-1 c, a CO2-rich atmosphere is disfavored but the measurement is still consistent with a thin carbon/oxygen mix atmosphere or an un weather ultramafic airless planet.

- **BUT this is only one wavelength!**

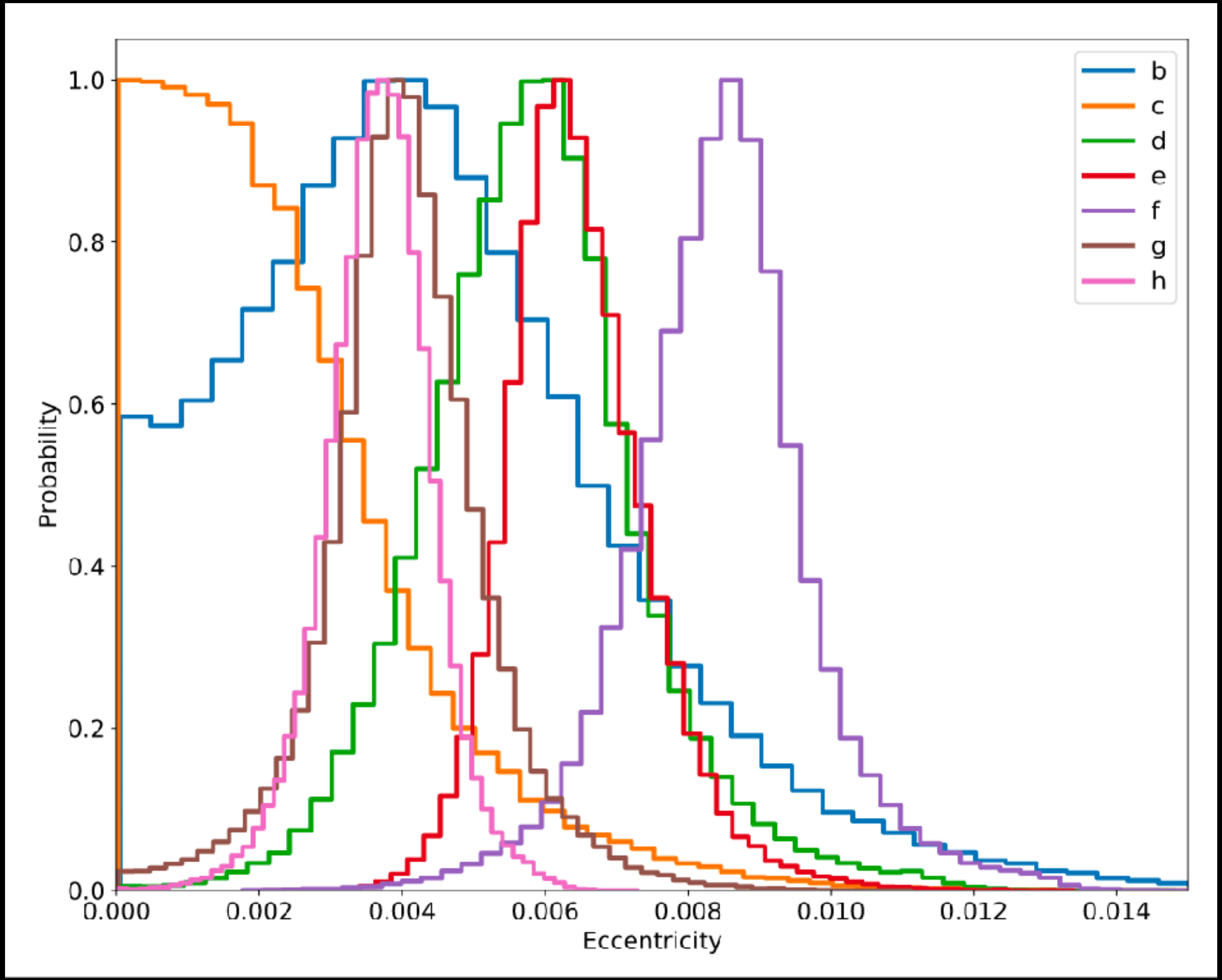
- 5 additional eclipses of planet b are going to be observed at $12.8\mu m$ microns (**in 10 days !!**) to help confirm (or not) this result.

- A double phase-curve of TRAPPIST-1 b+c will soon help us reveal the nature of both planets.

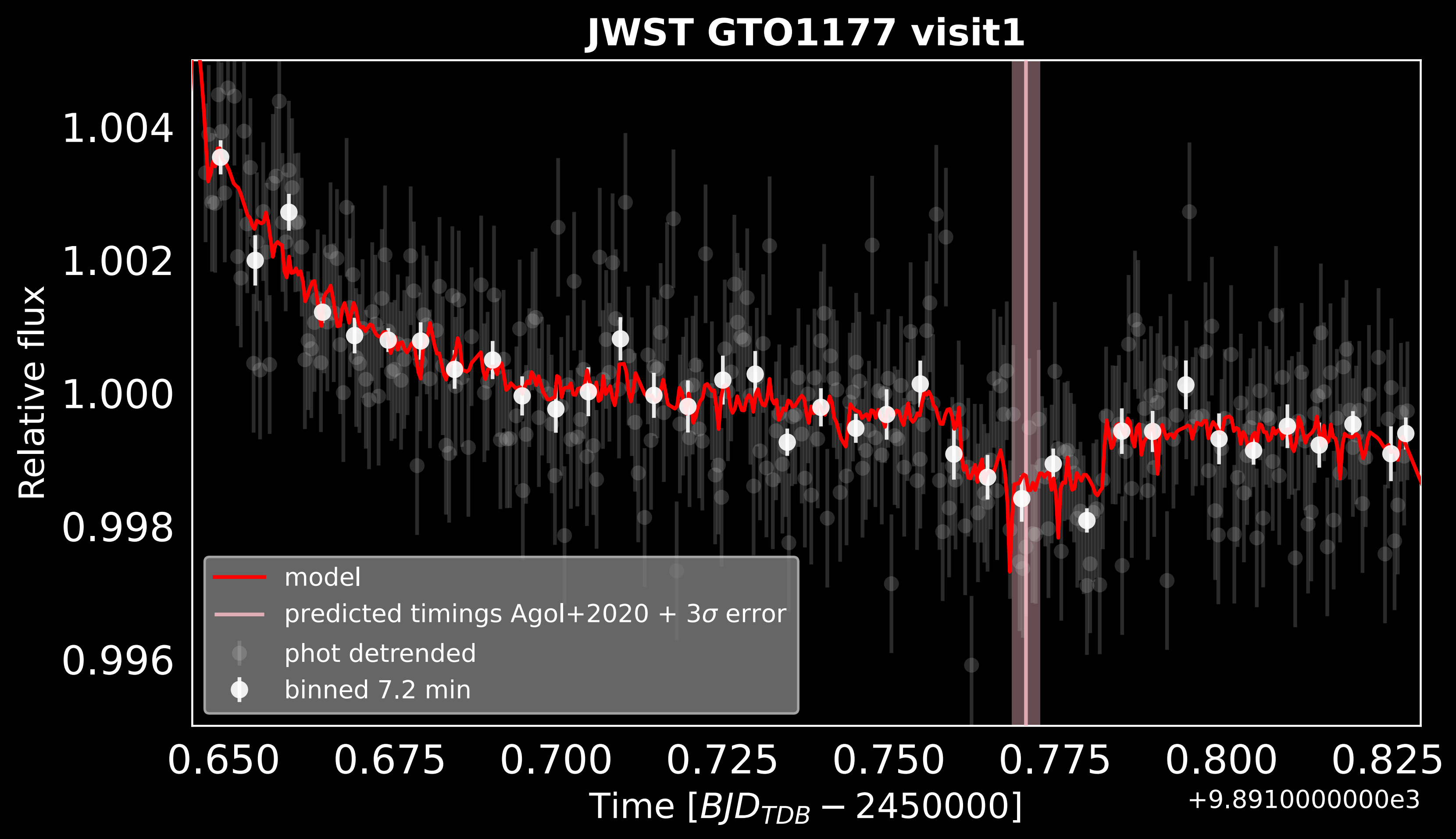

Thank you for your attention!

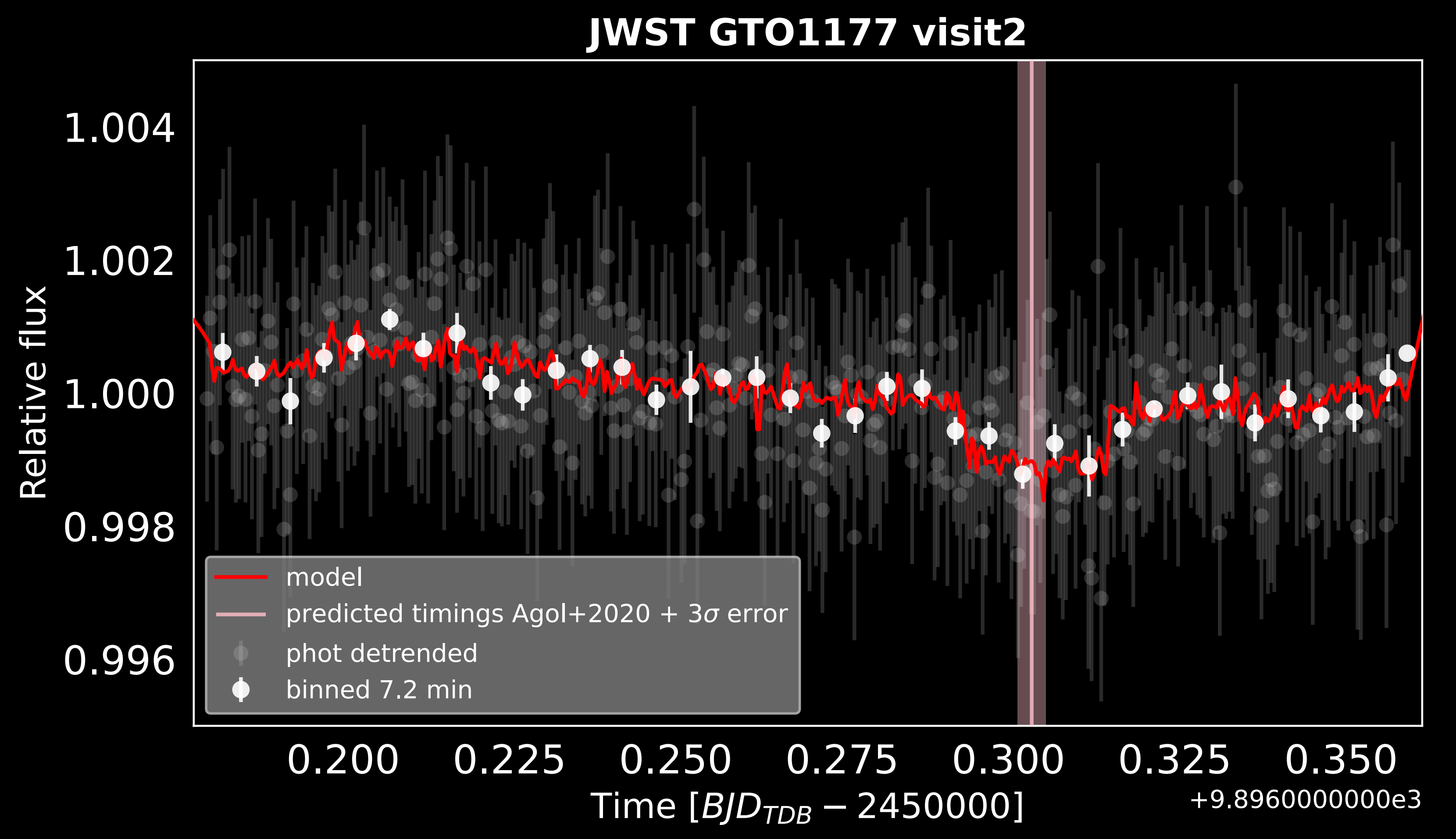
Eclipse timings

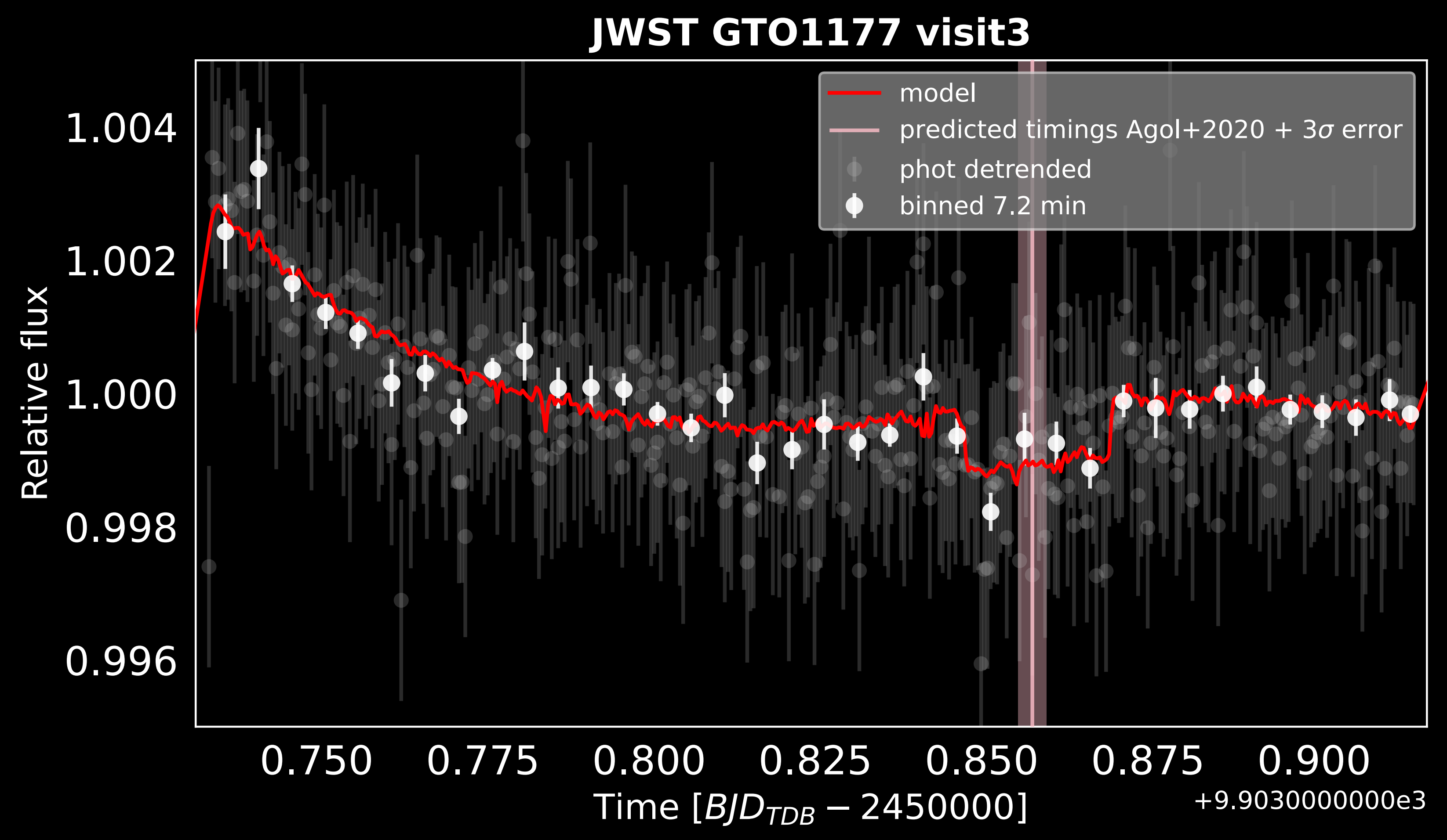
Agol et al. 2021

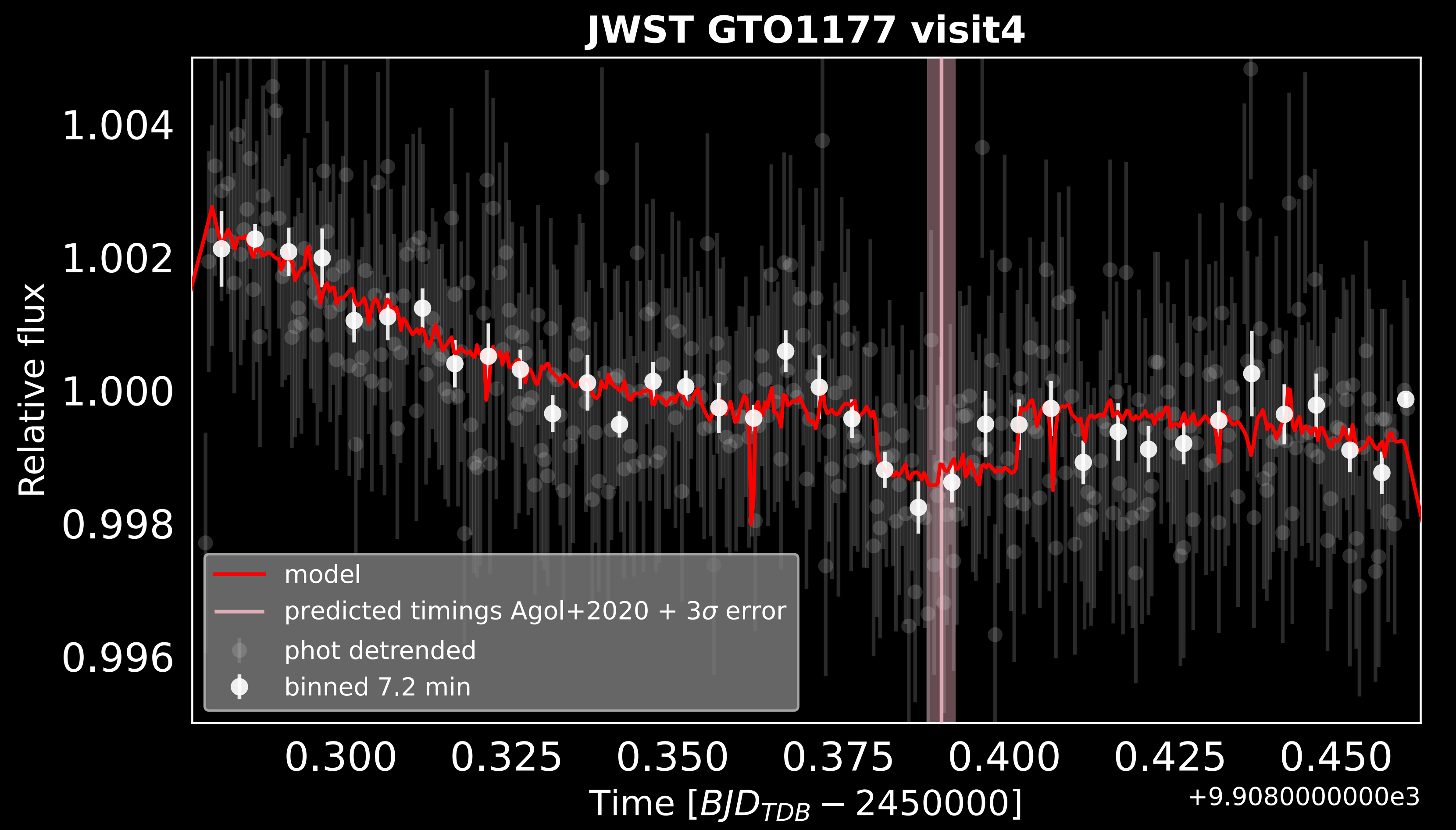


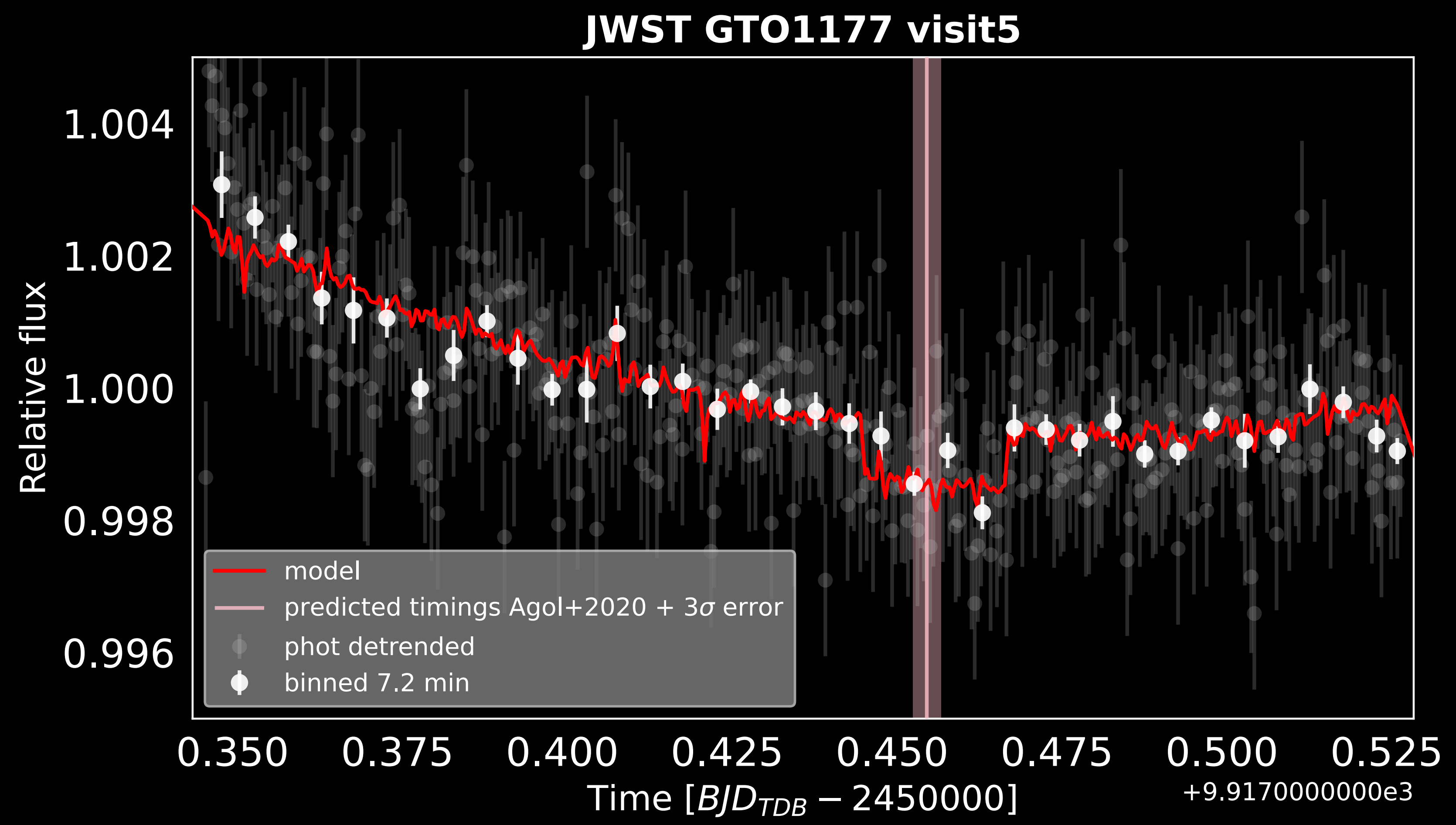
Individual fit for each visit with JWST





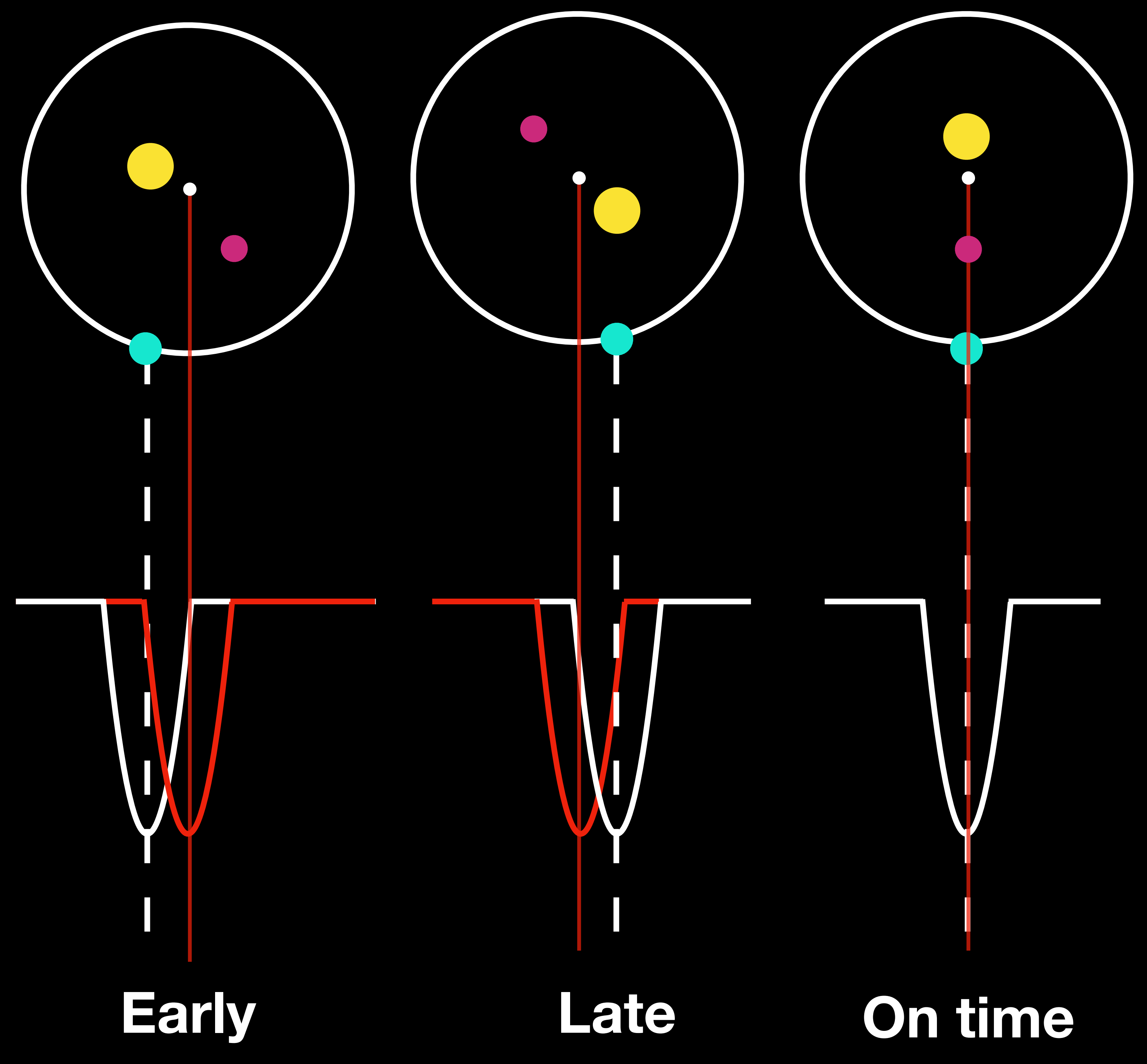




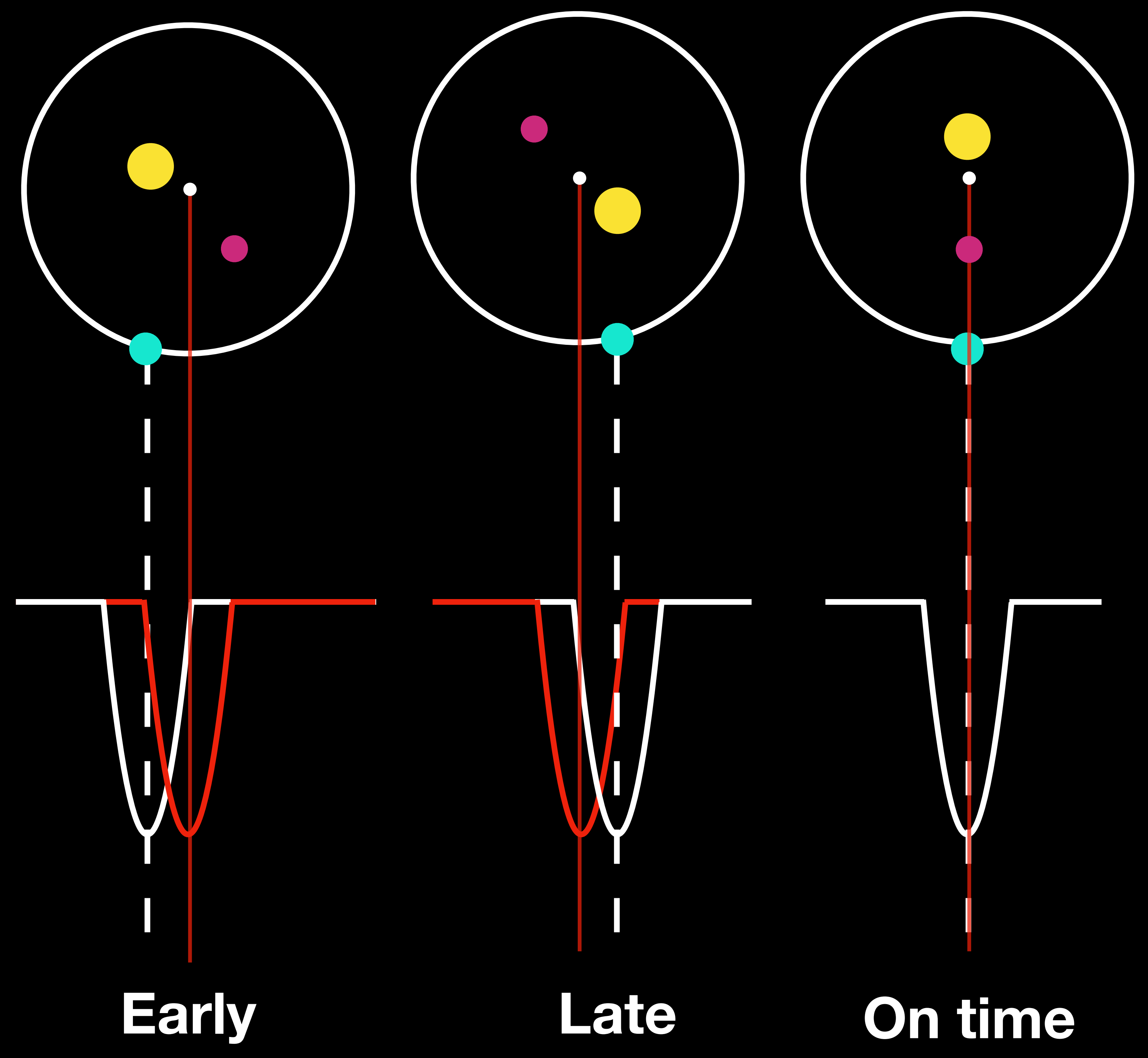


- The secondary eclipse of TRAPPIST-1 b is visible in each visit at 15 microns
- All eclipse timings are consistent with the model from *Agol et al. 2021* at less than 2 sigma

Transit timing variations (TTVs)



Transit timing variations (TTVs)



- From dynamical model we can derive the masses and orbits of the planets with exquisite precision
- Using TTVs Grimm+2018 and Agol+2021 derived masses for the TRAPPIST-1 planets with a **precision of 3 to 5%**, which is equivalent to a **radial-velocity precision of 2.5 cm/sec** !!

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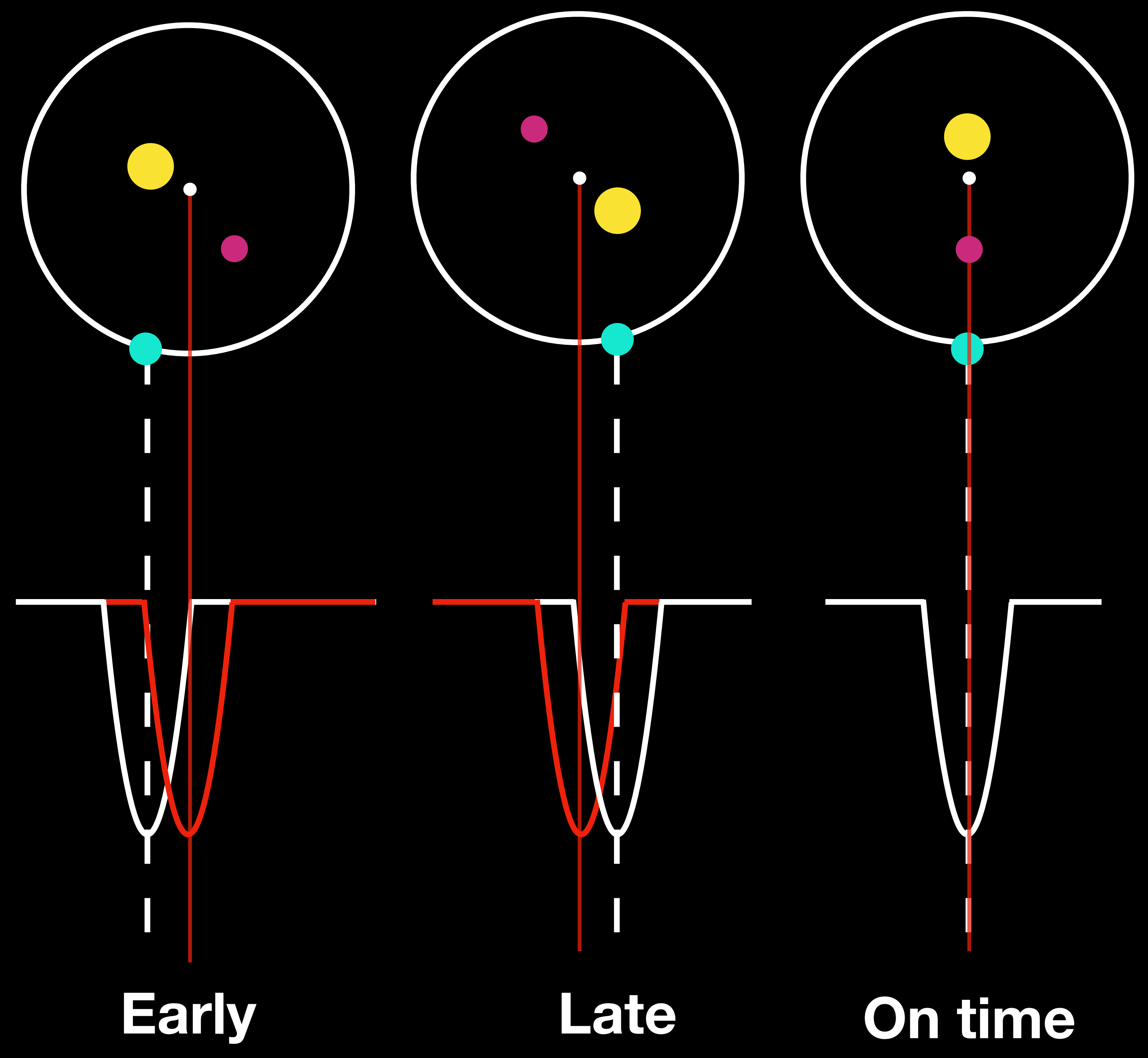

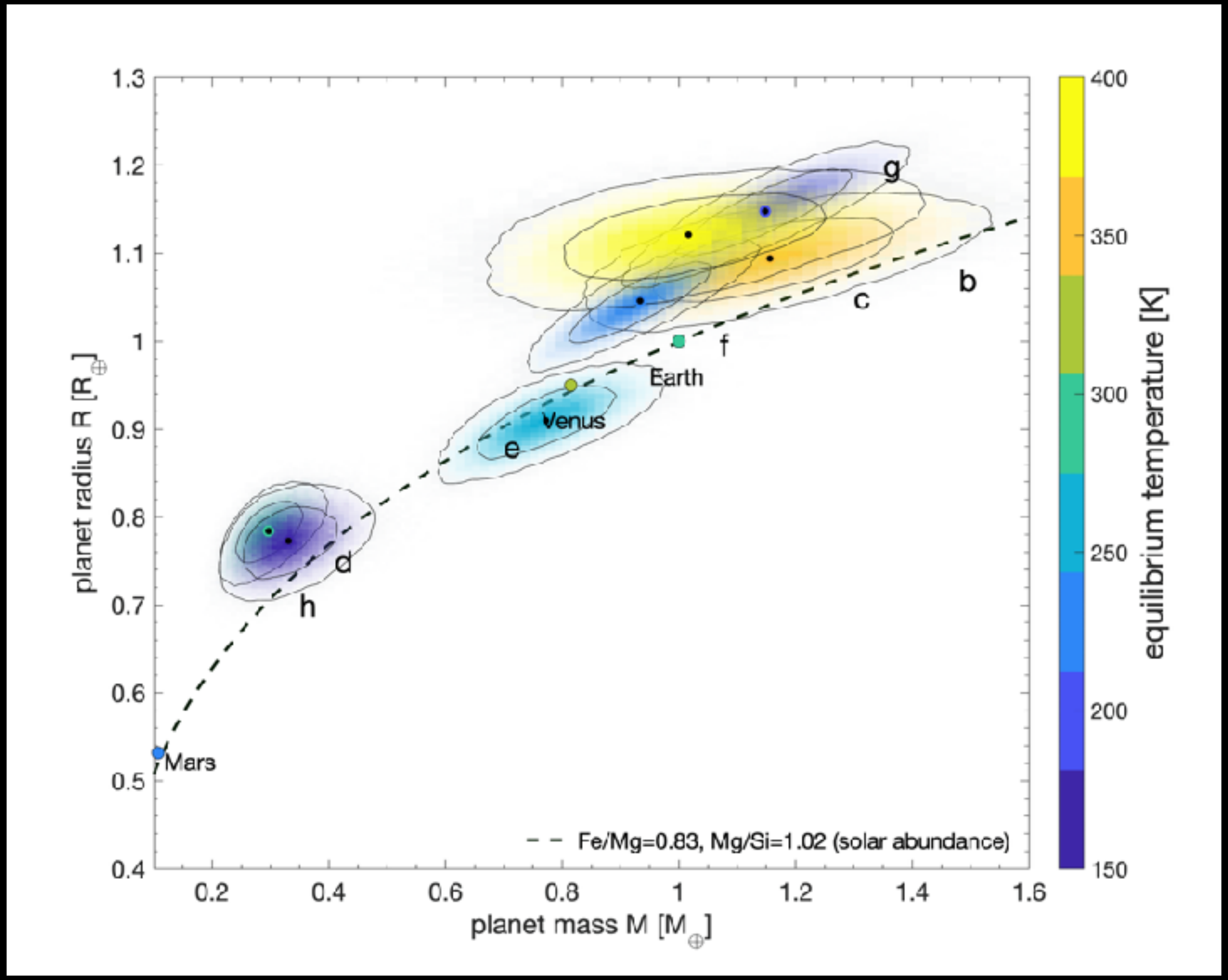

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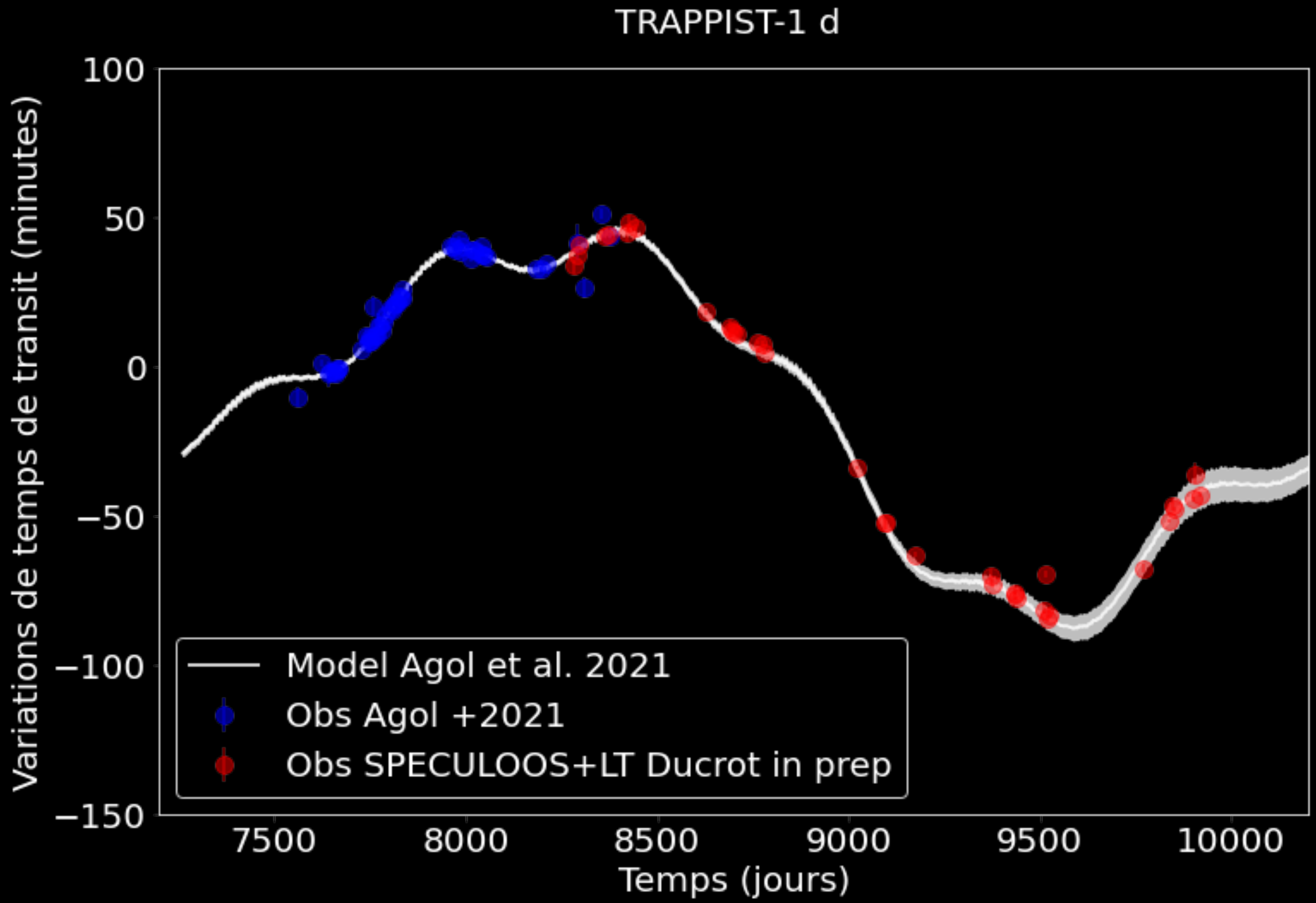

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