

# Observing Atmospheres (and Surfaces) of Exoplanets

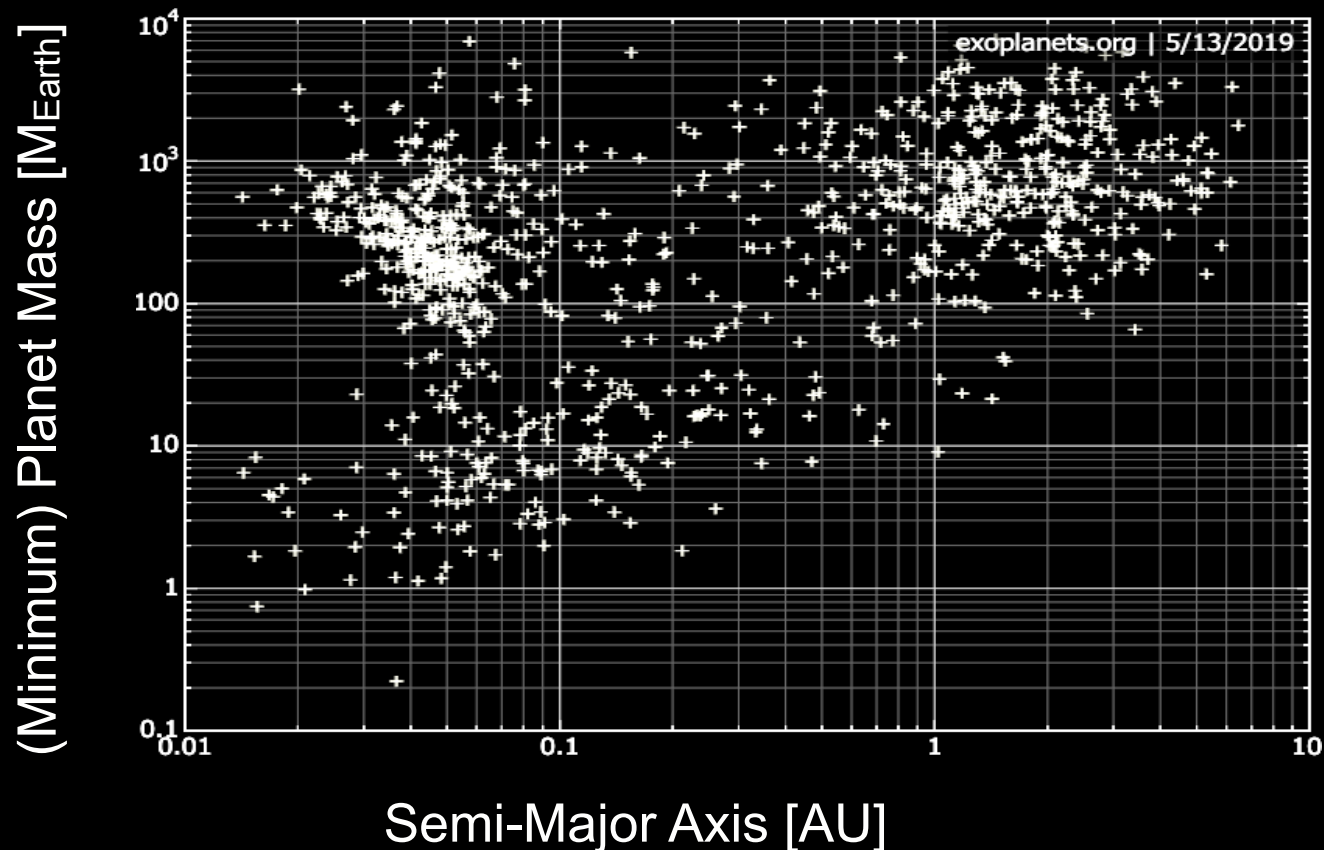
Yuka Fujii

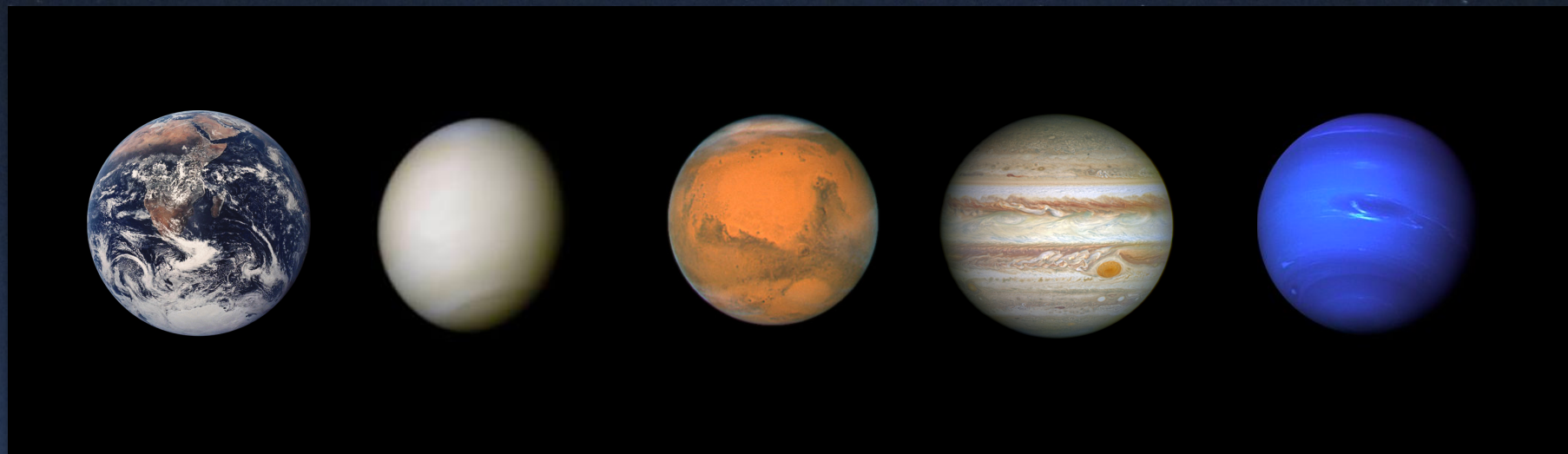
Earth-Life Science Institute,  
Tokyo Institute of Technology

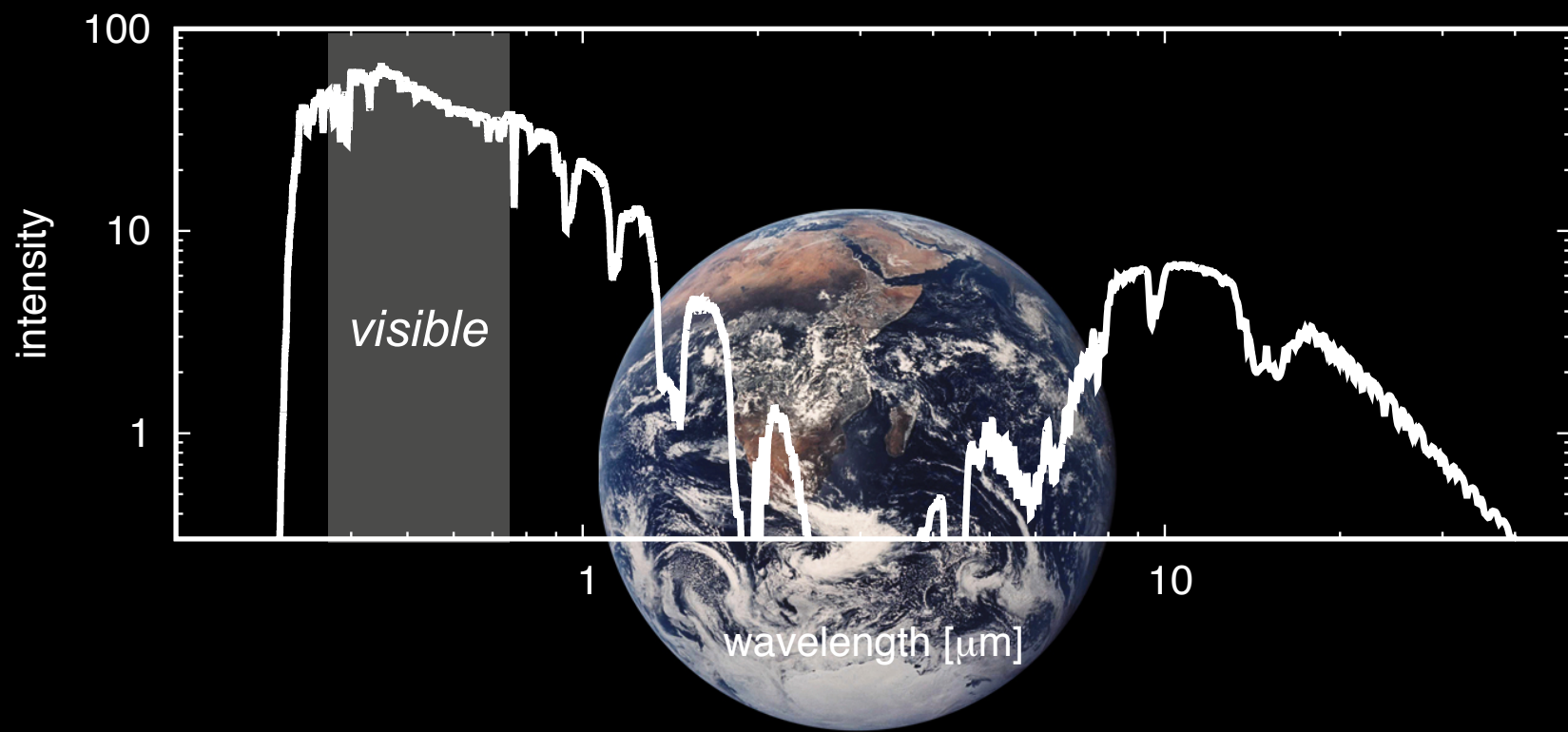


# Exoplanet Discovery usually come with Size (mass and/or radius) and Orbit

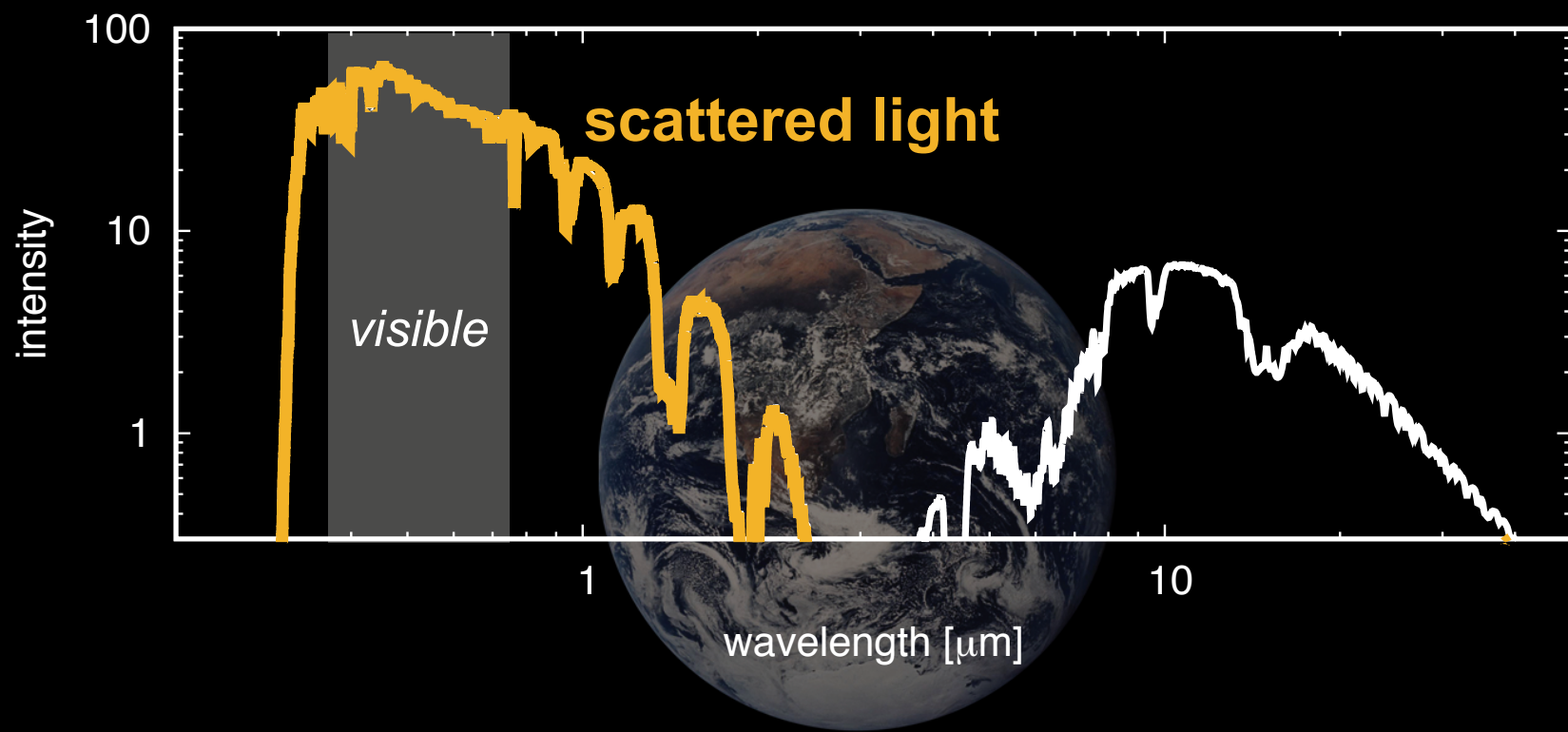
## Discovered Exoplanets

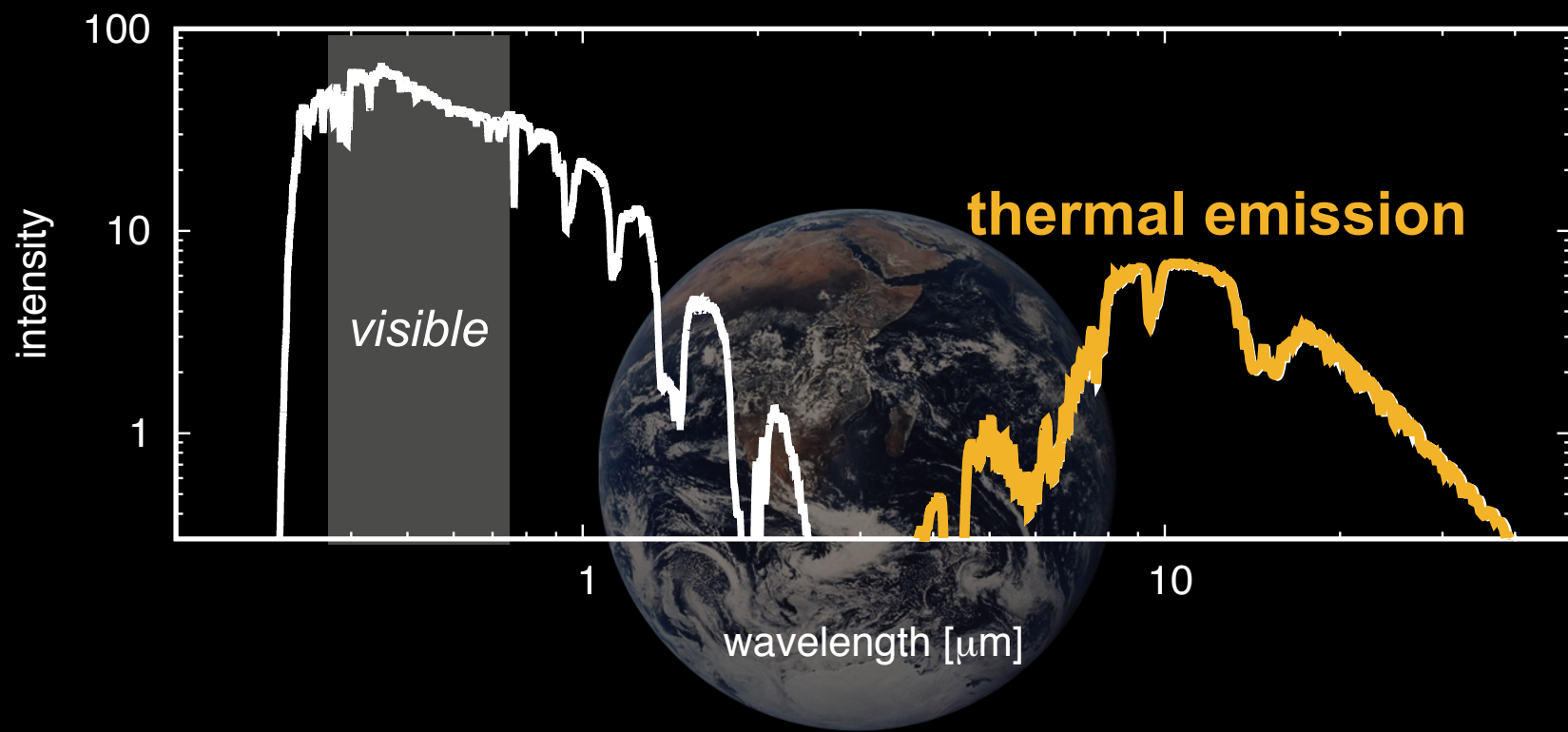


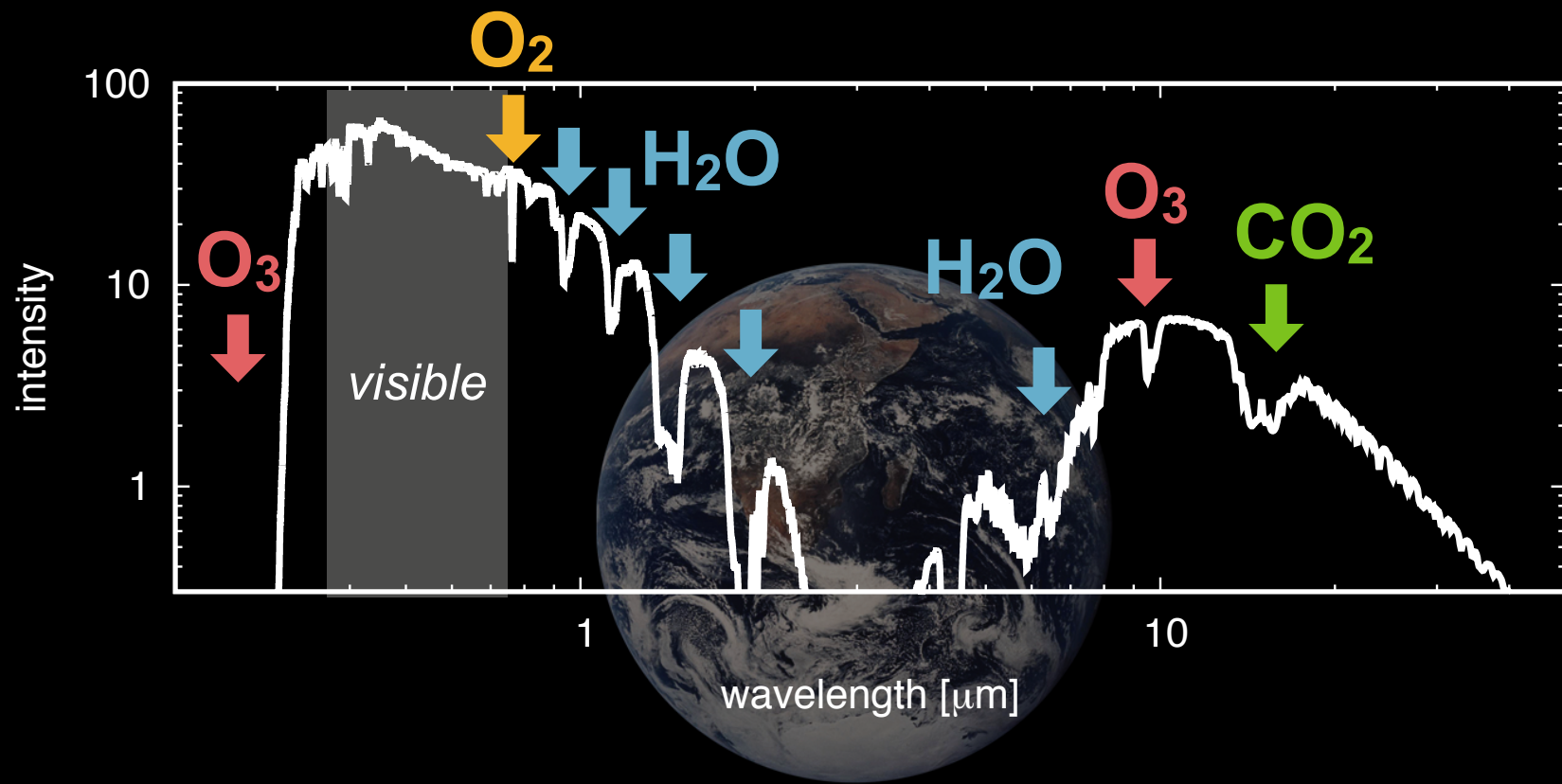


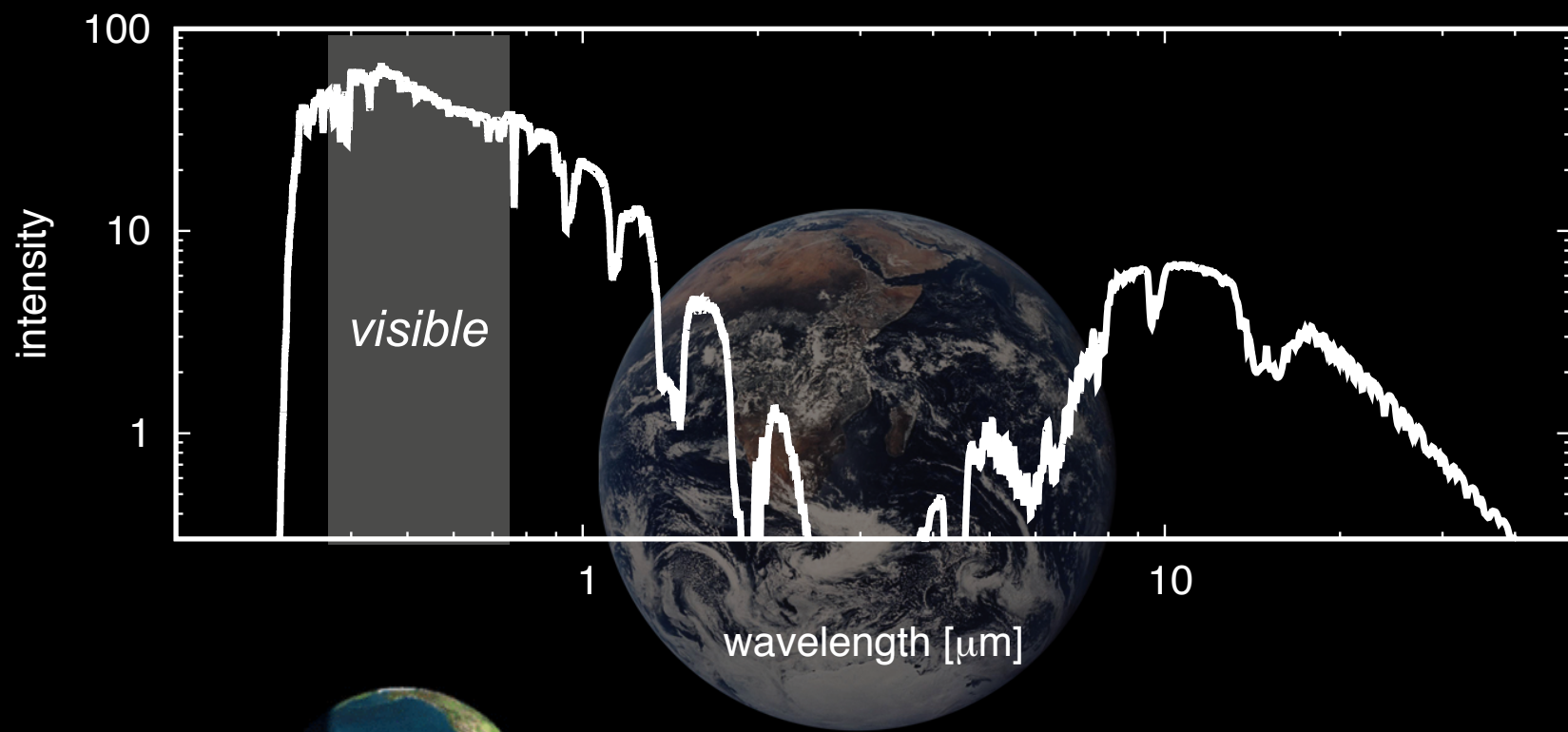








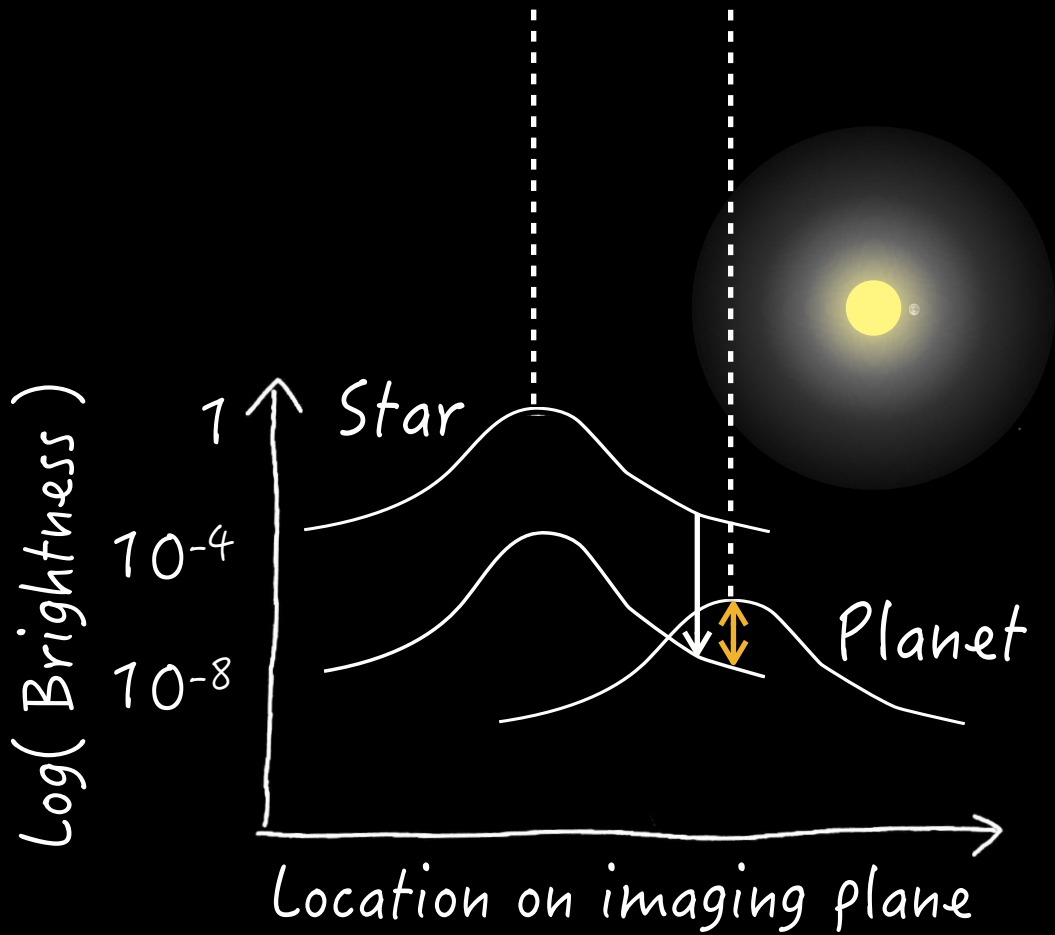






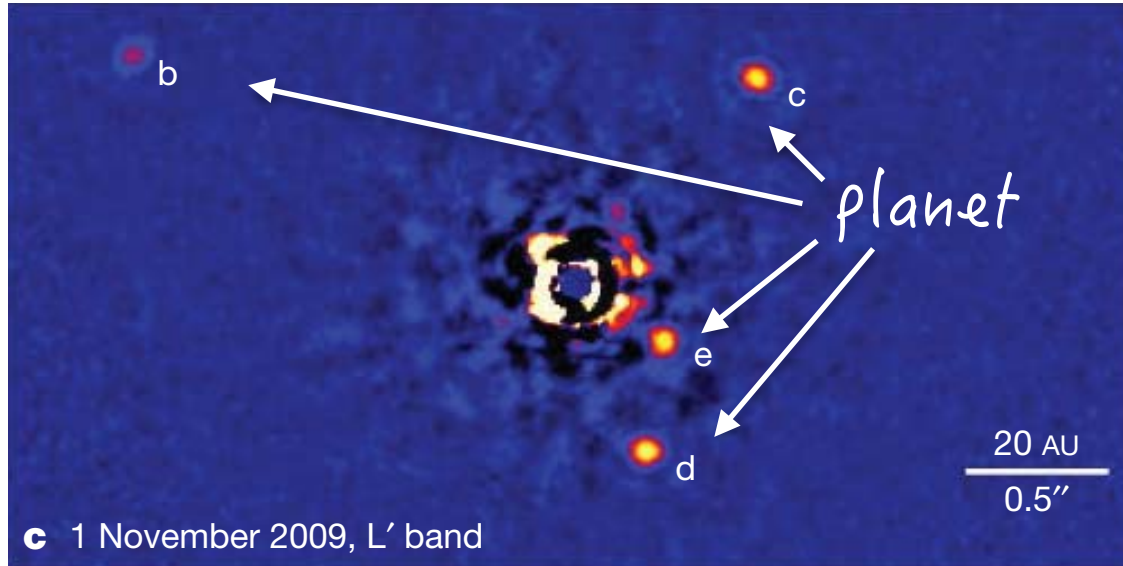


# Direct Imaging



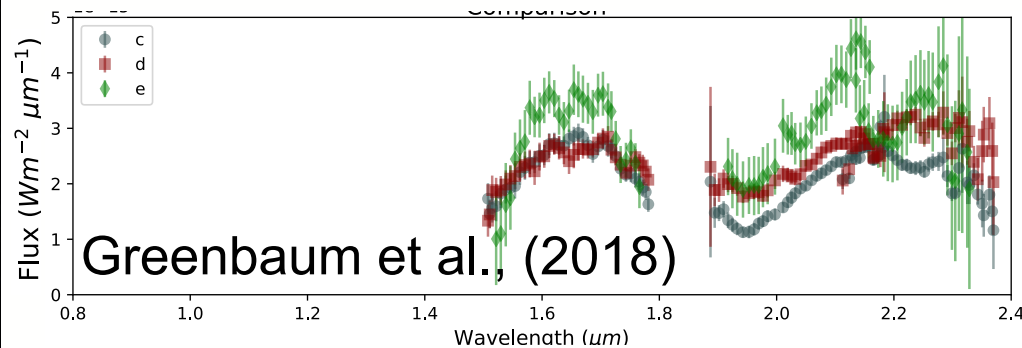
## Direct Imaging

Marois et al., (2010)

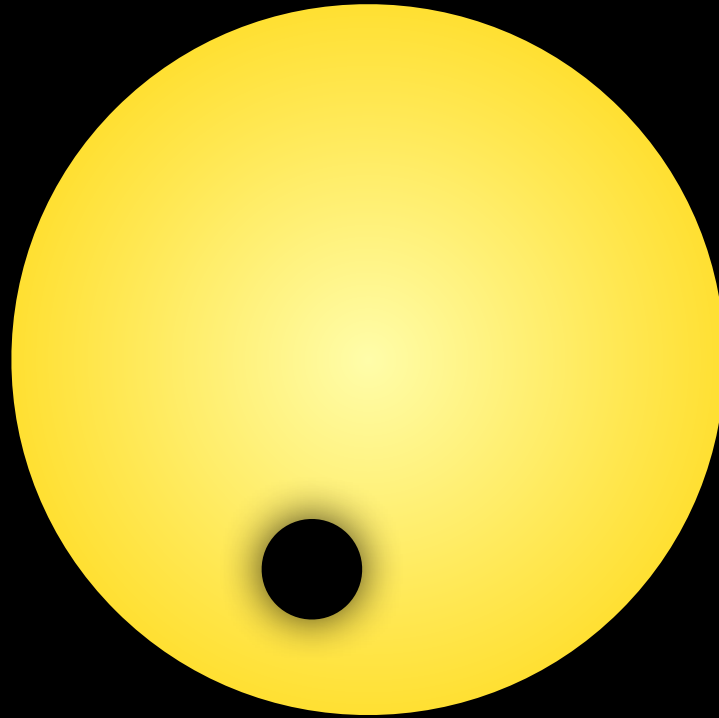


ent Orbits

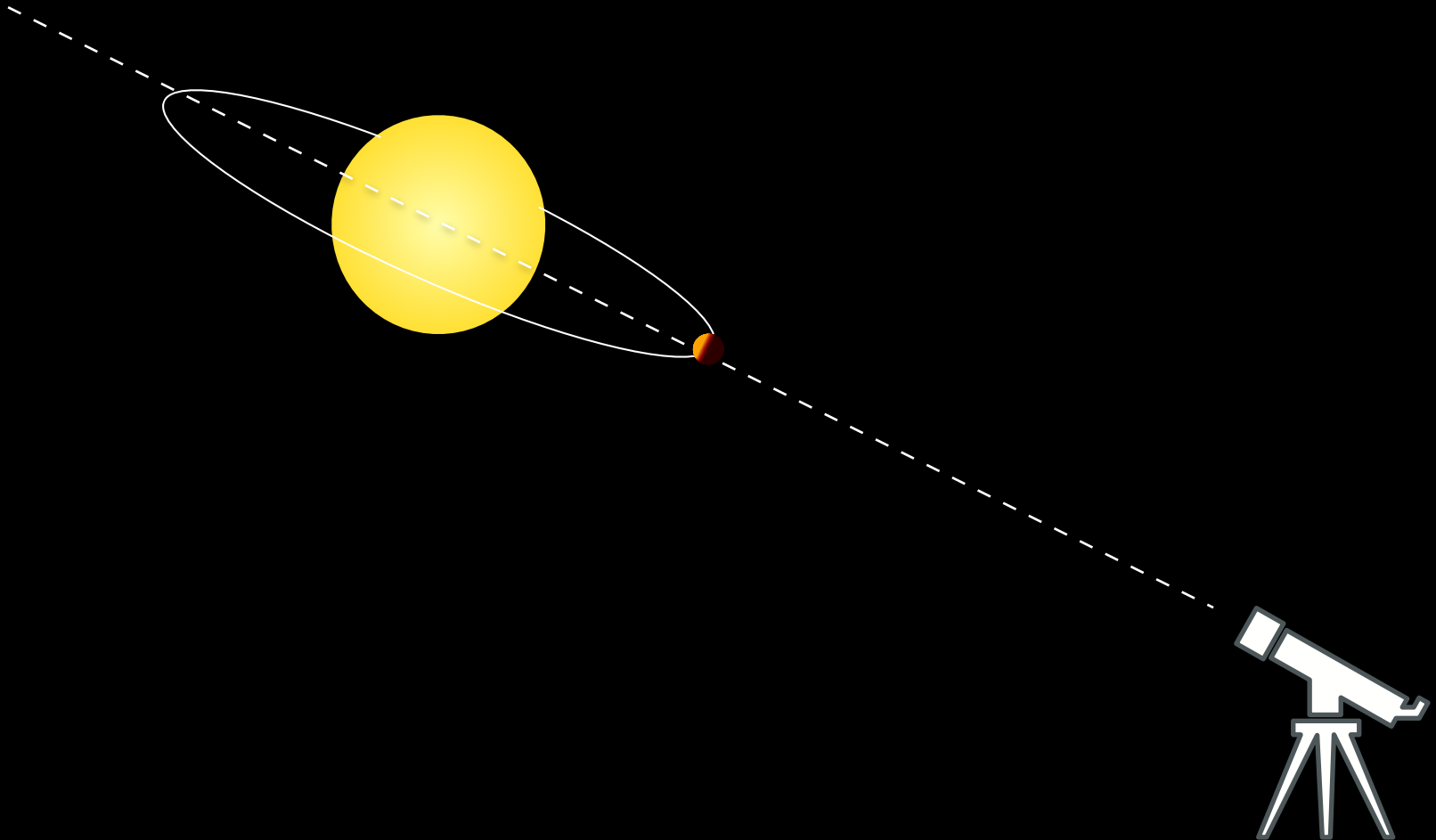
↓ Spectra of planets c, d, e



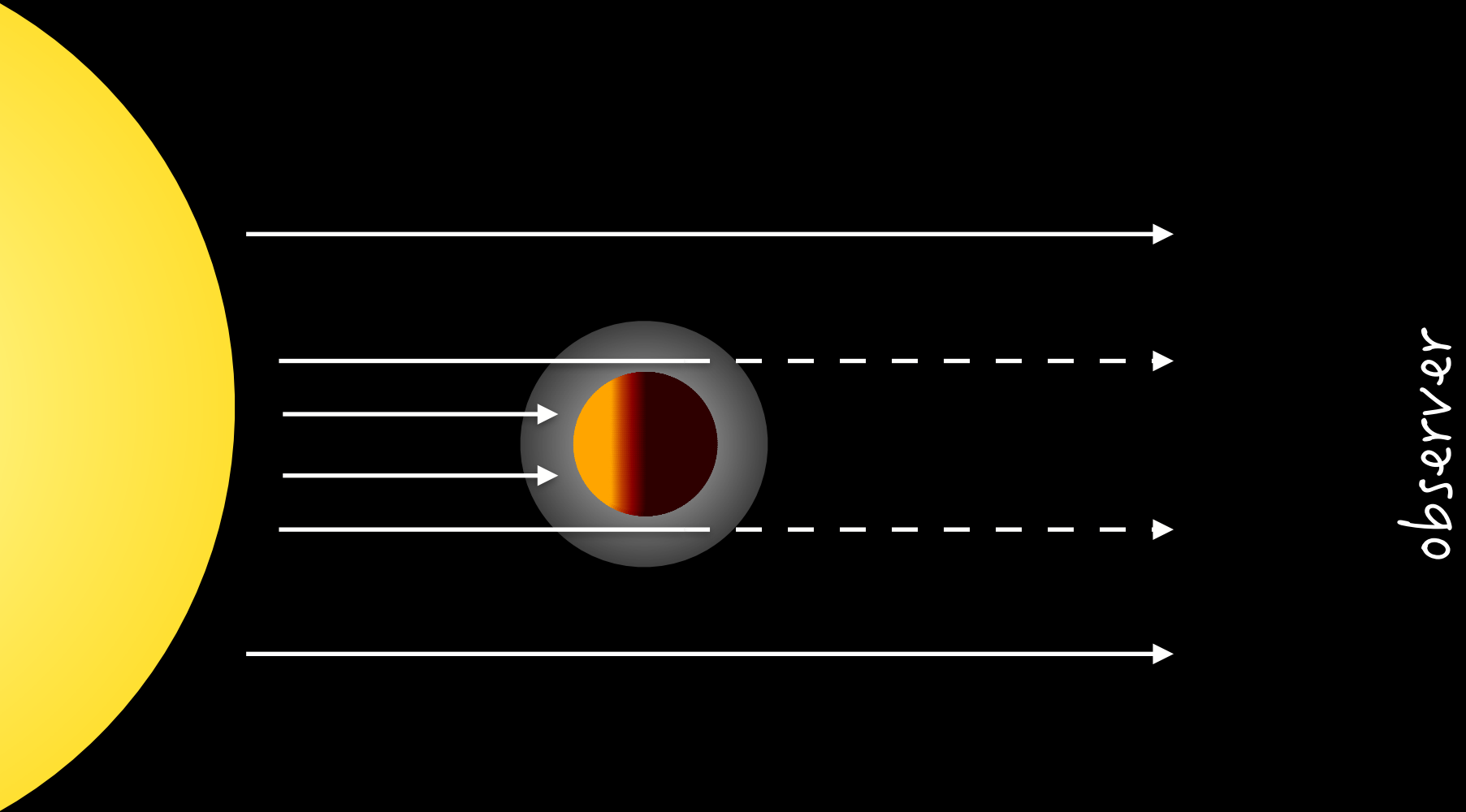
# *Transiting Planets*



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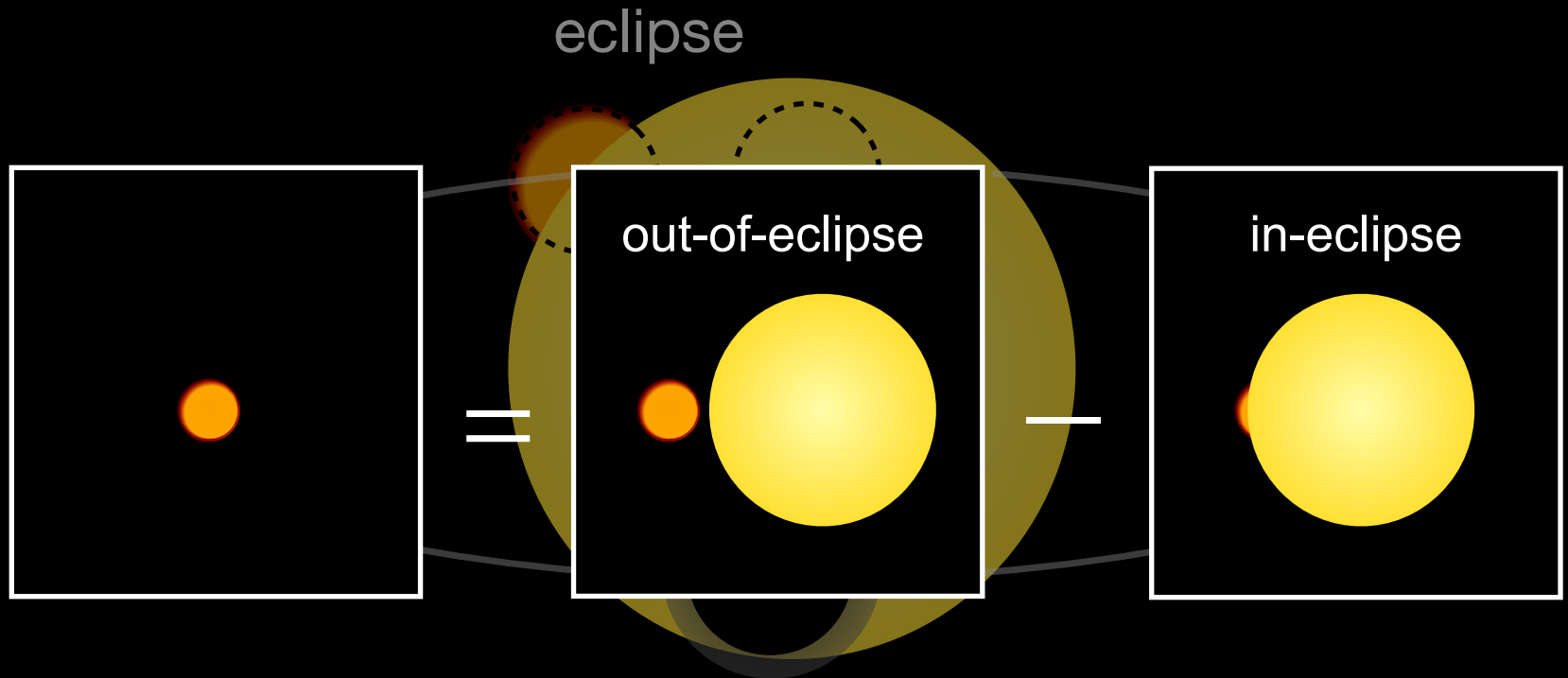


# Transmission Spectroscopy

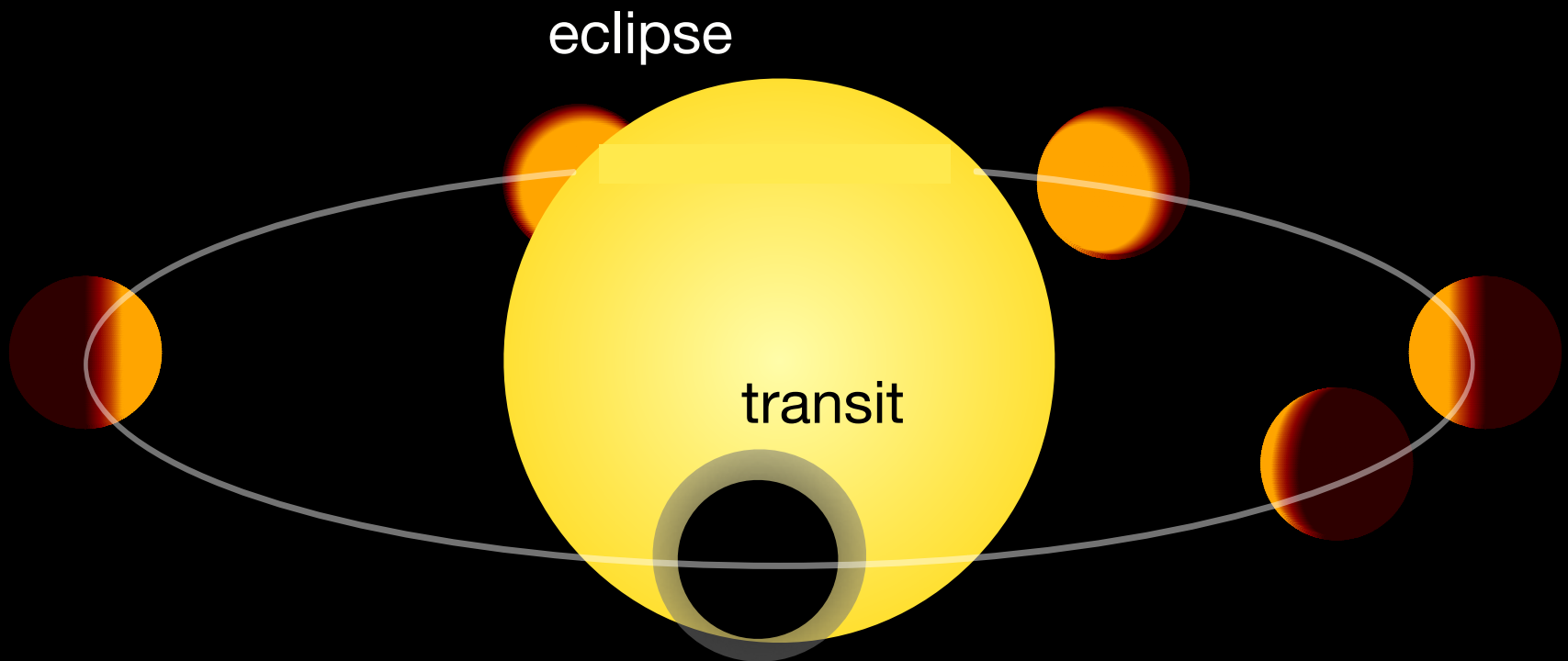




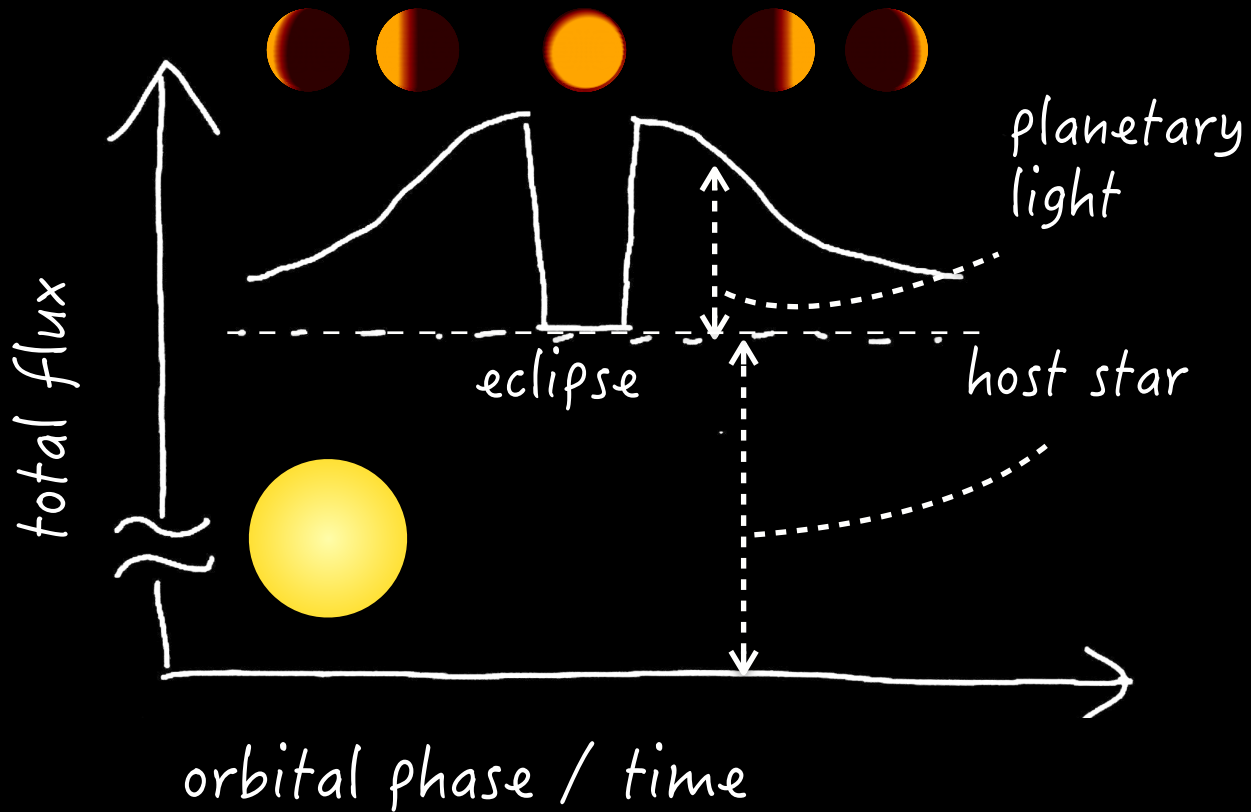
# (Secondary) Eclipse



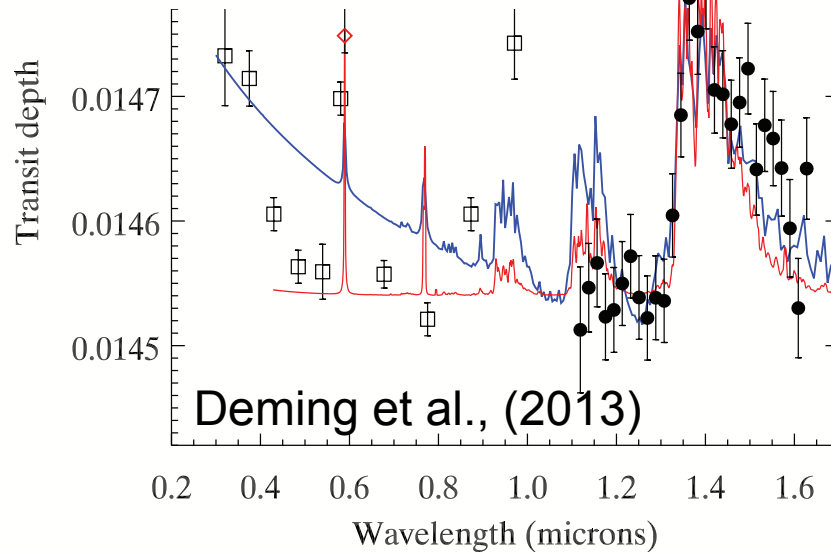
# Phase Variation



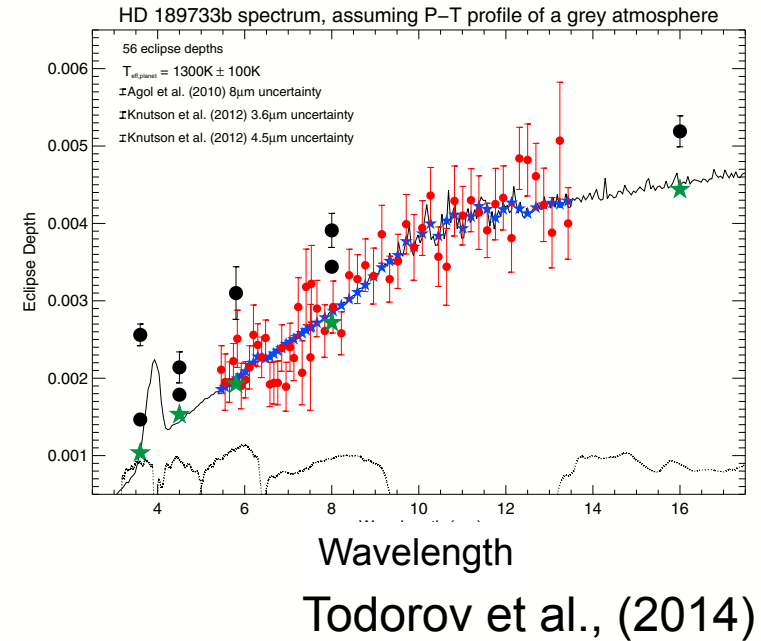
# Phase Variation



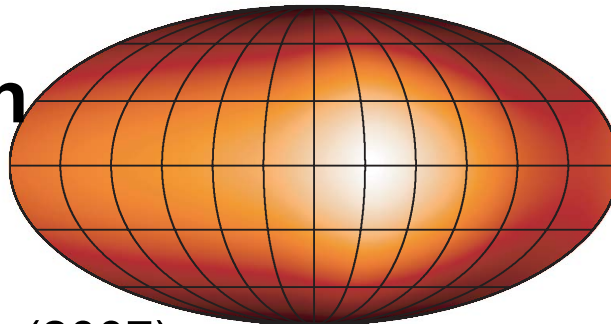
# Transmission Spectroscopy



# Eclipse Spectroscopy



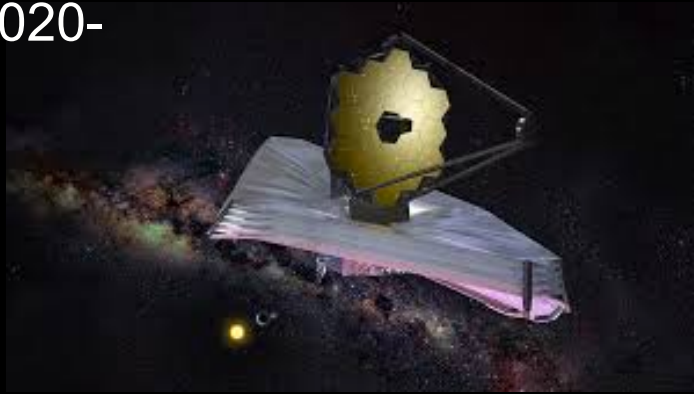
# Thermal Emission Map



Knutson et al., (2007)

# James Webb Space Telescope

2020-



# ARIEL

2028-



Ground-based  
Extremely  
Large Telescopes





# Summary

- Key observations to characterize atmospheres (and surfaces) of exoplanets
  - Direct Imaging
  - Transmission spectroscopy
  - Secondary eclipse
  - Phase curves



Using these techniques,  
how would you find life  
on an Earth-twin?

# Suggested Reading

C. Sagan et al., (1993) *Nature* 365, “A search for life on Earth from the Galileo Spacecraft”

L. Kaltenegger (2017) *Annu. Rev. Astron. Astrophys.* 2017. 55:433–85 “How to Characterize Habitable Worlds and Signs of Life”

Y. Fujii et al., (2018) *Astrobio.* “Exoplanet Biosignatures: Observational Prospects”

# References

The Exoplanet Orbit Database: <http://exoplanets.org/>

Robinson, T. D., Meadows, V. S., Crisp, D., et al. (2011)  
Astrobiology, 11, 393,

Marois, C., et al., (2010) Nature, 468, 1080–1083,

Greenbaum et al., (2018) Astronomical Journal, 155(6), 226

Deming et al., (2013) Astrophysical Journal, 774(2), 95

Todorov et al., (2014) Astrophysical Journal, 796(2), 100

Knutson et al., (2007) Nature, 447(7141), 183-186