Studying Solar System Bodies as Exoplanets


NASA/SwRI/MSSS/Gerald Eichstädt/Seán Doran – Dec 16, 2017

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2023 Sagan Summer Workshop

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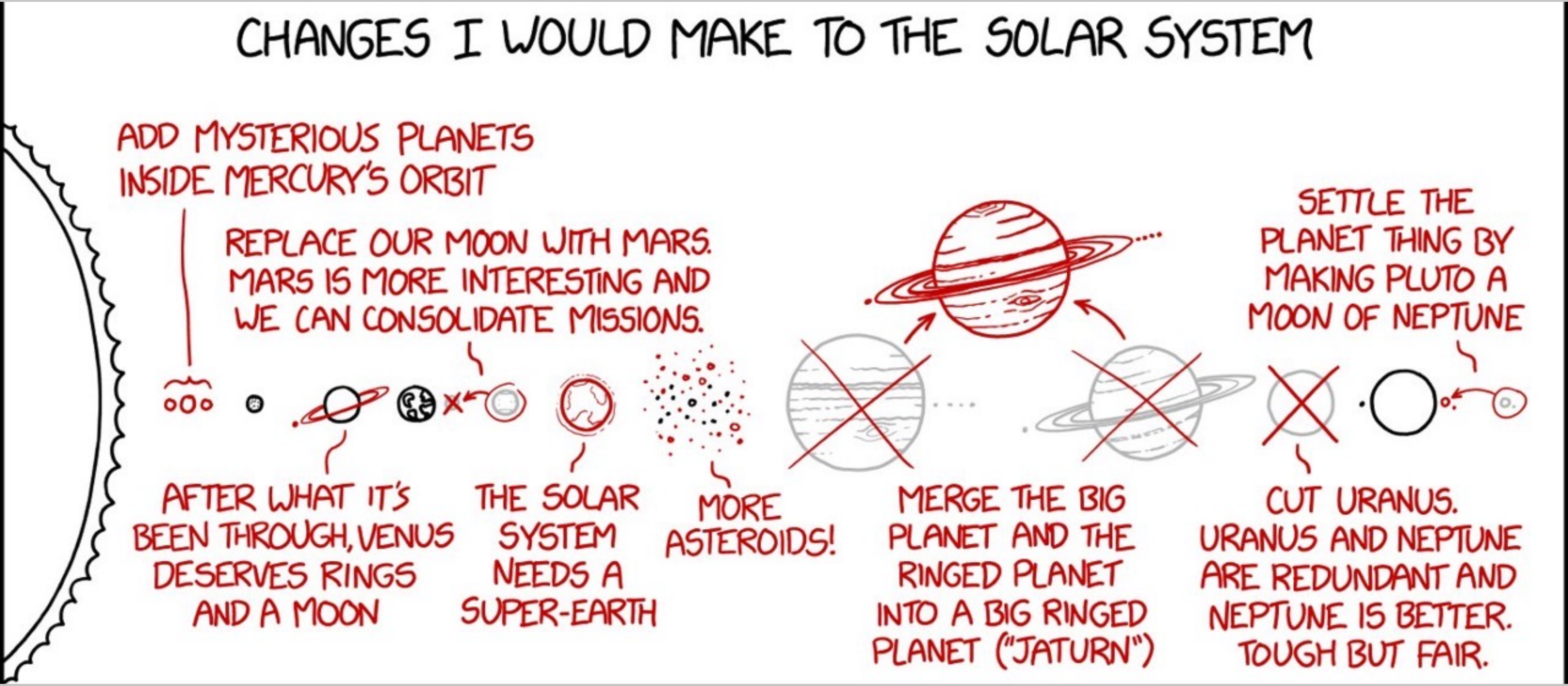
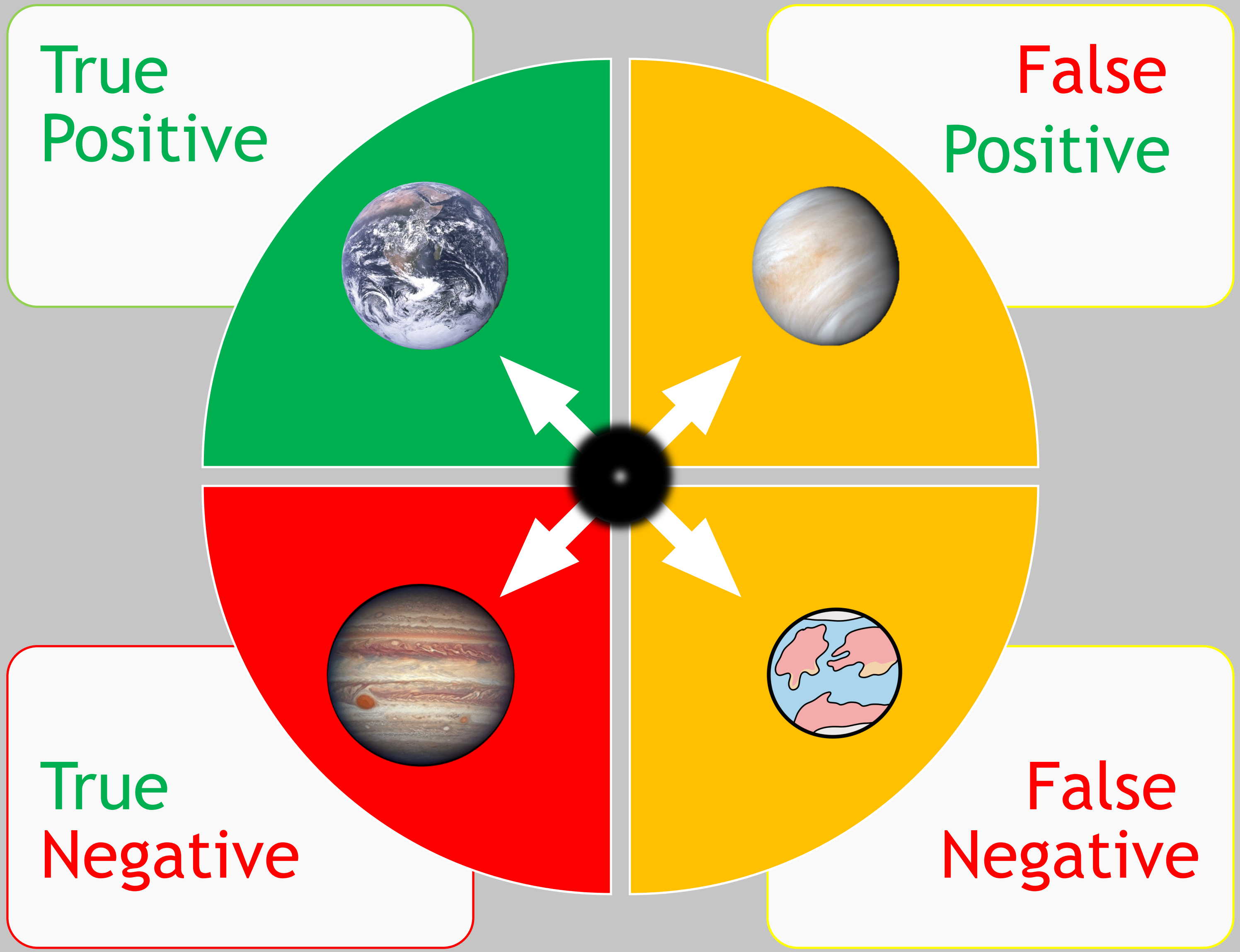
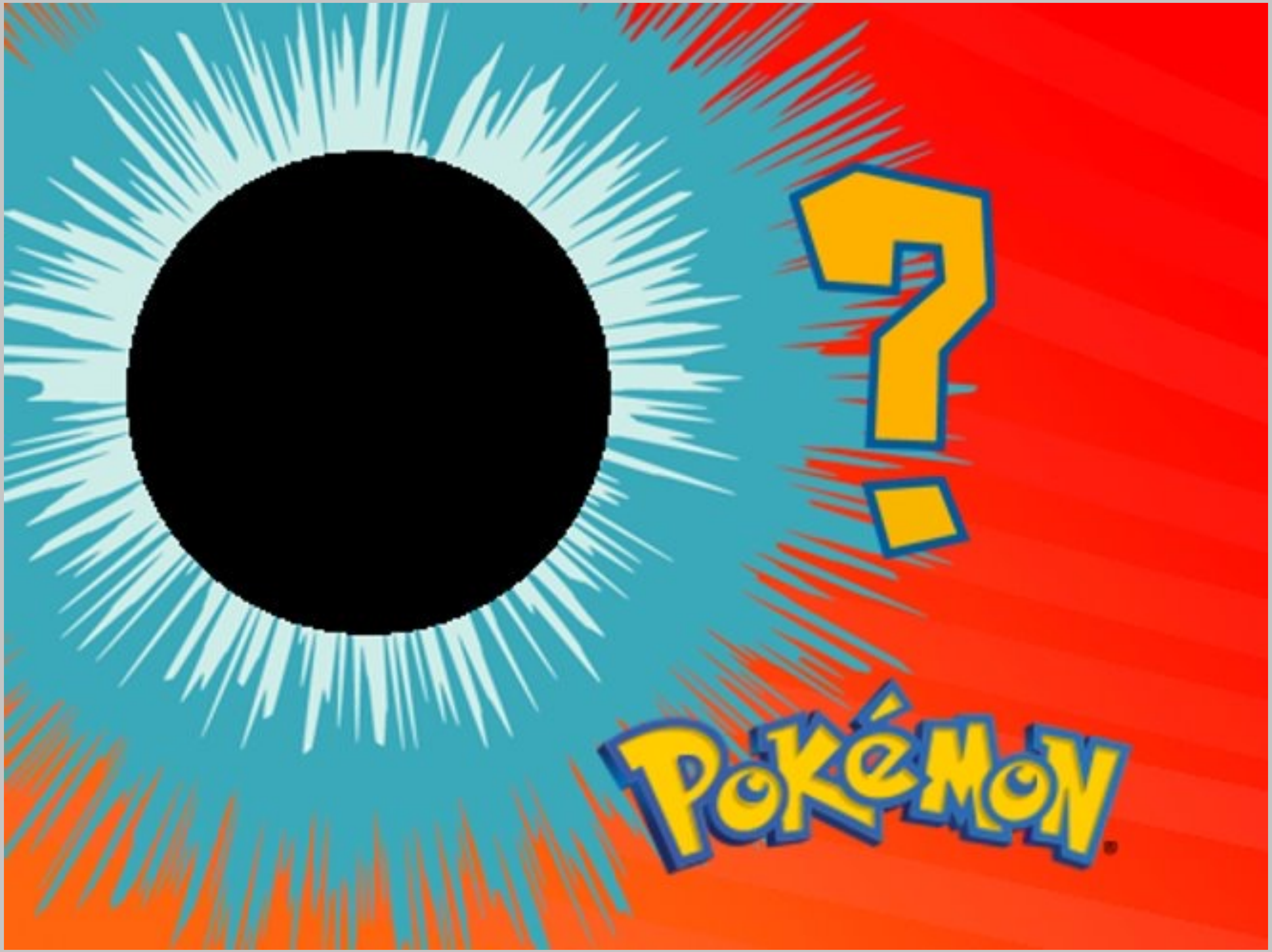


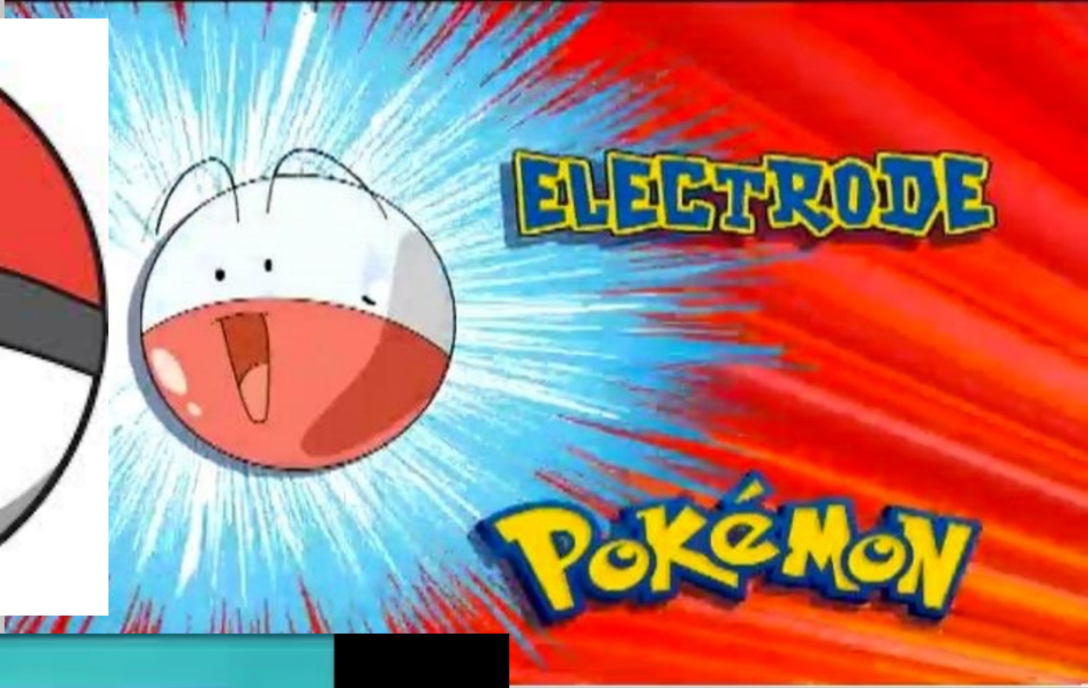
https://xkcd.com/2258/

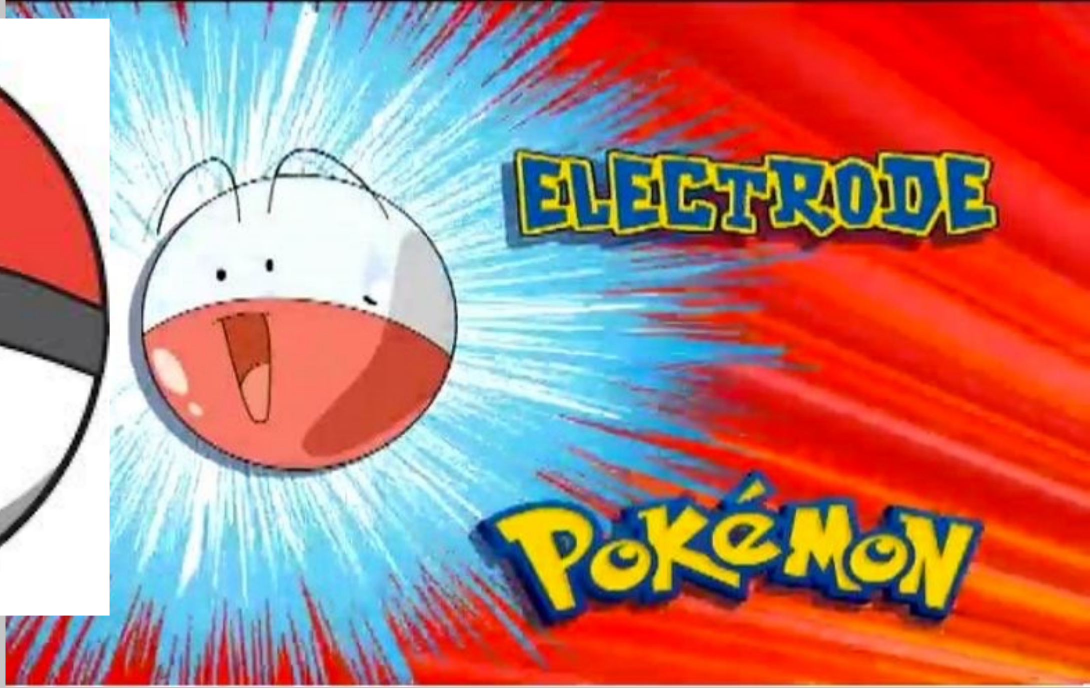
Ex: the search for life with direct imaging




Pokémon


VOLTORB
POKéMON


ELECTRODE
POKéMON

Jupiter is blue?!

How do we make analogous observations?

Science Goal	Science Question	Observable	Exoplanet Technique	Solar System Analog
Find a habitable planet	Is the planet's atmosphere habitable?	Water Vapor, Oxygen, Ozone, etc.	Spectroscopy	Transmission = Occultations, Emission/Reflection
	Is the planet's surface habitable?	Surface Ocean Glint	Orbital Phase Curves Direct Imaging	Rotational Light Curves Phase Curves

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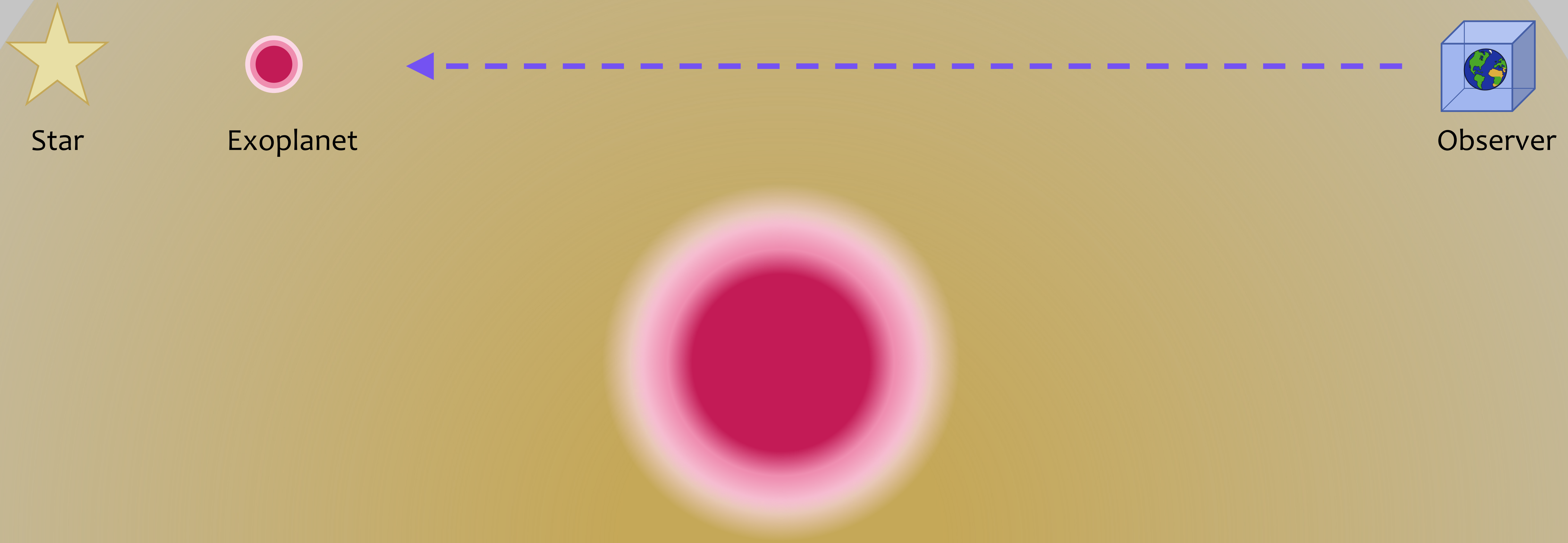
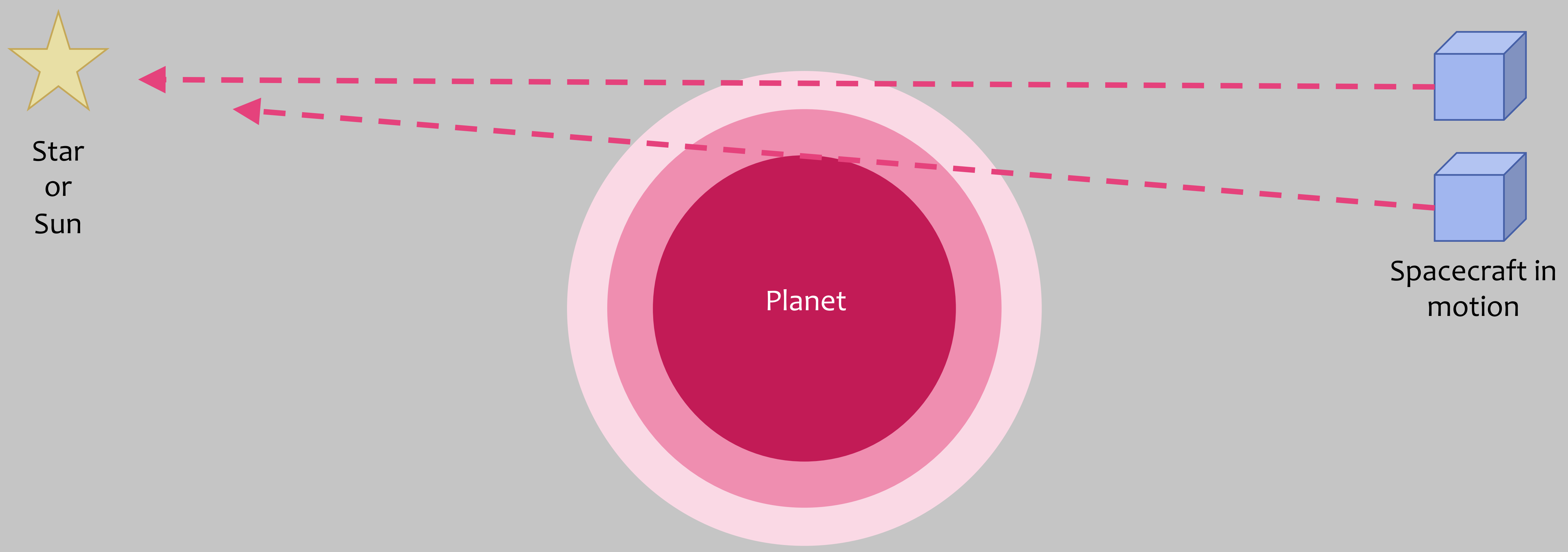
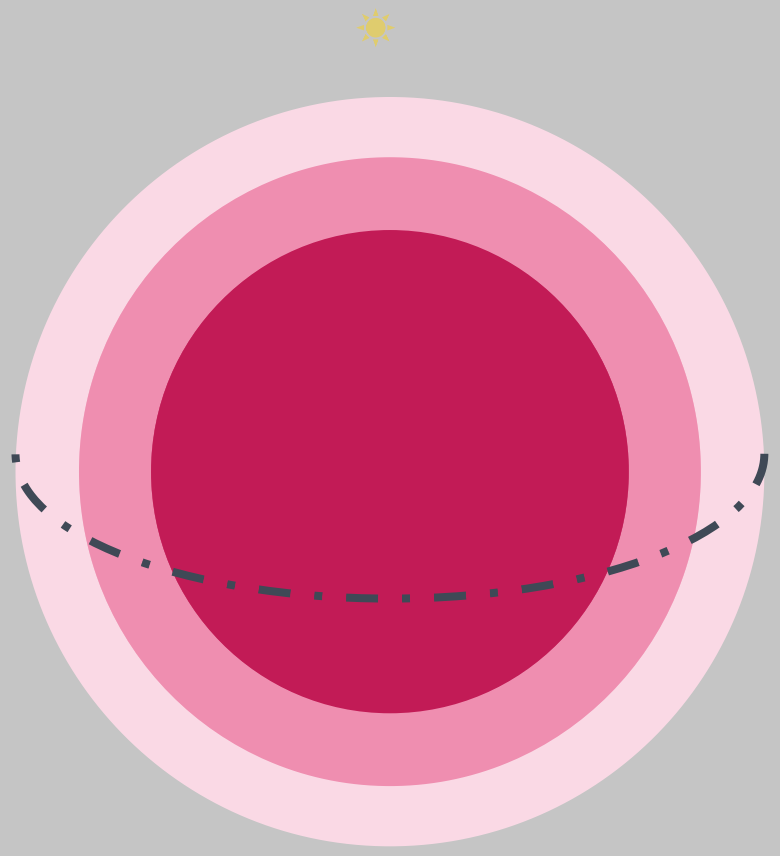
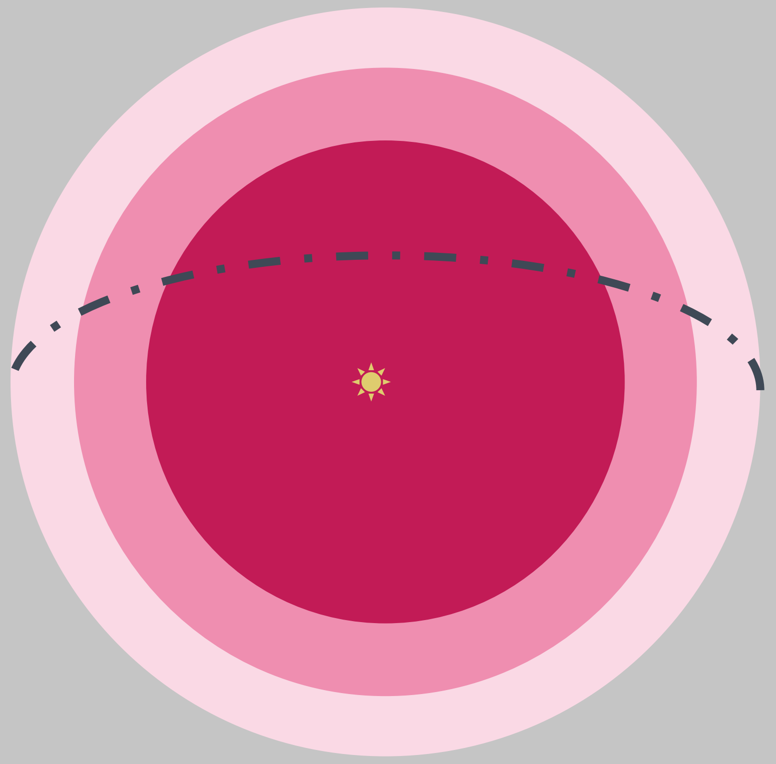
Transits



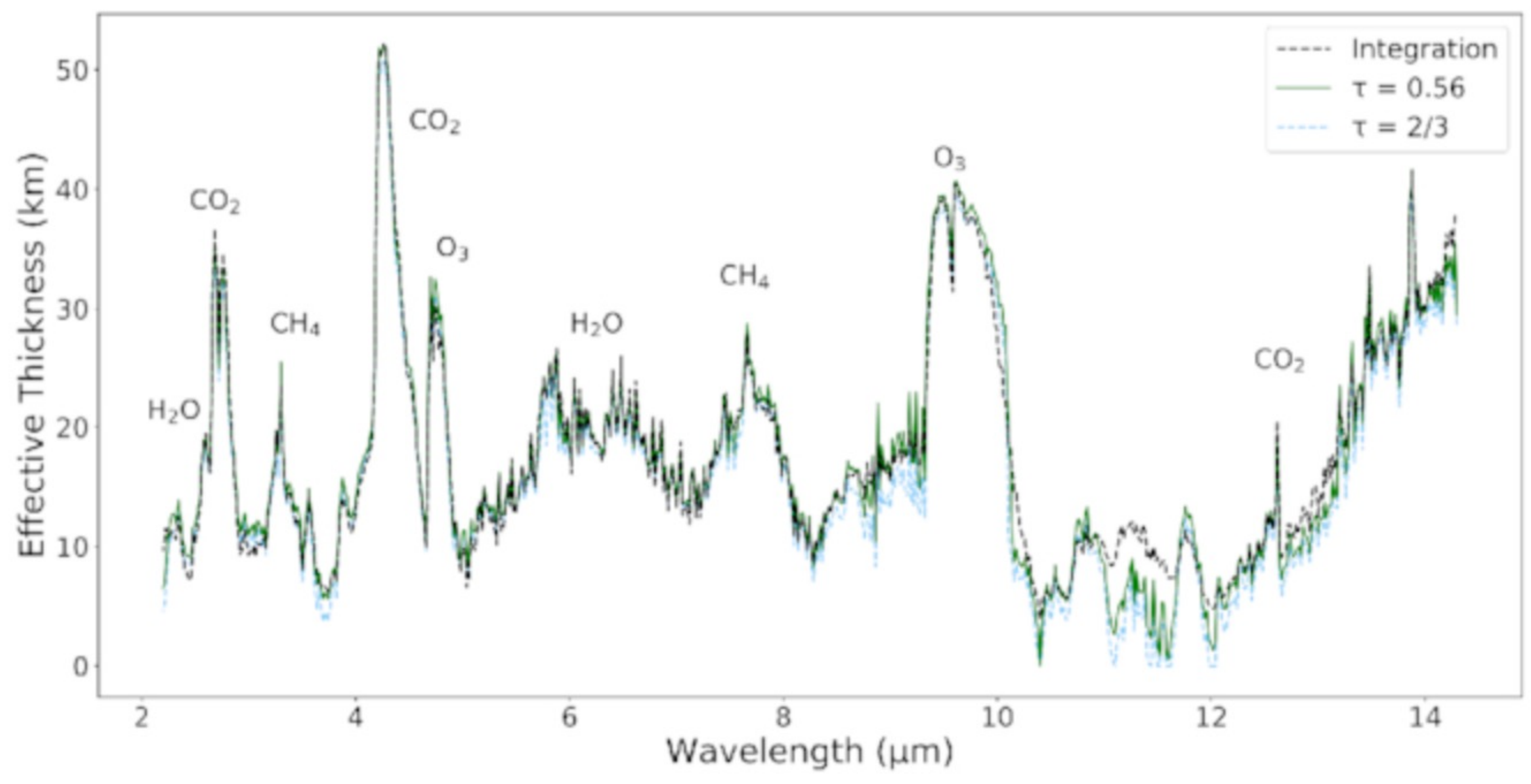
Occultations







Earth Occultations with the
Atmospheric Chemistry Experiment Fourier Transform Spectrometer on the SCISAT

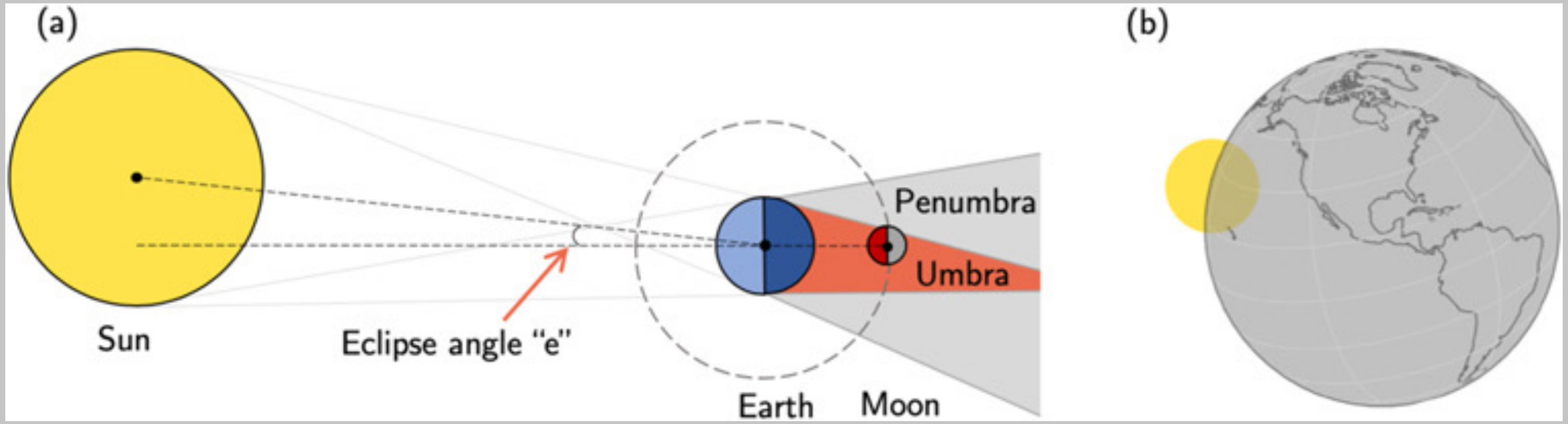


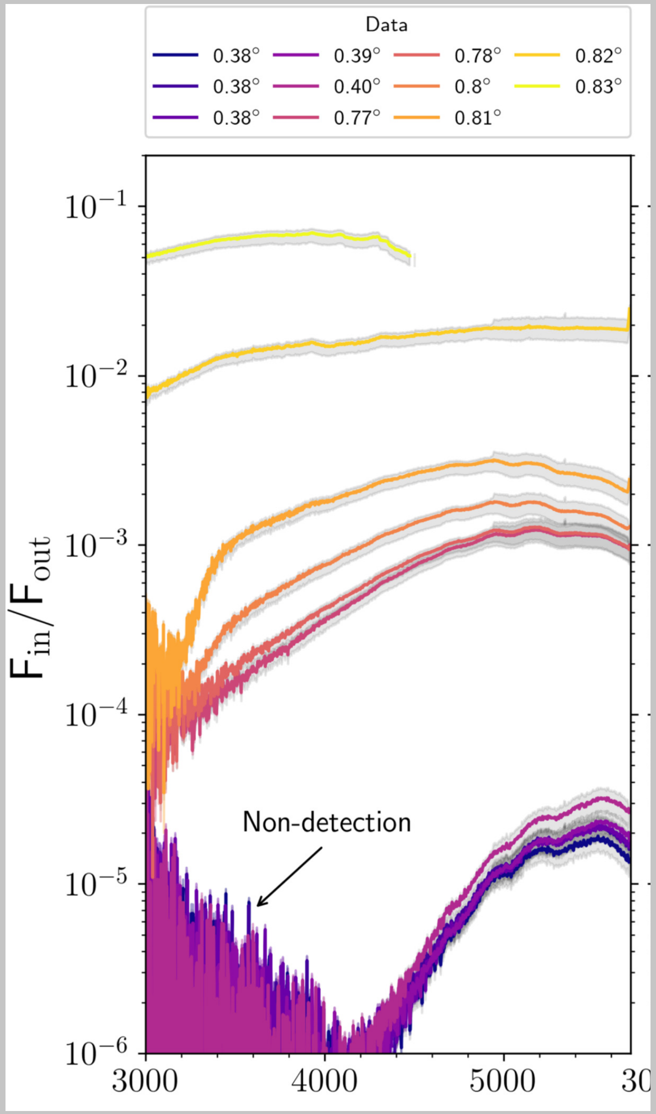
Effective thickness spectra of Earth made with the integration method (black-dotted line) and optical depth approximation, with τ = 0.56 (green) and τ = 2/3 (blue). These spectra represent globally averaged spectra and the spectral resolution has been reduced to 0.02 μm.

MacDonald et al. (2019 & 2020) MNRAS

Earth Transmission Spectrum from Lunar Eclipses with HST/STIS

When the Moon is entirely in the Earth's umbra (total or umbral eclipse), all sunlight reaching the lunar surface has been refracted or scattered through Earth's atmosphere. When the Moon is in the Earth's penumbra (penumbral eclipse), illumination comes from both unocculted sunlight and sunlight refracted and scattered through the planet's atmosphere, similar to the observation of an exoplanet transit. Eclipse angles, $e \lesssim 0.6$ correspond to the umbral phase, and $0.6 \lesssim e \lesssim 1.2$ correspond to the penumbral phase.

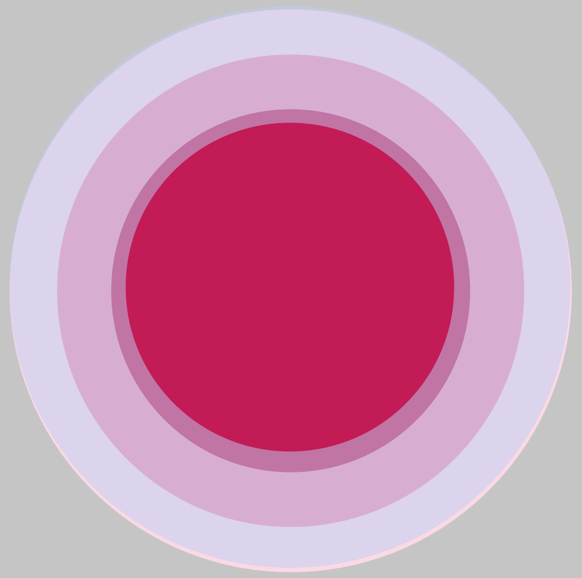




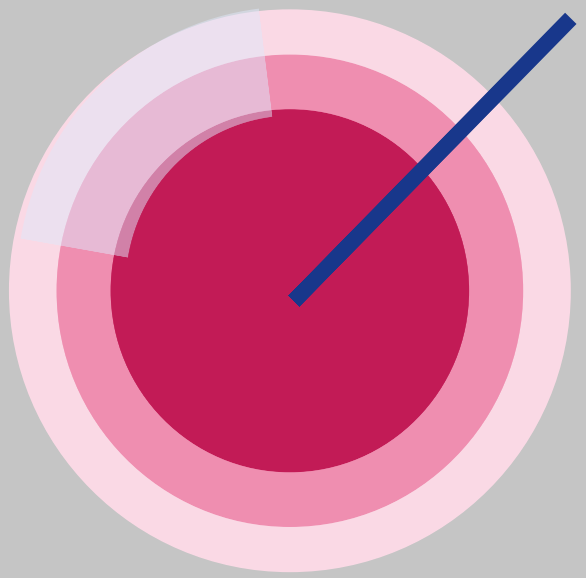
Youngblood et al. (2020) AJ

Exoplanet observations are hemispherically-averaged

Exoplanets



Solar System

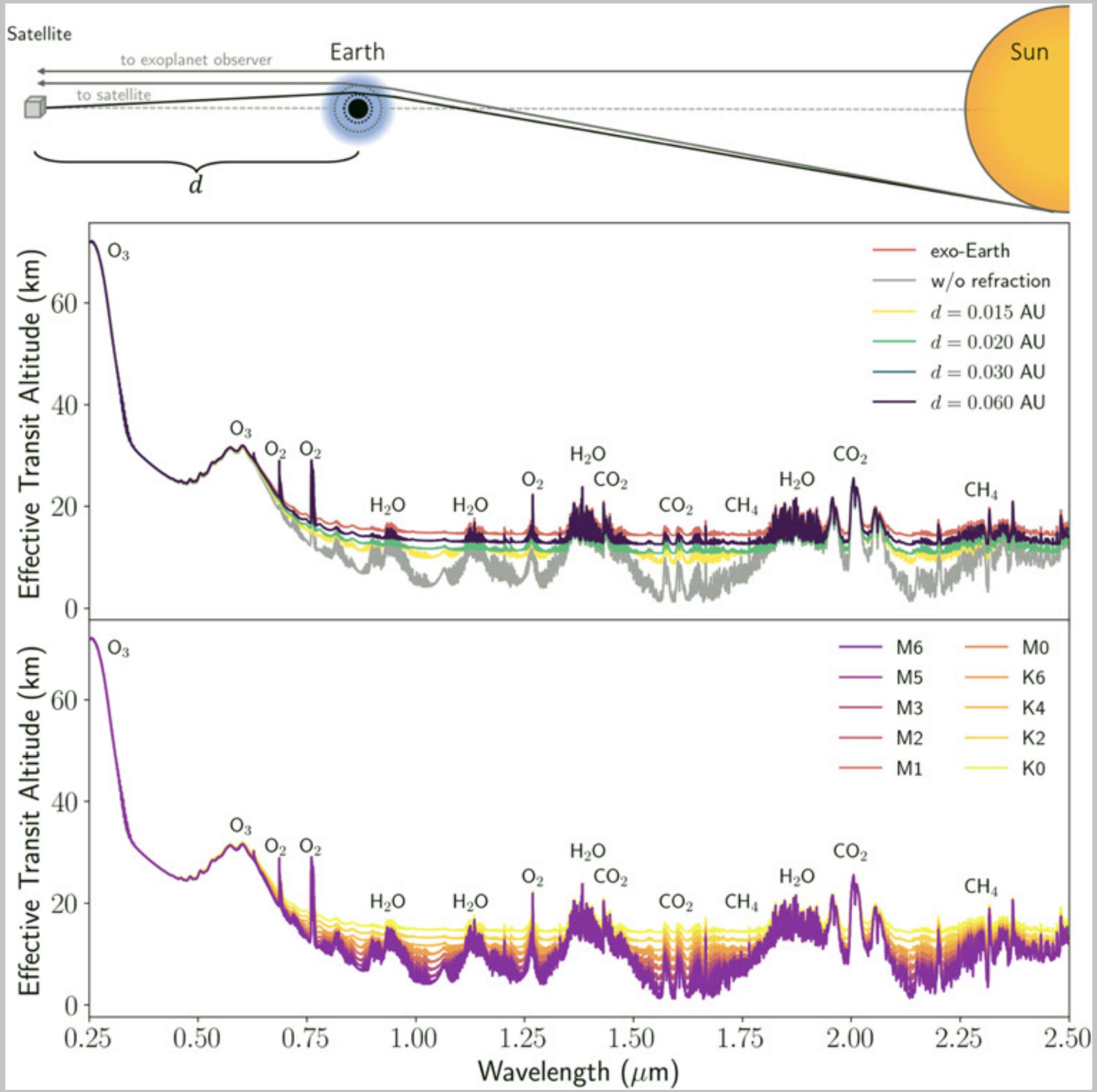


Mission Concept for Earth Transmission Spectra

Top: solar rays from the limb of the Sun refract as they transmit through the Earth's atmosphere, creating a critical refraction limit (dotted circles) that restricts the depth probed into the atmosphere.

Middle: simulated transmission spectra with and without refraction for an exo-Earth.

Bottom: simulated transmission spectra of possible exo-Earths around various K and M dwarfs. Depending on the distance an Earth transit is observed from, the satellite can access regions of the Earth's atmosphere that are analogous to Earth-like planets transiting K and M dwarfs.



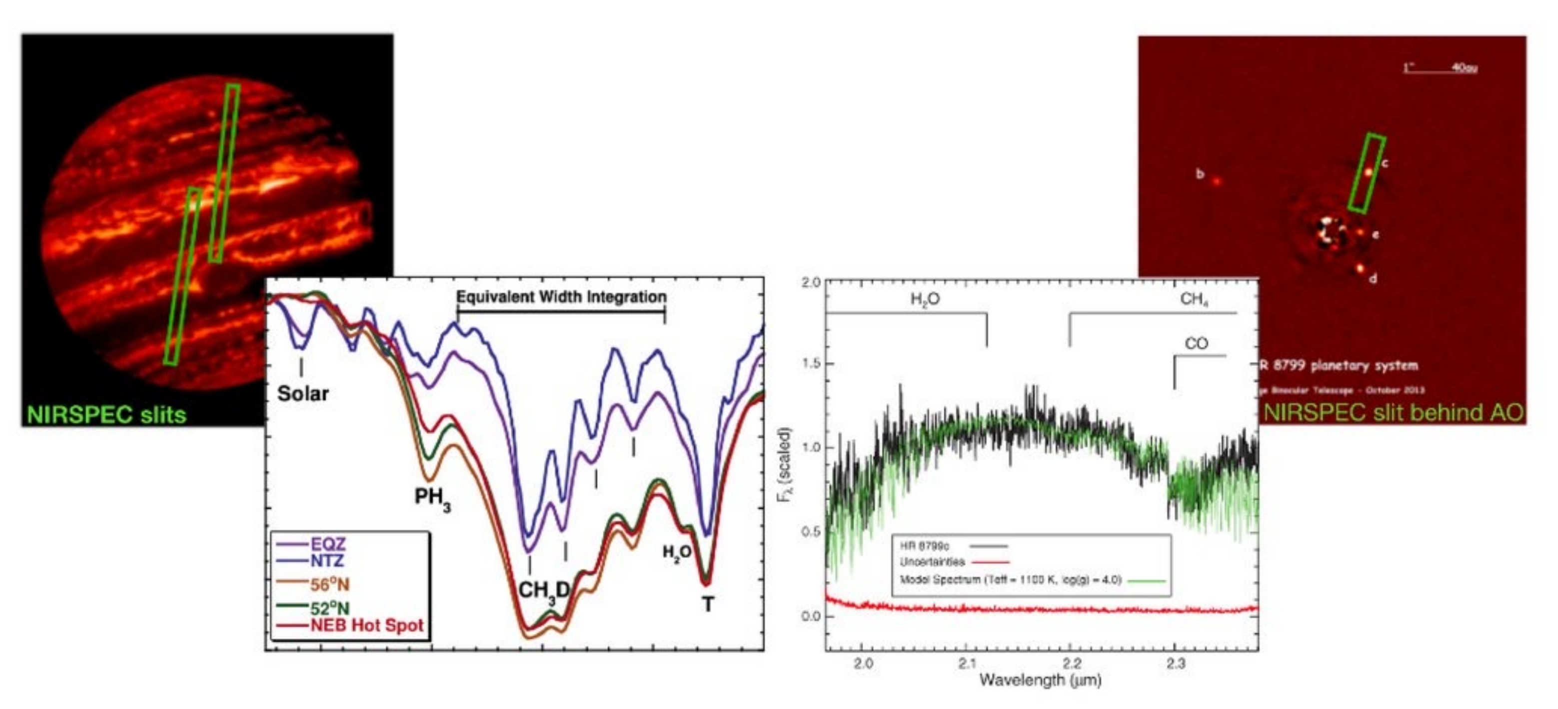
Mayorga et al. (2021) PSJ

Disk-Integrated Spectroscopy with PEAS on Lick Observatory

PEAS

Planet as Exoplanet Analog Spectrograph

Design features an integrated sphere which disk-integrates the light before it hits the spectrograph.



Martin et al. (2020) SPIE

How do we make analogous observations?

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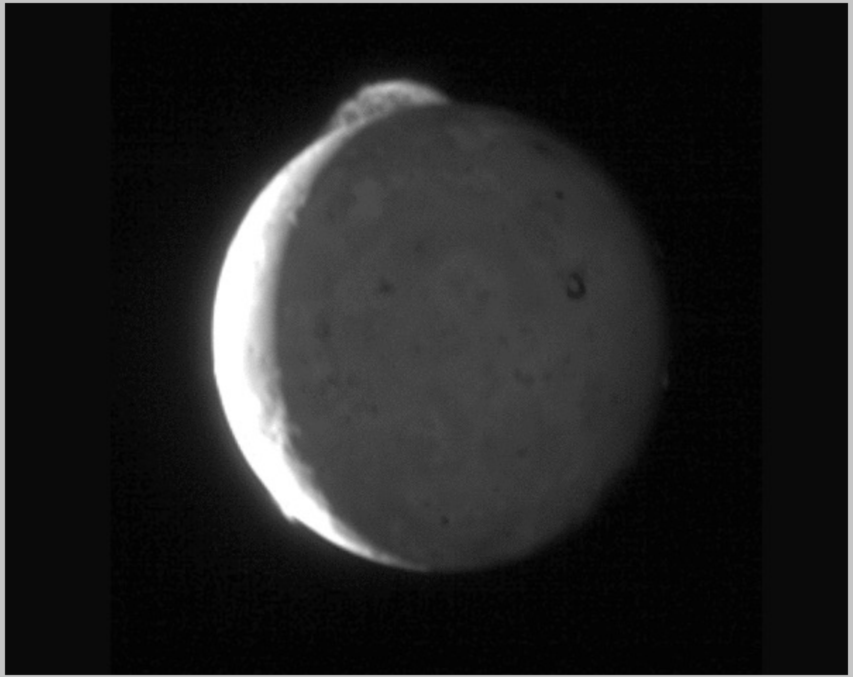
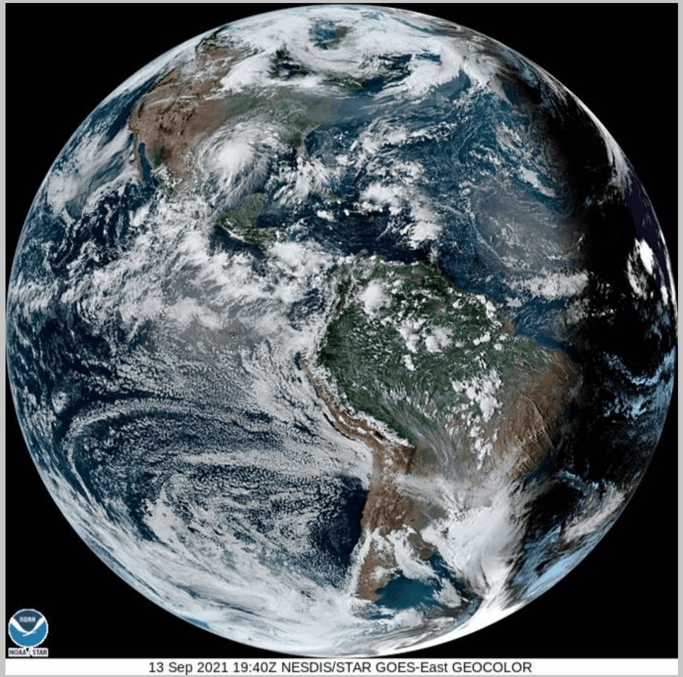
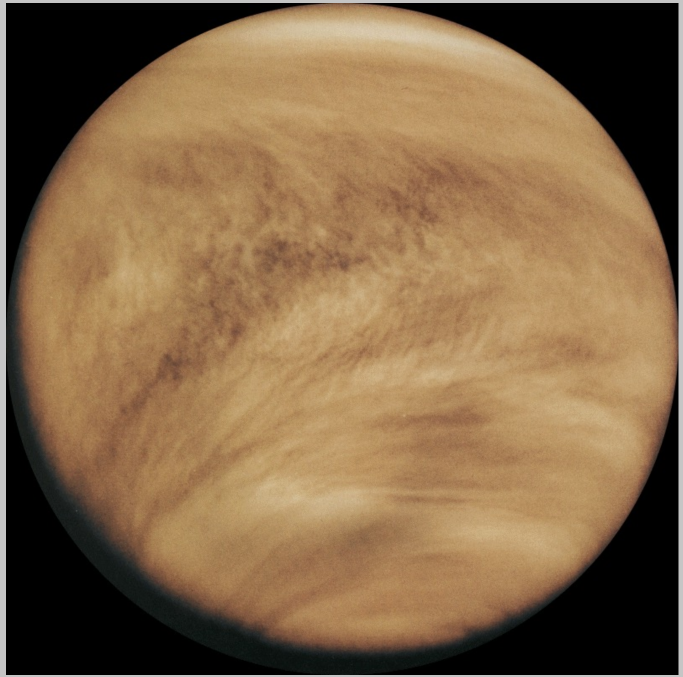
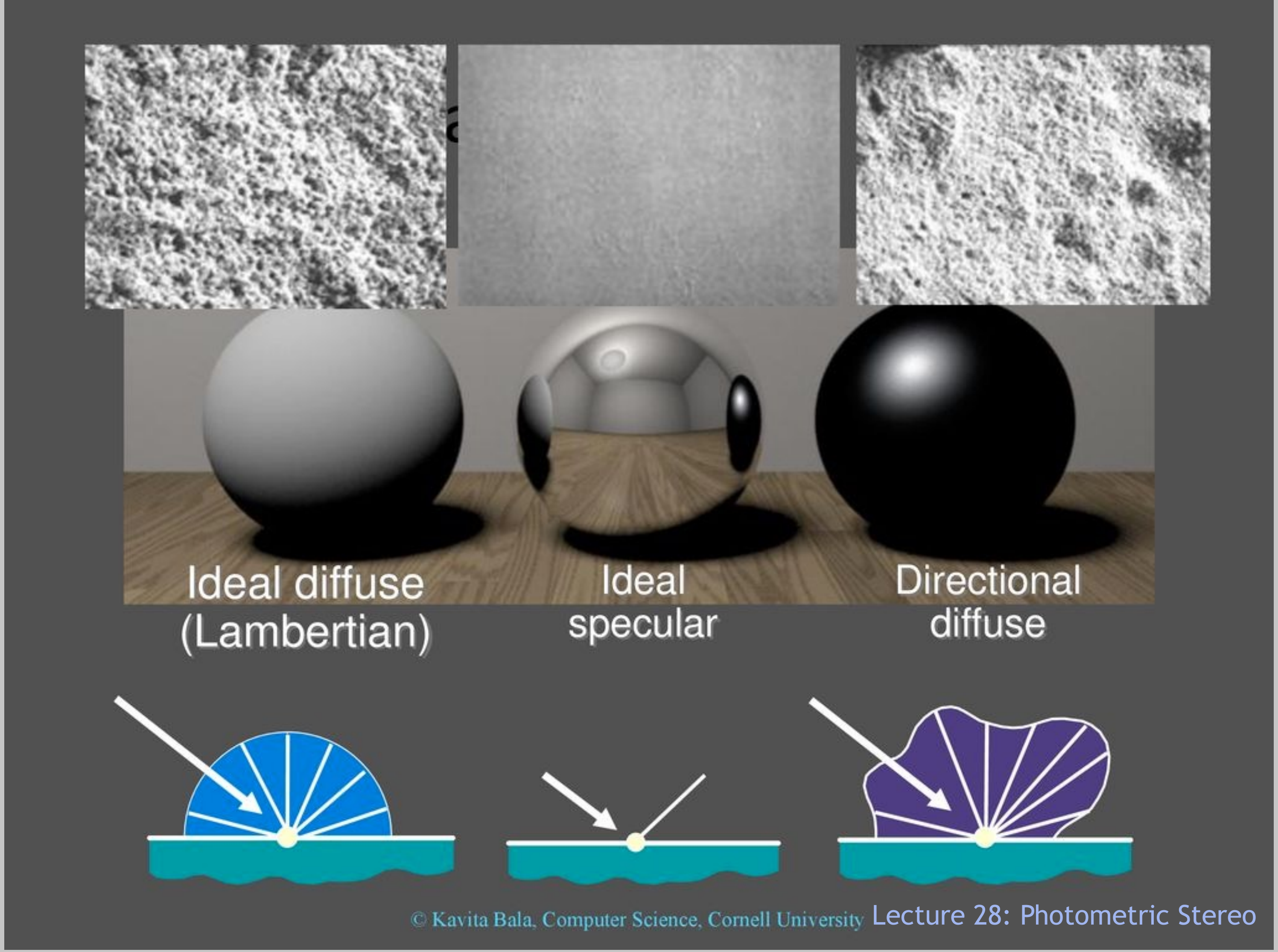
How do signatures of planetary variability/biology manifest in direct imaging observations?





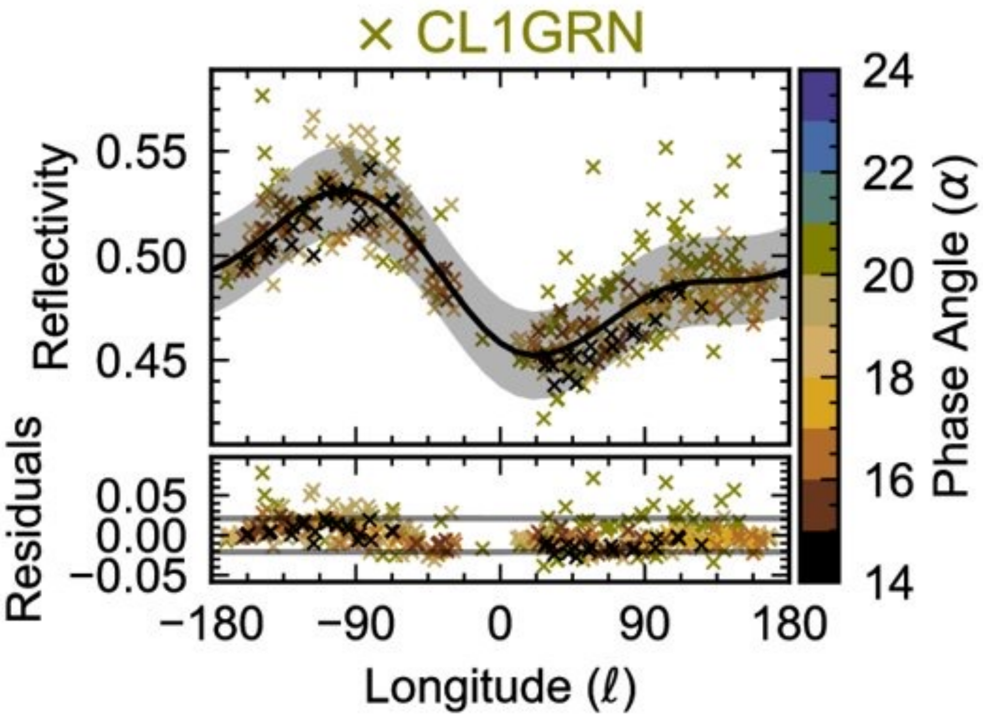


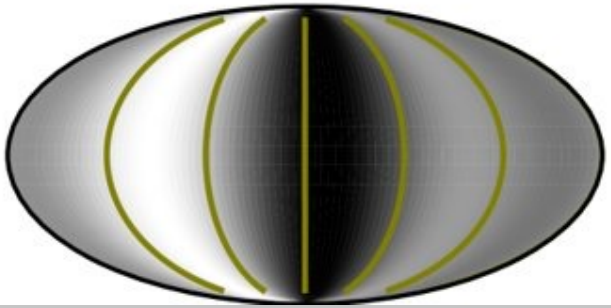
What can we characterize? What can we not?

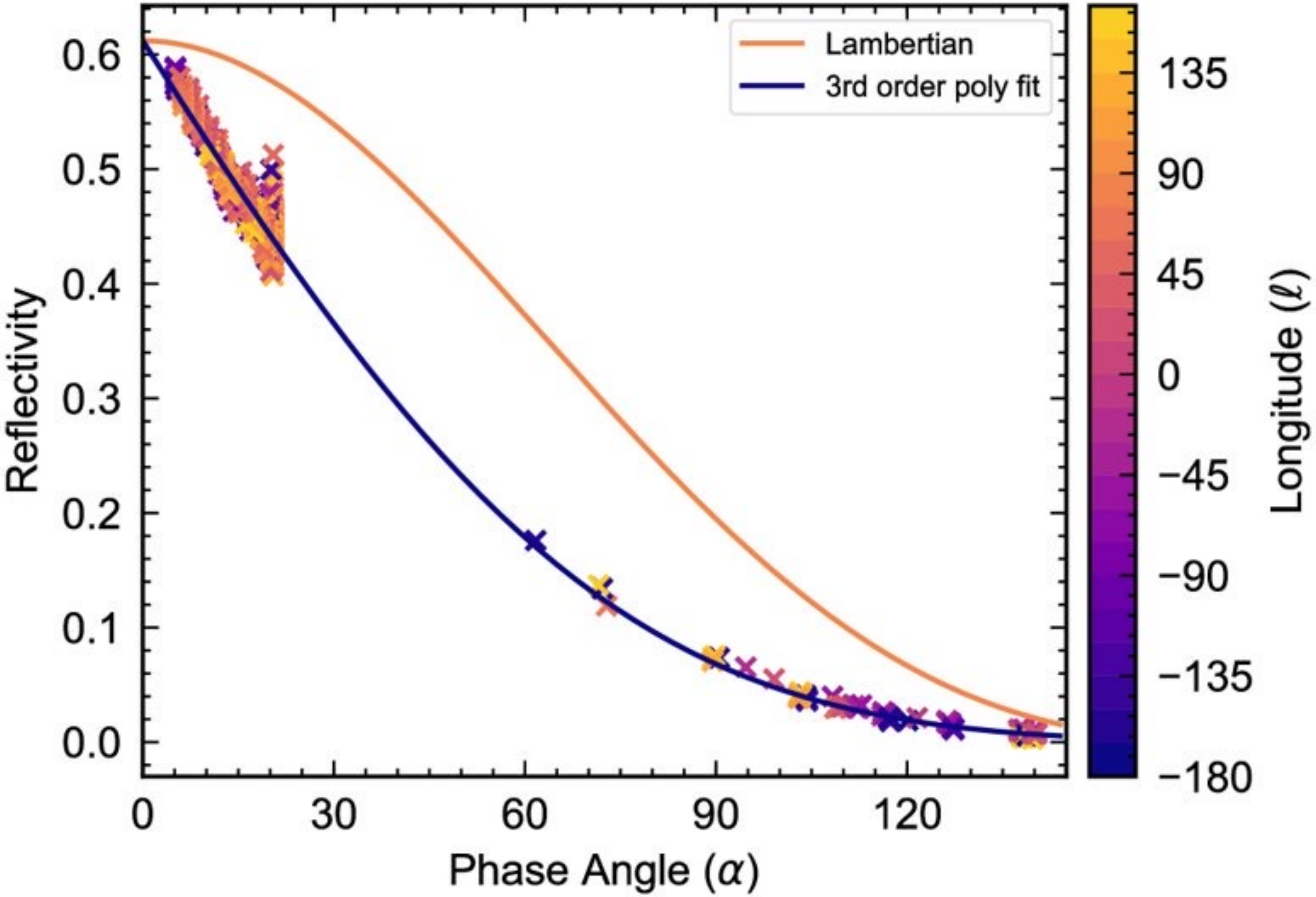


Phase Curve: A measure of reflectivity as a function of phase angle (star-planet-observer)

Planets have orbital and rotational motion!

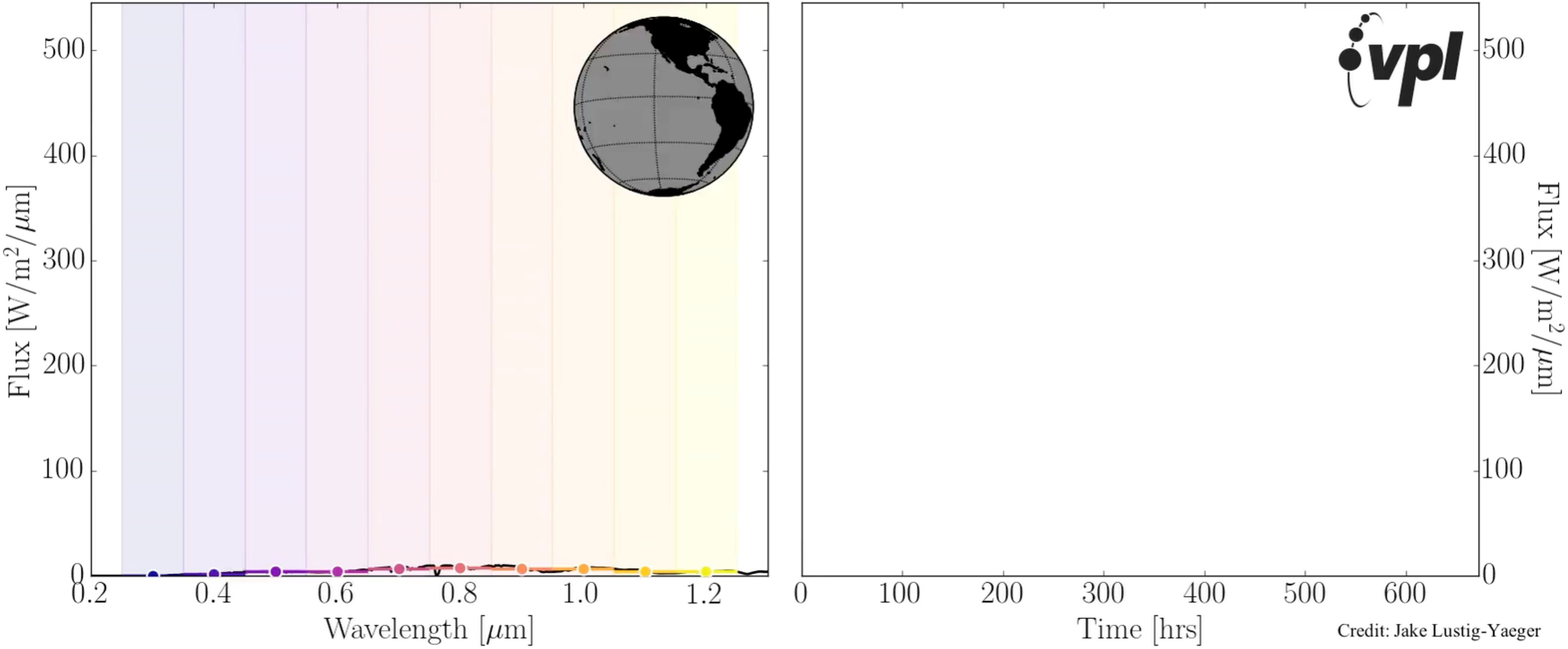




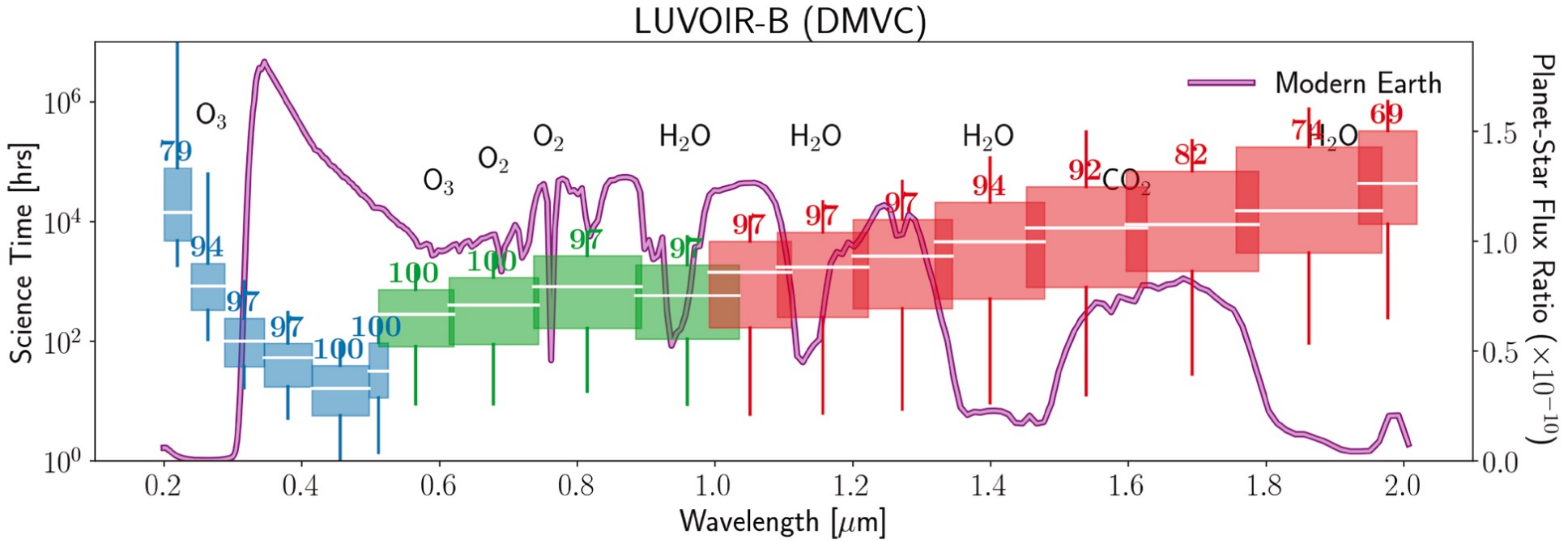


Mayorga et al. (2020) AJ

Io’s Variability with Rotation and Illumination as seen by Cassini/ISS



Simulations by E. Schwieterman using the VPL Earth Model (Robinson et al. 2011 AsBio)
Uses earth observing satellite data as atmospheric and cloud inputs, validated against EPOXI



Courtesy of J. Lustig Yaeger, LUVOIR Final Report

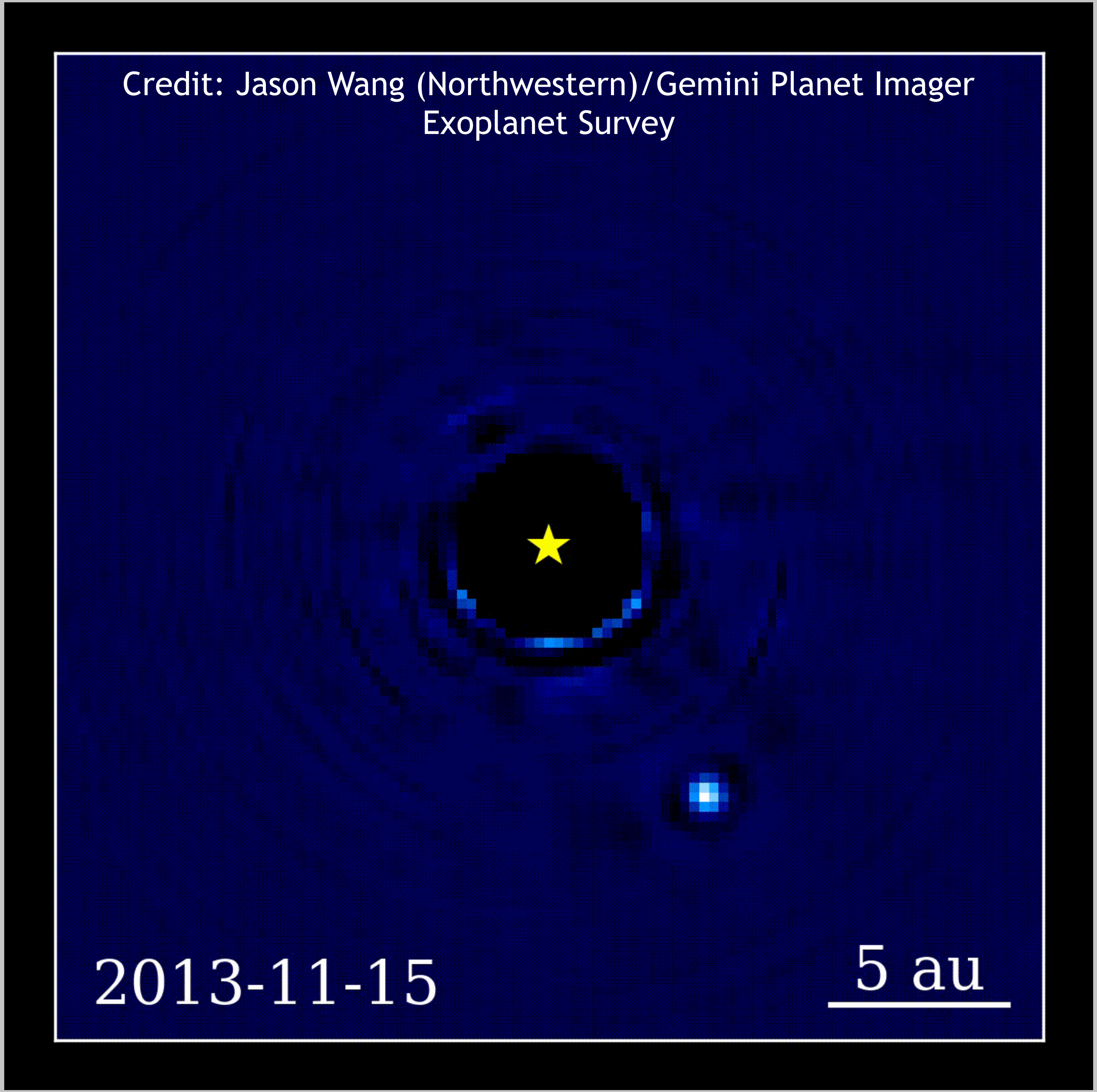

Credit: Jason Wang (Northwestern)/Gemini Planet Imager Exoplanet Survey
2013-11-15
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TABLE 3

PUBLISHED SPACECRAFT DATASETS FOR EARTH AS AN EXOPLANET

Spacecraft	Date[a]	Phase Angle(s)	Wavelength (μm)	Resolution[b]	Source(s)
Galileo	1990-12-10 1992-12-09 1992-12-16	35° 82° 89°	0.38–5.2	$\Delta\lambda = 0.01$–0.44 μm (vis) $\Delta\lambda = 0.025$ μm (NIR)	Sagan et al. (1993); Drossart et al. (1993)
MGS/TES	1996-11-23	n/a	6–50	— $\lambda/\Delta\lambda = 15$–$170$	Christensen & Pearl (1997)
EPOXI	2008-03-18 2008-05-28 2008-06-04 2009-03-27 2009-10-04	58° 75° 77° 87° 86°	0.37–4.54	— $\Delta\lambda \approx 0.1$ μm (vis) $\lambda/\Delta\lambda = 215$–$730$ (NIR)	Livengood et al. (2011); Cowan et al. (2011); Fujii et al. (2011); Robinson et al. (2011)
LCROSS	2009-08-01 2009-08-17 2009-09-18	23° 129° 75°	0.26–13.5	— $\lambda/\Delta\lambda = 300$–$800$ (vis) $\Delta\lambda = 0.3, 0.8$ μm (NIR) $\Delta\lambda = 4, 7.5$ μm (thermal)	Robinson et al. (2014)
DSCOVR	ongoing	4–12°	0.318–0.780	— $\Delta\lambda = 1$–3 nm	Biesecker et al. (2015); Yang et al. (2018)

[a]Based on UT at start of observations.

[b]Abbreviating visible range (∼0.4–1 μm) as "vis" and near-infrared range (∼1–5 μm) as "NIR."

Published spacecraft datasets for earth as an exoplanet labeled by northern hemisphere season, winter, spring, summer (Robinson & Reinhard 2020).

Mettler et al. 2023
3-15 microns

We need to make this table obsolete!

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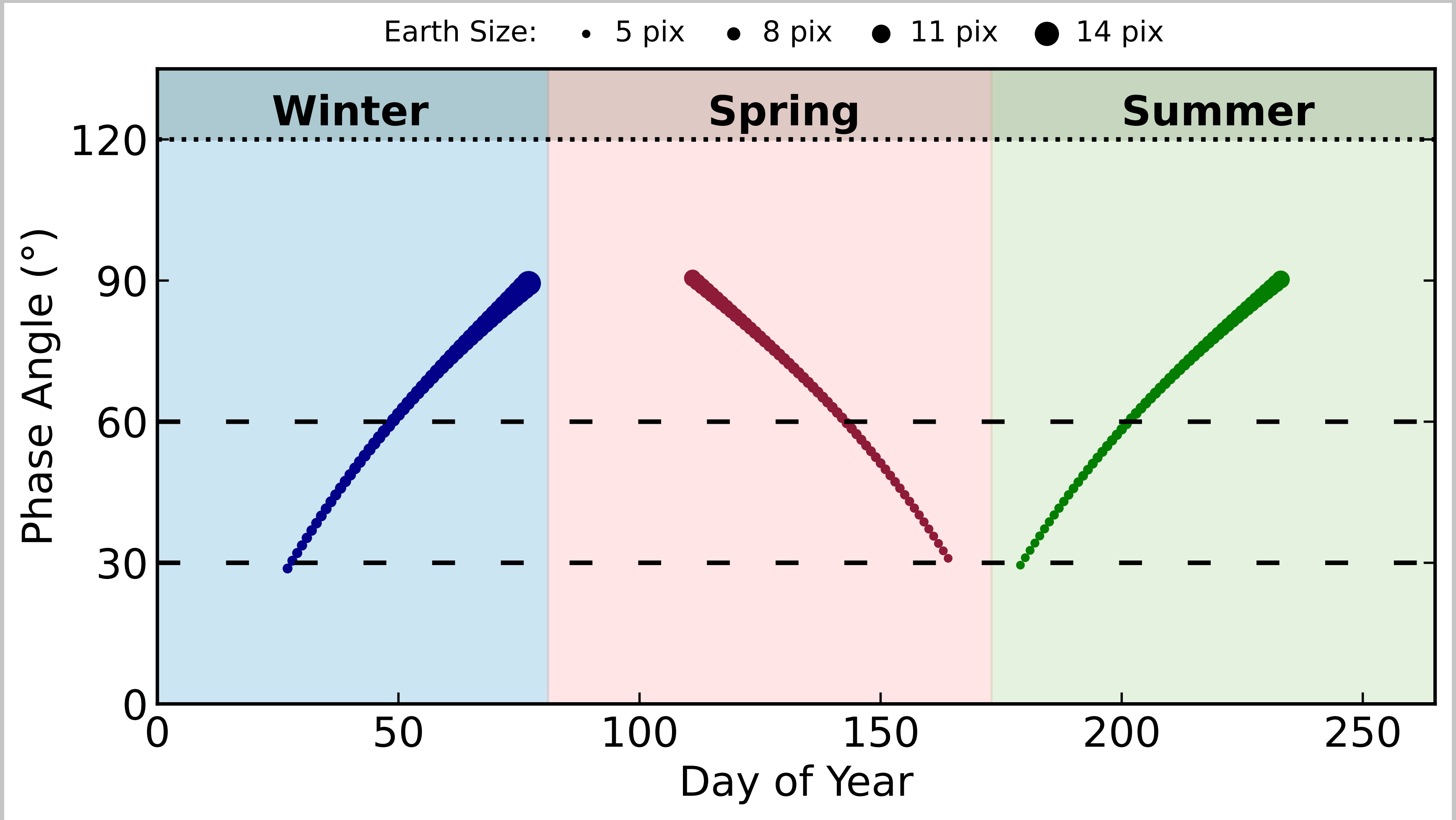
OSIRIS-APEX Proposed Observations



During the cruise to Apophis, three EGA flybys (2025:blue, 2027:green, and 2029:red) present opportunities to image Earth as an exoplanet analog and assess Earth's rotational and seasonal variability. The points are sized by the apparent pixel size of Earth in MapCam images.

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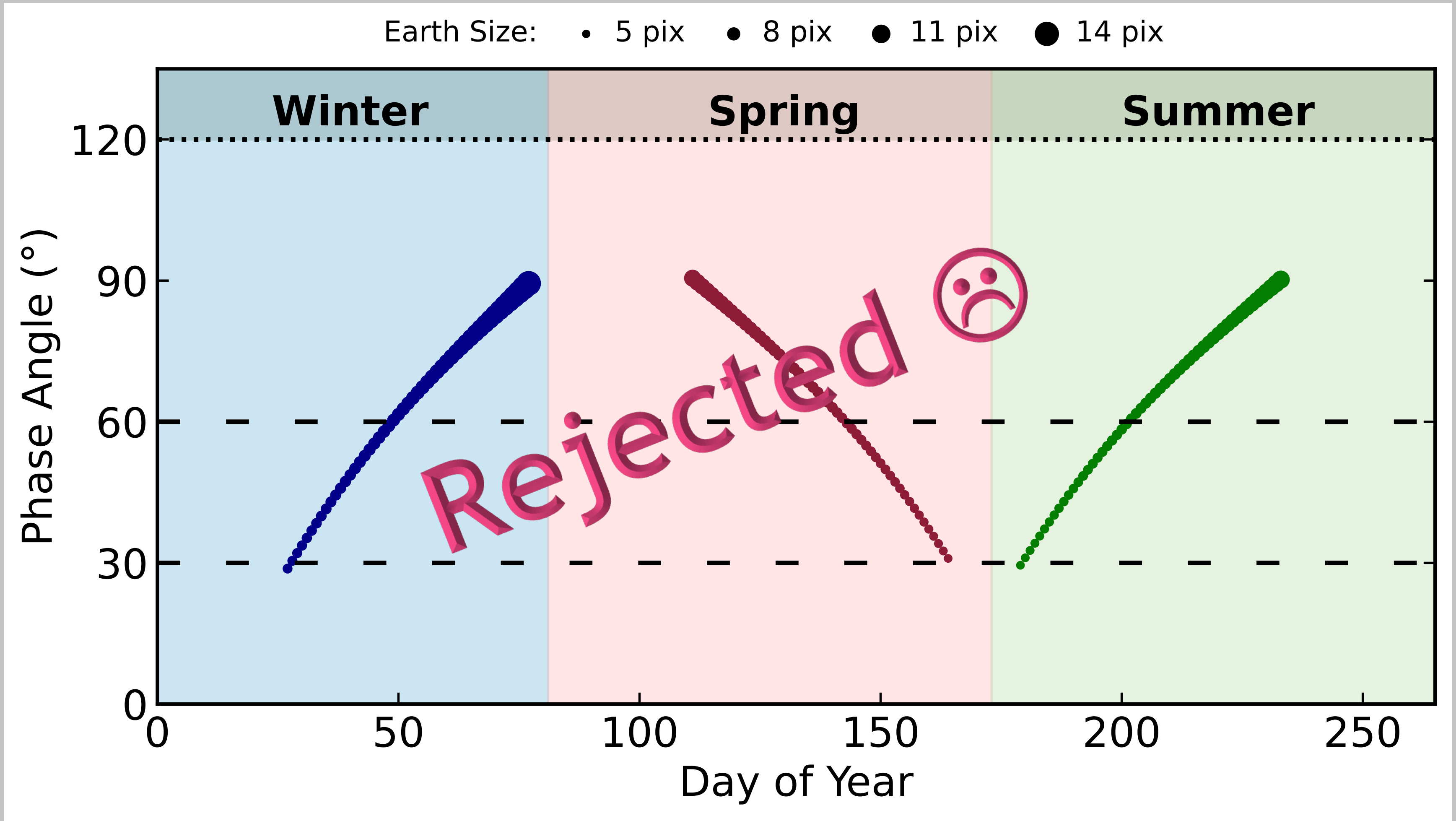

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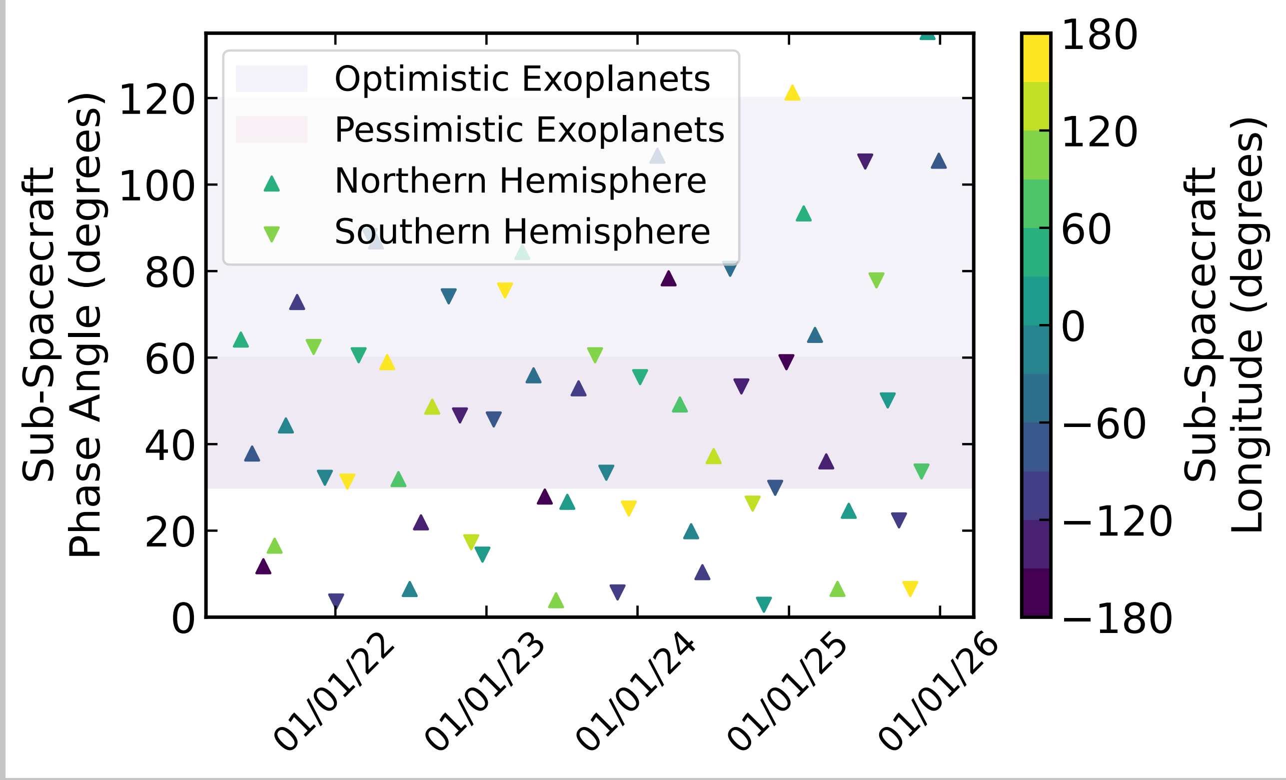
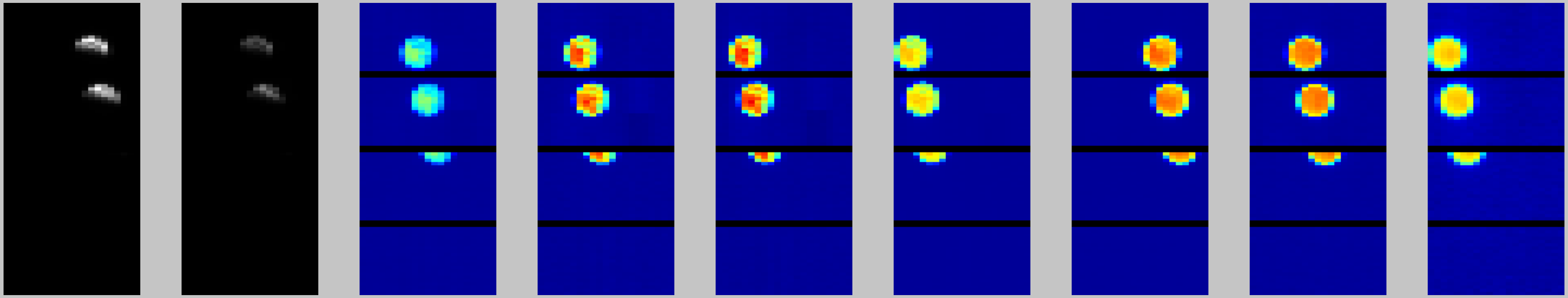
LRO/Diviner Earth Scans

- As part of extended mission, Earth scans in IR channels are being observed
- For use in studying Earth's atmosphere (retrieval testing, climate tracking) and for exoplanet use!



Phase angle ranges per Carrión-González et al. (2021)



Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6 Ch 7 Ch 8 Ch 9

Looking Forward

- Planets (and stars!) are 3D and dynamic, what is the magnitude of that variability?
- Given their changing faces, is stacking 100s of hours of spectra going to allow us to assess our chosen quantity?
- How can we connect our resolved observations of phenomena with their unresolved signals in exoplanet data?
- Systems will be randomly oriented in space, can we recognize our planets from their poles only?