INTERSTELLAR PROBE

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Earth as an Exoplanet: Capturing Multi-phase Spectra and Photometry

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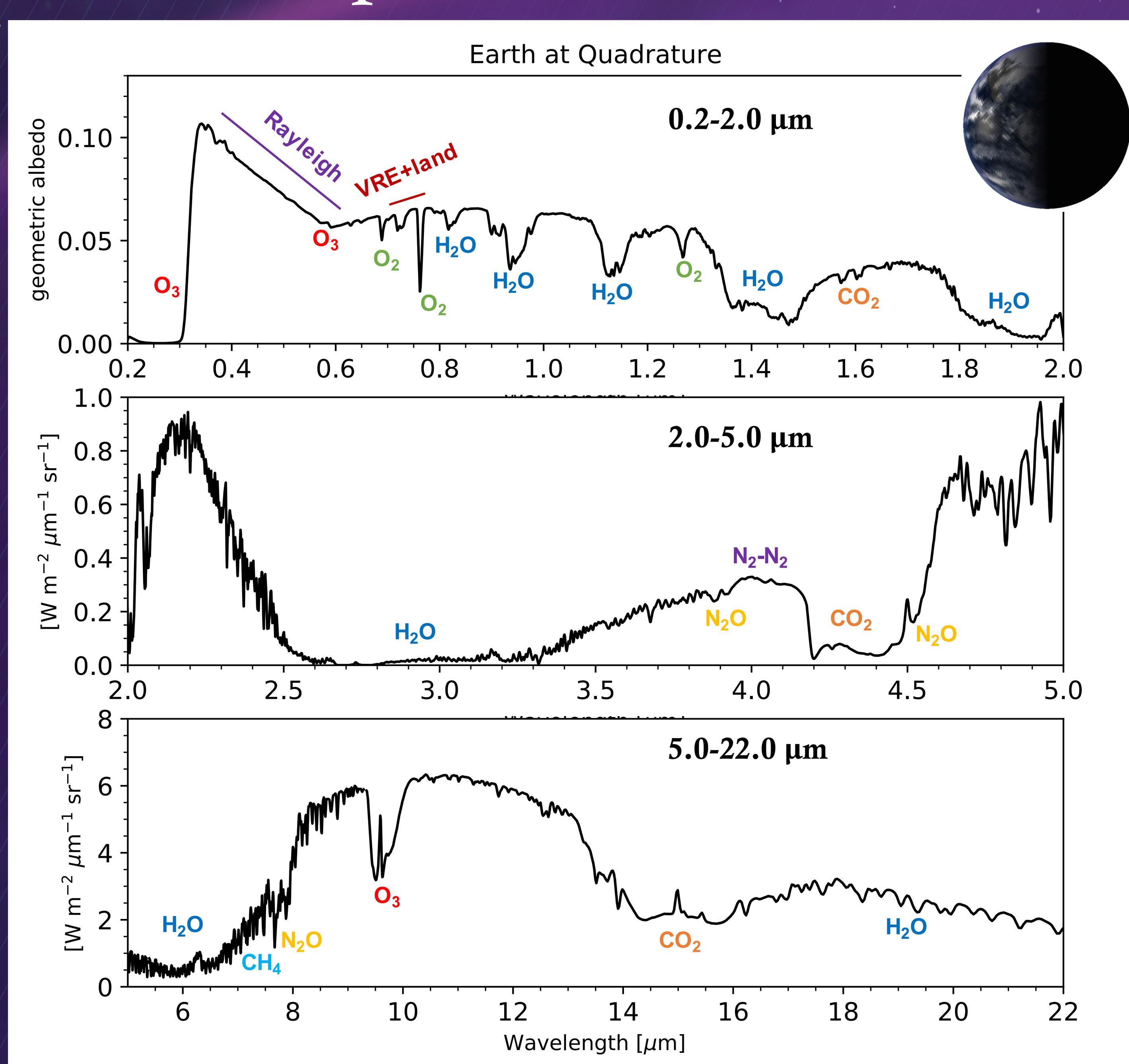
The Interstellar Probe could provide an unprecedented platform for lookback observations of the planets of our solar system, including Earth, simulating future direct-imaging observations of temperate and cool exoplanets. Planetary reflected light spectra and colors change with phase due to the varied scattering properties of gas molecules, cloud particles, and surfaces. While remote disk-integrated lookback observations of Earth and other worlds have been completed in the past (e.g., Sagan et al. 1993), they can be incomplete in viewing geometry and phase. This poster presents simulations of phase and rotationally dependent Earth spectra and photometry using the Virtual Planetary 3D Spectral Earth model. We identify critical habitability markers (CO_2, H_2O, glint, broadband colors) and biosignatures (O_2, O_3, vegetation red edge) that may be quantified by remote observations by the Interstellar Probe. Successful observations would allow astronomers to validate models with empirical data and enhance future interpretation of exoplanet photometry and spectra.

Earth Spectrum Summarized

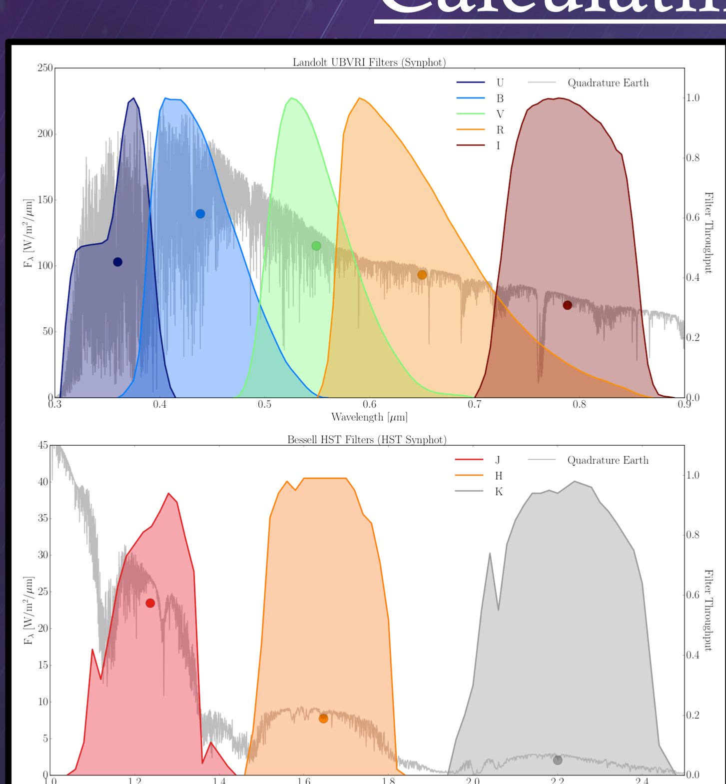


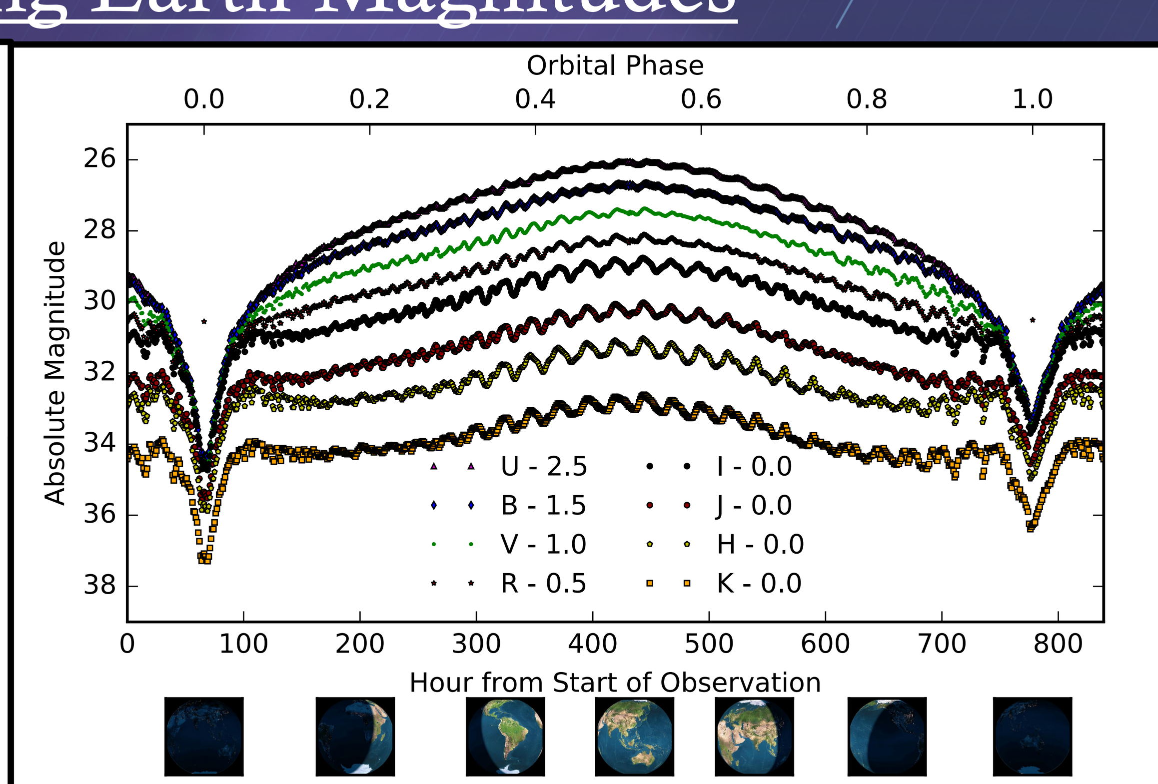
Habitability Signatures [µm]	
H_2O	0.65*, 0.72, 0.82, **0.94**, **1.1**, **1.38**, 1.**87**, **2.7**, **6.2**, > 20
CO_2	1.4*, **1.6**, 2.0, **4.3**, **15**
N_2	0.1-0.15, 2.1*, 4.2
Rayleigh	**0.35-0.6** (slope)
Glint	Most apparent > 0.7

Biosignatures [µm]	
O_2	**0.175-0.19**, 0.63*, 0.69, **0.76**, 1.06, **1.27**, 6.4*
O_3	**0.15-0.35**, 0.45-0.7, 4.7*, **9.6**
Vegetation	"Red edge" ~**0.7**
CH_4	0.89*, 1.0*, 1.15*, 1.4, 1.69, 2.2*, 3.3, 6.5*, **7.7**
N_2O	2.87*, 4.0, 4.5, **7.8**, 8.5*, 17*

*weak spectral feature at Earth abundance and/or overlap. **See Schwieterman+2018, Catling+2018

Calculating Earth Magnitudes





U-band Earth Magnitudes			
Distance	Crescent (18%)	Quadrature (50%)	Gibbous (75%)
1 AU	-0.62	-1.74	-2.42
10 AU	4.38	3.26	2.58
100 AU	9.38	8.26	7.58
1000 AU	14.38	13.26	12.58
10 pc (standard)	30.95	29.83	29.15

V-band Earth Magnitudes			
Distance	Crescent (18%)	Quadrature (50%)	Gibbous (75%)
1 AU	-1.15	-1.92	-2.61
10 AU	3.85	3.08	2.39
100 AU	8.85	8.08	7.39
1000 AU	13.85	13.08	12.39
10 pc (standard)	30.42	29.65	28.96

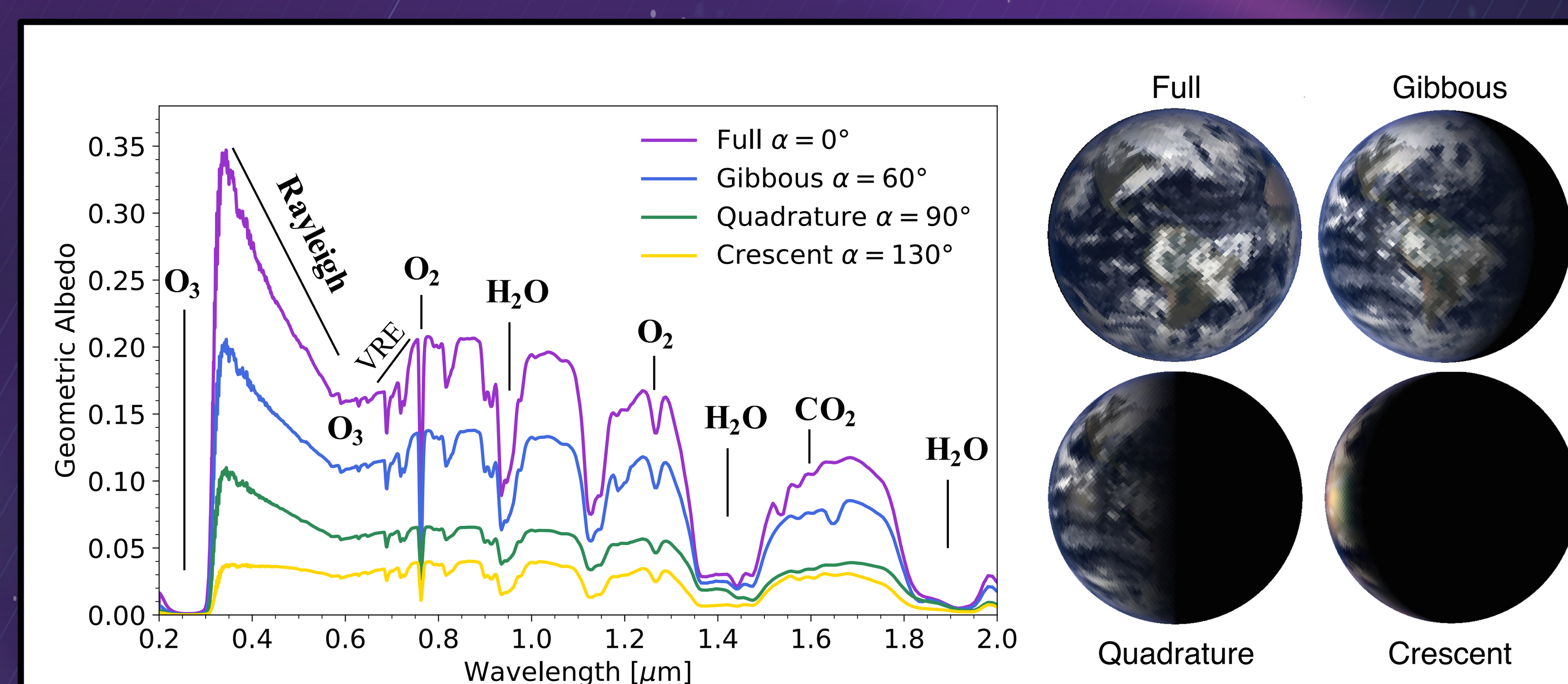
References

Catling, D. C., Krissansen-Totton, J., Kiang, N. Y., et al. 2018, *AsBio*, 18, 709–738
Glenar, D. A., Stubbs, T. J., Schwieterman, E. W., et al. 2019, *Icar*, 321, 841–856
Lustig-Yaeger, J., Meadows, V. S., Tovar Mendoza, G., et al. 2018, *AJ*, 156, 301
Robinson, T. D., Ennico, K., Meadows, V. S., et al. 2014, *ApJ*, 787, 171
Robinson, T. D., Meadows, V. S., Crisp, D., et al. 2011, *AsBio*, 11, 393–408
Sagan, C., Thompson, W. R., Carlson, R., et al. 1993, *Natur*, 365, 715–21
Schwieterman, E. et al. 2016, *AAS/DPS meeting #48, id.#122.15*
Schwieterman, E. W., Kiang, N. Y., Parenteau, M. N., et al. 2018, *AsBio*, 18, 663–708
Schwieterman, E. W., Robinson, T. D., Meadows, V. S., et al. 2015, *ApJ*, 810, 57

$$A_g(\lambda) = \frac{F_p(\lambda, \alpha = 0^\circ)}{F_{\odot,L}(\lambda)}.$$

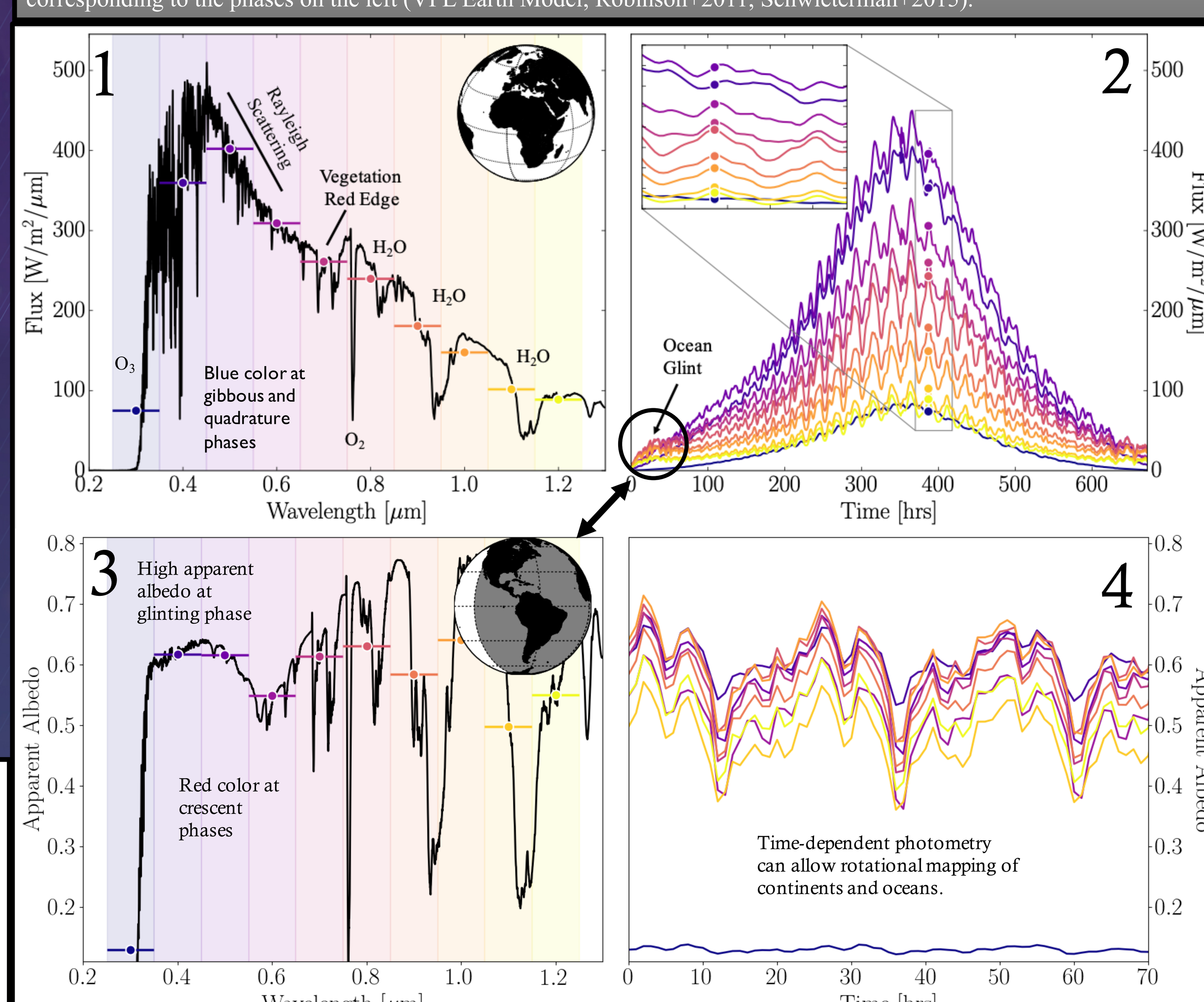
Multi-phase Spectra and Photometry: Can We See Ocean Glint?

Spectra as a function of Phase

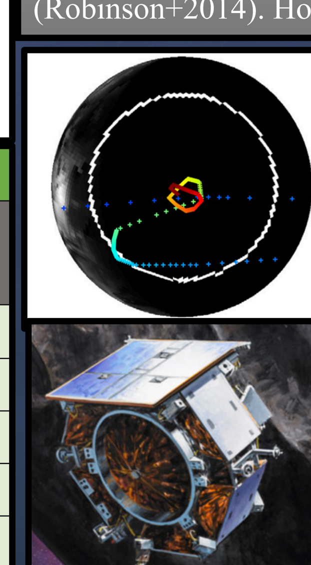


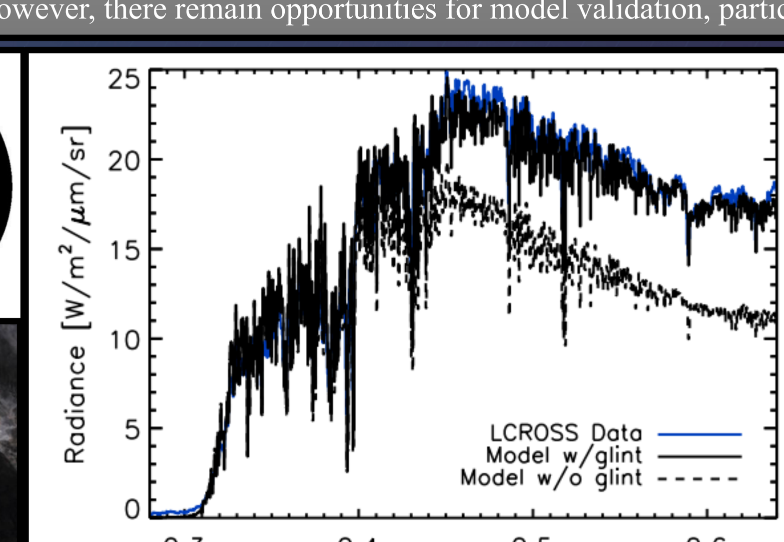
Left: Simulated UV-NIR (0.2-2.0 µm) Earth geometric spectral albedo as a function of phase. Geometric albedo is the brightness of the planet divided by that of a perfect Lambertian reflector at full phase. The planet is predicted to be brighter and bluer at fuller phases while it is dimmer and redder at crescent phase. **Right:** Simulated true color spectral datacubes corresponding to the phases on the left (VPL Earth Model; Robinson+2011, Schwieterman+2015).

Spectral Irradiance at the Moon



1) Full-phase spectral radiance as seen at the Moon; **2**) multi-phase photometric irradiance (100 nm bins); **3**) apparent albedo at crescent phase: apparent albedo is the brightness of the object divided by the brightness expected from a perfect Lambertian reflector at the same phase; **4**) 3-day photometric variation at crescent phase. We have calculated a comprehensive UV-FIR Earth spectral database that predicts Earth's spectrum with 1-hr cadence as seen from the Moon and with other geometries (Schwieterman+2016). These calculations have been used to inform the detectability of ocean glint on terrestrial exoplanets using multi-phase rotational mapping and a next-generation space telescope such as LUVOIR (Lustig-Yaeger+2018). Glint detection was validated by partial disk observations by LCROSS (Robinson+2014). However, there remain opportunities for model validation, particularly at critical crescent phase angles.





Left: Partial-disk validation of glint detection by comparing predications by the 3D Spectral Earth model to Earthlook observations by the LCROSS UV-Vis spectrometer (Robinson+2014).

$$\frac{F_p(\lambda, \alpha)}{F_\odot(\lambda)} = A_g(\lambda)\left(\frac{R_p}{d}\right)^2 \Phi(\lambda, \alpha).$$

Measure this

Derive this

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