**THE SCIENTIFIC CASE FOR AN EARTH TRANSIT OBSERVER.** N. R. Izenberg[1], K. B. Stevenson[1], J. Lustig-Yaeger[1], K. E. Mandt[1], E. M. May, L. C. Mayorga[1], K. S. Sotzen[1,2], J. Gonzalez-Quiles[2], B. Kilpatrick[3], E. Martin[4], C. Harman[5], and R. Miller[1], [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD, [2]John Hopkins University, Baltimore, MD, [3]Space Telescope Science Institute, Baltimore, MD, [4]University of California, Santa Cruz, Santa Cruz, CA, [5]NASA Ames Research Center, Mountain View, CA. (noam.izenberg@jhuapl.edu)

**Introduction:** Is the planet called 'Earth' habitable? Is it inhabited? We know the answers to these questions because we live on Earth, but what if we didn't? If Earth were an exoplanet, could we tell whether or not it's habitable? These are the questions that an Earth transit observation mission would seek to answer, by sending a near-ultraviolet to near-infrared spectrometer past the Earth-Sun L2 point, to observe transits of the Earth across the Sun as if it were an exoplanet. The transit technique used by such an investigation would be the same that will be used by the James Webb Space Telescope (JWST) to study some of the thousands of known exoplanets transiting their host stars.

**Searching for New Earths:** Upcoming NASA astrophysics missions such as JWST will search for signs of life on planets transiting nearby stars. Doing so will require stacking dozens of transmission spectra to build up sufficient signal to noise while simultaneously accounting for challenging systematic effects such as variability and refraction [1-3]. An Earth transit observing mission concept would address long-standing concerns about the reliability of co-adding planet spectra from multiple transits in the face of relatively large astrophysical systematics via a proof-of-concept targeting the only planet on which we *know* life exists.

The key science objective of an Earth transit observation mission would be to determine if the transit technique is an effective means to detect signs of life on Earth-like planets. The goal of such a mission would be to observe multiple Earth transits, coupled with independent knowledge of contemporaneous solar activity and terrestrial conditions, and to extract time varying spectra of the Earth's atmosphere, and look to identify key atmospheric species that would indicate that Earth is habitable - or inhabited.

This methodology test would be a critical first step for the in-depth atmospheric characterization of potentially habitable worlds.

**Observing Earth as a Transiting Exoplanet:** A transit occurs when a planet passes in front of its host star, thus blocking part of the star's light as seen by the observer. When seen as a point source, the fractional dip in light is determined by the planet-to-star area ratio; however, when the star and planet are spatially resolved, the transit depth is determined by their angular radii. The total transit duration, $t_{14}$, begins at time $t_1$ and ends at $t_4$ (Fig. 1), while the full transit duration spans $t_2$-$t_3$. We obtain a transmission spectrum by measuring the planet's apparent change in size as a function of wavelength. Light from the host star passes through the planet's atmospheric annulus where it interacts with atoms and molecules. The annulus becomes opaque (and the planet appears larger) at wavelengths where these chemical species strongly absorb in the planetary atmosphere. Transmission spectroscopy data are sensitive to relative chemical abundances and the presence of cloud or haze particles within the atmosphere.

**Science Goals:** The science goals for an Earth transit observation mission would be to:

1. Detect signs of life in Earth's atmosphere by using the same methodology intended for exoplanets to measure the abundance of habitability indicators (e.g., $H_2O$ and $CO_2$) and biosignature pairs (e.g., $O_2 + CH_4$ and $O_3 + CH_4$) (Fig. 2 and [4]);
2. Constrain the magnitude and impact of stellar and planet variability on measured transmission spectra; and
3. Assess the feasibility of stacking multiple transmission spectra when deriving atmospheric abundances of potentially habitable exoplanets transiting nearby M-dwarf stars.

**Approach:** In order to accomplish the science goals, we need a near-UV through near-IR spectrometer (0.25–2.5 μm) carried by a small spacecraft (from a SmallSat to a larger CubeSat) to beyond the Earth-Sun L2 point. From there, the spacecraft would use propulsion (solar electric or conventional) to travel along the Sun-Earth line (out to a maximum distance of 1.05 AU) in a helix or zigzag trajectory that induces multiple transits of the Earth across the Sun, each lasting up to 40 hours in total duration. The single, dedicated instrument would collect sunlight in disk-integrated fashion to remove spatial information and relax pointing stability requirements.

Transits in this region would generate transmission spectrum feature sizes that, at a distance of 0.02 AU from the Earth, are ~2500 times larger than observing the system as a point source. The predicted feature sizes are comparable to those of many hot Jupiter exoplanets and, thus, feasible using current detector technology. The measured molecular abundances, refraction levels, and effective number of transits will inform, and provide direct comparisons to, the potentially-habitable M-dwarf systems soon to be observed with JWST [5].

**References:** [1] Rackham *et al.*, 2018, *ApJ,* 853(2), 122; [2] Rackham *et al.*, 2019, *AJ,* 157(3), 96; [3] Wakeford *et al.*, 2019, *AJ* 157(1), 11; [4] Robinson *et al.*, *Astrobiology* 11, 393–408; [5] Lustig-Yaeger *et al.*, 2019, AJ, 158(1), 27.

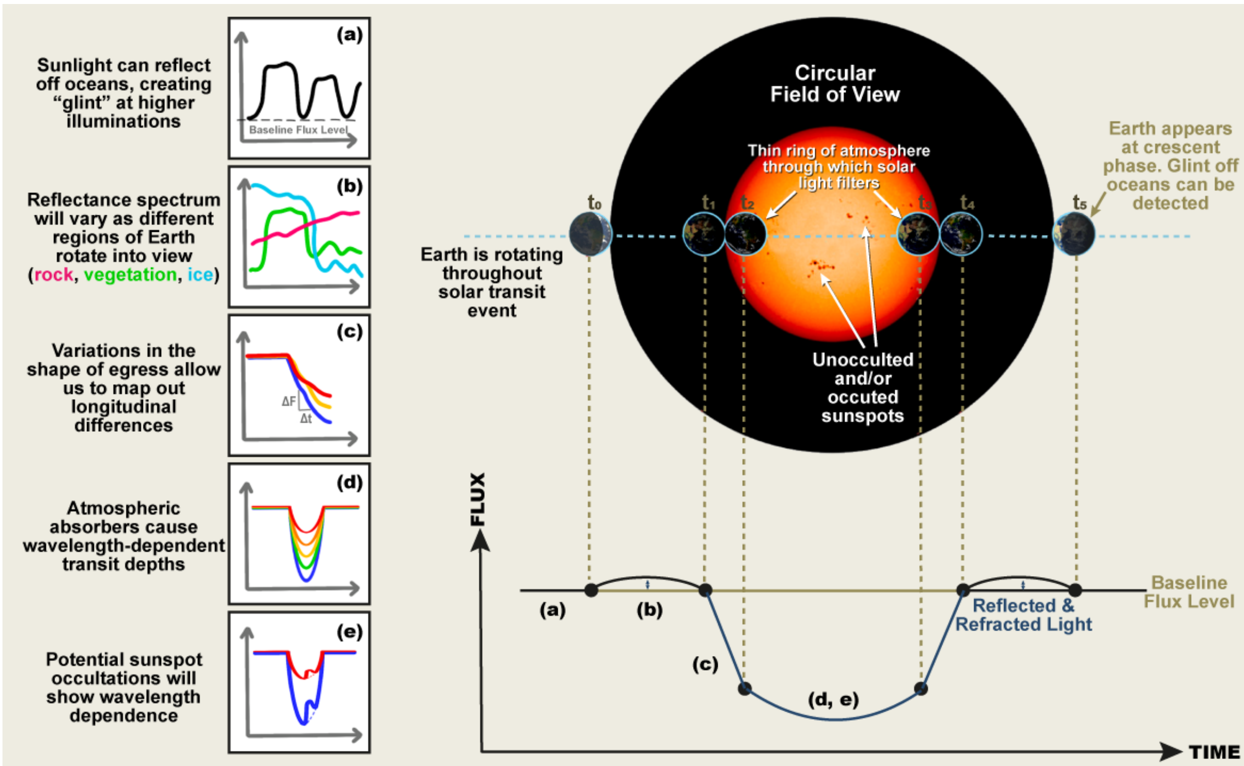


*Figure 1. A schematic representation of a single Earth transit across the Sun not far beyond L2. We highlight several features that will be seen in these observations, including (a) ocean glint, which occurs when looking back at Earth outside of transit events; (b) wavelength and temporal variability of reflected and refracted light; (c) ingress/egress as different longitudes and clouds rotate into view; (d) wavelength variability in transit depth due to absorption through and scattering by atmospheric constituents (Fig. 2); and (e) stellar variability due to occulted and unocculted spots and faculae that can impact the measured transmission spectrum. For all subpanels except (b), axes are flux vs. time and colors represent different wavelengths; for (b) the axes are flux vs. wavelength and the colors represent different contributions.*

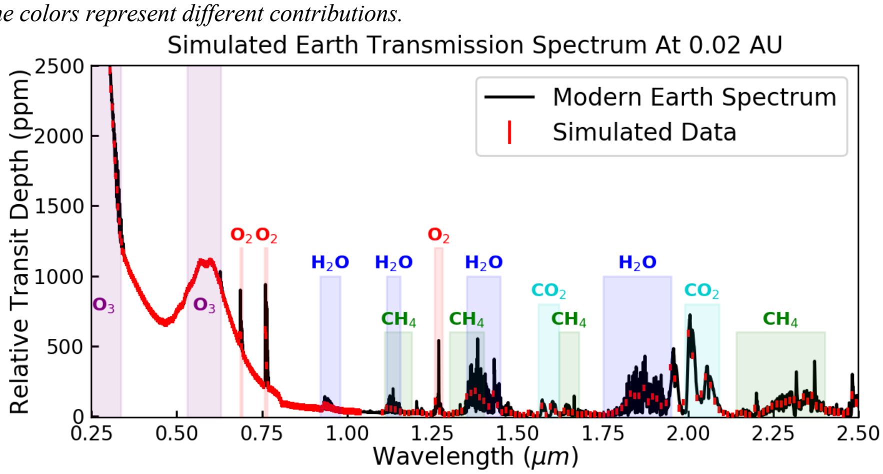


*Figure 2. Model transmission spectrum with simulated Earth-Sun transit data at a distance of 0.02 AU from the Earth (scaled from [4]). The height of the red error bars from a 5-min integration are barely discernible in this figure. A transit observer needs to be sensitive to standard habitability indicators ($H_2O$, $CO_2$) and biosignature pairs ($O_2$+$CH_4$, $O_3$+$CH_4$) that JWST will search for in M-dwarf planets.*