MAPPING SURFACES AND CLOUDS ON TERRESTRIAL EXOPLANETS OBSERVED WITH NEXT-GENERATION CORONAGRAPH-EQUIPPED TELESCOPES. J. Lustig-Yaeger[1,2,3], G. Tovar[1,2], Y. Fujii[4], E. W. Schwieterman[2,5], and V. S. Meadows[1,2,3], [1]Univ. of Washington, Department of Astronomy (jlustigy@uw.edu), [2]NAI Virtual Planetary Laboratory, [3]Univ. of Washington, Astrobiology Program, [4]NASA Goddard Institute for Space Studies, [5]University of California, Riverside.

Introduction: A single exposure of a directly imaged habitable exoplanet will contain no spatial information, despite potentially containing reflected light from continents, oceans, and clouds. However, as it rotates on its axis we may observe subtle modulations in the time-series photometry as different surface features rotate in and out of view. Fitting these lightcurves allows us to infer the exoplanet's longitudinal surface map. In this presentation, we discuss the prospects and limitations of using rotational variability to map terrestrial exoplanets using NASA's next-generation telescope concepts, and the insights into exoplanet habitablility that can be gained from such observations.

Methods: We forward model time-series, multi-band photometry of an Earth-analog exoplanet under various observational assumptions, and then invert the problem to solve for the surface covering fractions and geometric albedo spectra of dominant surface types. The models used are introduced below.

VPL Earth Model. Earth is our only example of a habitable world and is a critical reference point for potentially habitable exoplanets. Although disk-averaged views of Earth that mimic exoplanet data can be obtained by interplanetary spacecrafts, these datasets are often restricted in wavelength range, and are limited to Earth phase angles and viewing geometries that the spacecraft can feasibly access. We can overcome these observational limitations using a sophisticated UV-MIR spectral model of Earth that has been validated against spacecraft observations in wavelength-dependent brightness and phase[1,2]. This model is used to create multi-wavelength, time-dependent, disk-averaged observations of Earth. Figure 1 shows the geometric albedo of Earth as a function of time, generated using the VPL Earth Model.

Coronagraph Noise Model. Since stars outshine planets so immensely, directly imaging Earth-like exoplanets demands overcoming a contrast of ~10^{-10}. This type of observations requires a coronagraph or starshade to block the star's light and reveal the underlying exoplanetary system. We use a coronagraph noise model[3] – which accounts for telescope, instrument, and astrophysical noise – to simulate multi-band lightcurves and assess the mapping capabilities of and technical requirements for next-generation coronagraphic telescopes, such as the Large UV/Optical/IR (LUVOIR) Surveyor and Habitable Exoplanet Imaging Mission (HabEx).

Mapping. Building off previous studies[4,5,6], we use Principle Component Analysis (PCA) to identify the number of unique surfaces contained in our synthetic directly-imaged exoplanet lightcurves. We then employ a new rotation unmixing model to simultaneously extract the longitudinal covering fraction and geometric albedo spectrum for each surface.

Results: We identify optimal wavelength bands to characterize surface features on Earth-like exoplanets. We find the integration time needed for mapping Earth-like exoplanets with next-generation telescopes is in the tens to hundreds of hours, which is comparable to the integration time needed to acquire spectra for the same planets. In many simulated observations we are able to extract the Vegetation Red Edge (VRE) signal, but identifying its biological origin relies on our prior knowledge of the planet. For the relatively short exposures and simultaneous multi-band photometry explored here, decreasing detector readnoise and increasing the coronagraphic null bandwidth will expand the potential of future terrestrial exoplanet mapping.

References: [1] Robinson T. et al. (2011) *Astrobiology*, *11*, 5, 393-408. [2] Robinson T. et al. (2014) *Astrobiology*, *787*, 2, 12-24. [3] Robinson T. et al. (2016) *PASP*, *128*, 960, 025003. [4] Cowan N. et al. (2009) *ApJ*, *700*, 2, 915-923. [5] Fujii Y. et al. (2010), *ApJ*, *715*, 2, 866-880. [6] Cowan N. and Strait T. (2013), *ApJL*, *765*, 1, L17.

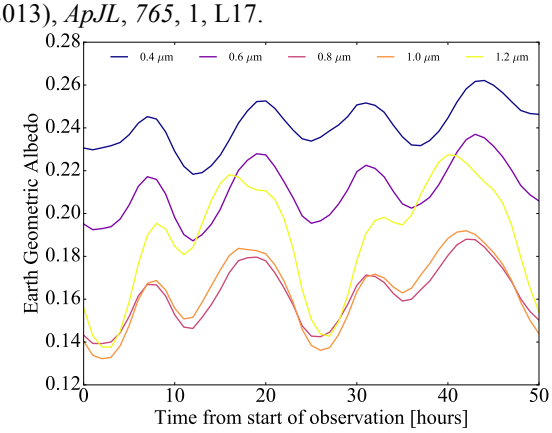

Figure 1: Evolution of Earth's geometric albedo over two days, across five broad spectral bands in the optical and NIR. The sinusoidal modulations track the bright continents and dark oceans rotating in and out of view. The amplitude of the albedo variations at different wavelengths contains information about the type of surface in view.