DETECTING OCEANS ON EXOPLANETS USING PHASE-DEPENDENT MAPPING WITH NEXT-GENERATION CORONAGRAPH-EQUIPPED TELESCOPES. J. Lustig-Yaeger[1,2,3], G. Tovar[1,2,3], E. W. Schwieterman[2,4], Y. Fujii[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]University of California, Riverside, [5]Earth-Life Science Institute, Tokyo Institute of Technology.

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 one 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 habitability that can be gained from such observations. In particular, habitability may be assessed via detection of specular reflection from a liquid ocean, which is enhanced when the planet is near crescent phase [1]. However, scattering from aerosols and clouds may display similar phase-dependent properties. Here we describe a novel combination of observations that use time-resolved, multi-band photometry as a function of phase to identify the phase-dependent behavior of the dominant reflecting surfaces, and thereby increase the robustness of ocean detection.

Methods: We model time-series, multi-band photometry of a realistic Earth-analog exoplanet [1,2,3] 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 spacecraft, 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 [2,3]. This model is used to create multi-wavelength, time-dependent, disk-averaged observations of Earth.

Coronagraph Noise Model. Stars significantly outshine planets, often by a factor of $\sim 10^{10}$, and directly imaging Earth-like exoplanets requires suppressing the star's light to overcome this contrast. Star-light suppression could be obtained by using a coronagraph or starshade to block the star's light and reveal the underlying exoplanetary system. We use a coronagraph noise model [4] – which accounts for telescope, instrument, and astrophysical noise – to simulate multi-band lightcurves of an Earth-like planet, 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 on previous terrestrial mapping studies [5,6,7], 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. Despite this solution containing fundamental degeneracies, important inferences into relative surface colors and their longitudinal distributions can still be determined [8].

Results: Using our Earth, telescope, and mapping models we extract the longitudinal albedo maps for the dominant surfaces on Earth as if it were an exoplanet, observed at quadrature and crescent phases. At quadrature, the dominant surface is dark blue, whereas at crescent, the same longitudinal map (to within measurement uncertainties), shows that the derived surface albedo is now ~4x more reflective. Using the extracted map as the key, we demonstrate that the same surface that appears dark blue at quadrature phase is a non-Lambertian, specular reflecting surface at crescent. This is a strong suggestion that liquid surface water is present on the exoplanet of interest.

Conclusion: Phase-dependent longitudinal mapping could be used with next generation direct-imaging telescopes to infer the surface composition of Earth-sized exoplanets, including the detection of liquid surface water.

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