CONSTRAINING HABITABILITY THROUGH REFLECTED LIGHT OBSERVATIONS OF TERRETRIAL PLANETS. Y. K. Feng[1], T. D. Robinson[1], and J. J. Fortney[1], [1]Department of Astronomy and Astrophysics, University of California, Santa Cruz, 1156 High St., Santa Cruz, CA, 95064, USA; kat.feng@ucsc.edu

Introduction: Characterizing exoplanets is key to unlocking questions surrounding planet formation and evolution, and understanding whether processes taking place on Solar System worlds are common. Current methods rely on transits and moderate contrast direct imaging, well-suited for short-period planets and young, self-luminous giant planets, respectively. In spite of the technological challenges involved, the characterization of habitable Earth-like planets may soon be within reach. Results from NASA's *Kepler* mission [1] estimate that one in ten Sun-like stars hosts a terrestrial planet in a one-year orbit [2]. Such an orbit places a planet within the Habitable Zone of its Sun-like host, so that liquid water might be sustained on the planet's surface. However, given the geometric requirements for a transit to occur, direct imaging is the preferred method for studying Earth-like exoplanets.

The coming decades holds enormous potential for the direct imaging of exoplanets, fueled by NASA's upcoming *Wide-Field InfraRed Survey Telescope* (*WFIRST*) mission and the Habitable Exoplanet Imaging (HabEx) and the Large UltraViolet-Optical-InfraRed (LUVOIR) mission concepts. The latter, especially, aim to achieve the high contrasts (~10^{-10}) needed to observe Earth-like planets.

Here, we perform the first systematic exploration of the information content in reflected light data from terrestrial planets around Sun-like stars. We use a Bayesian retrieval framework [3,4] to examine the feasibility of detecting key atmospheric species when observing an Earth-like planet with a future high-contrast instrument (e.g., *WFIRST* with a starshade).

A retrieval, or inverse technique, is a powerful data driven way to fully characterize uncertainty distributions for quantities used in a parameterized forward model. In our forward model, we utilize a well-tested albedo code [5–8] to simulate the reflected light spectrum of an Earth-sized planet around a Sun-like star (see figure). The species of interest in our model atmosphere include water vapor, ozone, and oxygen. We incorporate Rayleigh scattering due to molecular nitrogen, a wavelength-independent surface albedo, and pressure-dependent molecular opacities.

We simulate data for wavelength resolutions (R) of 50 and 70. For each resolution, we examine the retrieval performance at signal-to-noise ratios (SNR) of 5, 10, and 20, using a published high contrast noise model [9]. Having multiple sets of data allows us to consider the trade-offs between R and SNR combinations. We also discuss future work and improvements, including extensions to super-Earths.

Results: We find that for both R = 50 and R = 70, we are able to detect either a Rayleigh scattering slope or a molecular species. At R = 50, a SNR of 20 is necessary for water vapor, ozone, and oxygen to be measured simultaneously, while at R = 70, only a SNR of 10 is needed. We also find that cloud parameterizations are critical to making accurate inferences.

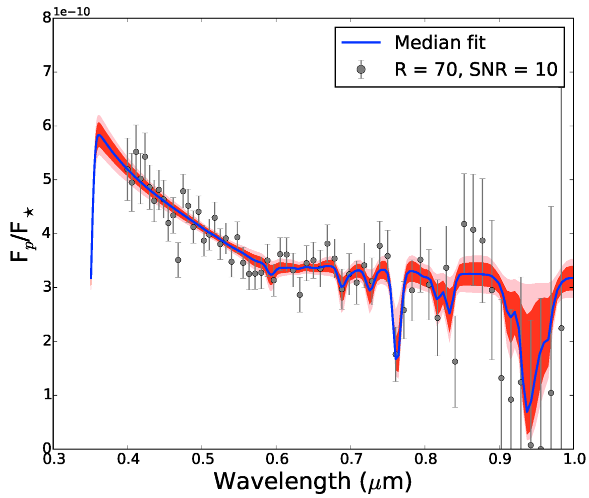

Figure: Planet-to-star flux ratios vs. wavelength in microns. Data points and error bars represent simulated observations at a wavelength resolution of 70 and SNR of 10. Overplotted are the median fit (blue solid line), and the 1-sigma (red) and 2-sigma (pink) spread in fits from corresponding retrievals.

Conclusions: We have created the first retrieval framework to interpret reflected light data from Earth-like planets to prepare for the era of space-based high contrast imaging. This tool demonstrates the capabilities of detecting molecules such as water and ozone in a terrestrial atmosphere and could be utilized to understand the science return of a mission concept given a proposed architecture, thus aiding the planning of upcoming missions in a concrete statistical manner.

References: [1] Borucki W. J. et al. (2010) *Science, 327,* 977. [2] Burke C. J. et al. (2015) *Astrophys J, 809,* 1. [3] Line M. R. et al. (2013) *Astrophys J, 775,* 2. [4] Buchner J. et al. (2014) *Astron Astrophys, 564,* A125. [5] McKay C. P. et al. (1989) *Icarus, 80,* 23. [6] Marley M. S. et al. (1999) *Astrophy J, 513,* 879. [7] Cahoy K. L. et al. (2010) *Astrophy J, 724,* 189. [8] Lupu R. E. et al. (2016) *Astrophys J, 152,* 217. [9] Robinson T. D. et al. (2016) *PASP, 128,* 960.