CHARACTERIZING EARTH ANALOGS IN REFLECTED LIGHT: ATMOSPHERIC RETRIEVAL STUDIES FOR FUTURE SPACE TELESCOPES. 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 technological challenges, the characterization of habitable Earth-like planets may soon be within reach. Results from NASA's *Kepler* mission suggest that one in ten Sun-like stars hosts a terrestrial planet in a one-year orbit [1]. However, given the geometric requirements for a transit to occur, direct imaging is the preferred method to study Earth-like exoplanets.

The coming decades hold 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 ($\sim 10^{-10}$) 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 [2,3] 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 [4–7] to simulate the reflected light spectrum of an Earth-sized planet around a Sun-like star. 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 include one parameterized water cloud layer and fractional cloudiness. We also retrieve for planet radius and surface gravity.

We simulate data for wavelength resolutions (R) of 70 and 140. For each resolution, we examine the retrieval performance at signal-to-noise ratios (SNR) of 5, 10, 15, and 20, using a published high contrast noise model [8]. We also examine the results for data sets similar to *WFIRST* observations, which utilize photometry in the Rayleigh-scattering regime. We discuss future work and improvements, including extensions to super-Earths.

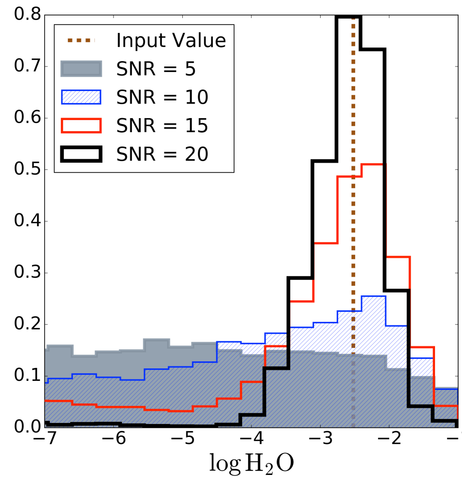

Figure: The posterior distributions of water as retrieved from simulated data sets with wavelength resolution of 70 with increasing SNR.

Results: Having multiple sets of data allows us to consider the trade-offs between R and SNR combinations. The figure above demonstrates the improvement in constraint of the water vapor abundance for a given R as SNR increases. We find that at R = 70, a SNR of 15 is necessary for water vapor, ozone, and oxygen to be measured simultaneously, while at R = 140, a SNR of 10 is needed.

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 capability to constrain molecular abundances for 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.

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