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Observations of terrestrial exoplanet environments remain an important frontier in comparative planetary science. Studies of habitable zone (HZ) terrestrial planets will set our own Earth in a broader context, and help reveal the diversity of processes that shape worlds like our own. Complementing these observations, studies of high insolation terrestrial exoplanets such as GJ1132b [1] and the inner TRAPPIST-1 planets [2,3,4] can provide insights into extremes of terrestrial planet evolution—and may reveal planetary processes that could mimic signs of life. In the next 5 years, observations of Earth-sized planets orbiting M dwarfs will be attempted with HST, Spitzer, JWST and ground-based telescopes. Thermal phase curves with JWST could be used to search for the presence of an atmosphere, and molecules such as CO_2 and O_3 [5,6]. While transmission spectroscopy of terrestrial planet atmospheres with JWST will be extremely challenging, it provides our first chance to characterize these atmospheres with sufficient precision to search for life. However, atmospheric refraction, clouds and hazes may limit JWST's ability to sample the deep atmosphere of habitable zone terrestrial planets [7,8], reducing the detectability of water vapor in the lower atmosphere, and confining biosignature searches to gases that are abundant in the upper atmosphere—such as evenly-mixed O_2, or photochemical byproducts of biogenic gases [9,10].

Ground-based telescopes will use starlight suppression and/or high-resolution spectroscopy to search for O_2 and other gases in M dwarf planetary atmospheres. Transmission spectroscopy may be used for transiting planets [11], and a combination of starlight suppression and high-resolution reflected-light spectroscopy could probe the atmospheres of nearby non-transiting planets like Proxima Centauri b [12,13]. In the next 10 years Extremely Large Telescopes (ELTs) on the ground will increase the power of high-resolution spectroscopy for M dwarf planets, and at least one planned first generation instrument may acquire 10μm direct-imaging observations of planets orbiting Sun-like stars [14]. The NASA WFIRST mission, if flown with a starshade [15], may observe a few HZ terrestrials.

For the decade beyond that, NASA is currently considering three telescope concepts that could observe terrestrial exoplanets. Two of these, HabEx [16] and LUVOIR [17], would use direct imaging to study terrestrial HZ planets, potentially probing the entire atmospheric column and planetary surface of HZ planets orbiting more Sun-like stars. These observations would complement the transmission and ground-based spectroscopy of M dwarf planets, and telescope sizes under consideration would enable detection of as many as 160 HZ terrestrials[18]. These telescopes will monitor time- and phase-dependent photometry to generate spatially-resolved maps of the planets [19], search for signs of ocean glint [20] and surface inhomogeneity, and use direct imaging spectroscopy in the visible-NIR to determine atmospheric and surface composition [6].

In this review we will discuss the desired measurements to characterize terrestrial planets for signs of habitability and life. This work is supported by theoretical modeling of a diversity of terrestrial exoplanet environments for habitable Earth-like, early Earth and highly-evolved M dwarf HZ and hot terrestrial planets - with photochemistry and climates that are driven by host stars of different spectral types. We will present simulated observations of these planets for transmission (JWST), ground-based (ELTs) and direct imaging (HabEx/LUVOIR-class) observations. We will identify the most observable features of these planetary environments, and the strengths and limitations of each class of observation, and identify suites of complementary observations that can provide the most robust characterization of habitability and biosignatures.

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