In-Depth Atmospheric Characterization of the Temperate Water World Candidate LHS1140 b

Thematic Areas (Check all that apply):

☒ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☒ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☒ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☒ (Theme D) A specific concept for a large-scale (∼500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: Assessing the habitability of rocky planets orbiting low-mass stars is a primary objective of the JWST mission. The ultimate aim is to detect their tenuous secondary atmospheres, which could potentially indicate the presence of liquid water on the surface. LHS1140 b, a nearby temperate super-Earth transiting a relatively inactive mid M-dwarf, stands out as one of the most promising targets for this endeavor. Recent reanalysis of both archival radial velocity and transit data has provided remarkably precise measurements of the mass and radius of both planets in the LHS1140 system, with an accuracy of 3% and 2%, respectively[1]. The position of LHS1140 b on the mass-radius diagram (see Fig. 1) suggests that it could be: a super-Earth with a small (∼0.1%) H/He-rich envelope, an airless and coreless planet with a core mass fraction (CMF) <4% or, more likely, a water world with a significant (10-20%) water mass fraction (WMF). Internal structure models[2,3] informed with measured stellar abundances of Fe and Mg are used to constrain both the CMF and WMF of LHS1140 b: $19.9^{+5.7}_{-5.8}\%$ and $13.2^{+4.7}_{-4.9}\%$, respectively. If LHS1140 b has an Earth-like atmosphere (400 ppm of CO_2), Global Climate Model (GCM) models[4–6] show that the planet would be a snowball with a significant liquid patch at the sub-stellar point. The atmospheric spectrum is predicted[7–9] to be dominated by small (∼15 ppm) CO_2 features that can be detected (4σ) with NIRSpec in ∼20 visits[10], the optimal configuration being 10 visits with G235H and 10 others with G395H. Since only 4 visits are available per year for LHS1140 b, this program will need to be executed over a period of ∼5 years.

Anticipated Science Objectives:

The specific goal of this proposal is to seek the detection of atmospheric CO_2 in LHS1140 b which would indirectly implies the presence of liquid water on its surface, as predicted by state-of-the-art GCM models[4–6] (see Fig. 1). To put the potential discovery of liquid water on LHS1140 b into context, it is important that LHS1140 c be studied with similar depth. In this case, we recommend using NIRISS SOSS and NIRSpec G395H (10 visits each ∼50 hrs), the former chosen over G235H for its wider wavelength coverage better suited to properly characterize the potential transit light source effect[11,12] (TLS) associated with unocculted spots/faculae, which may be responsible for the ∼100 ppm water-like signal detected with HST on LHS1140 b[13].

Urgency: The long-term nature of this program imposes a prompt execution.

Risk/Feasibility: Whether LHS1140 b is a water-world or a super-Earth with a very small (0.1%) H/He-rich envelope would still make this planet very unique to justify a transmission spectroscopy program on the same scale as proposed here, i.e., ∼170 hrs, 120 for LHS1140 b and ∼50 for LHS1140 c. To put the word "risk" into proper context, this program would represents less than 0.4% of the whole JWST's time over 5 years, which is a negligible investment compared to the huge potential scientific return of detecting a secondary atmosphere of a temperate super-Earth. One obvious potential risk is the threat associated with stellar activity that contaminates transmission spectra but the proposed SOSS program on LHS1140 c will serve to characterize the TLS effect as shown in[12].

Timeliness: The new mass and radius constraints of the LHS1140 planets offers new exciting insights into the nature of the LHS1140 planets, in particular for LHS1140 b, which should now be considered as a strong water-world candidate. The time is ripe to initiate a comprehensive atmospheric characterization program of this unique planetary system.

Cannot be accomplished in the normal GO cycle: This program cannot be executed as a multi-cycle GO programs since it requires more than 3 cycles. A reconnaissance, medium-size version of this proposal was submitted in Cycle 2 with excellent feedback but it was declined partly because it was felt that one should wait for Cycle 1 data (GO2334) to be released to support future proposals, i.e. effectively waiting for Cycle 4 to resubmit! The GO route is clearly impossible for the proposed program on LHS1140 b while, for c, reconnaissance programs with NIRISS, NIRSpec and MIRI are certainly possible. A full proposal could be provided should the Working Group elect to require it for their final selections.

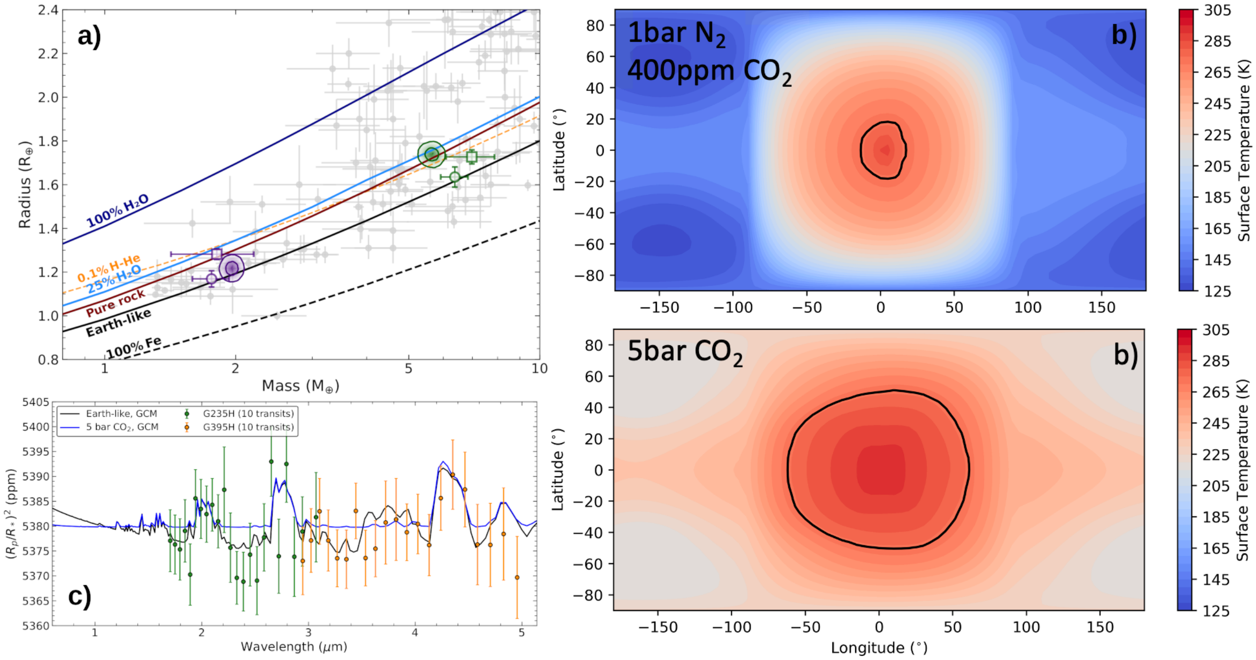

Figure 1: **Panel a**: Mass–radius diagram of exoplanets (gray points) with various theoretical pure composition curves[14–16]. New mass and radius posteriors (1- and 2-σ contours) of LHS1140 b (green) and LHS1140 c (purple) are drawn[1]. Published values from[17] and[18] are shown with open squares and circles respectively. LHS1140 b new density constraint is compatible with a rocky world with a small ($\sim$0.1%) H/He-rich envelope, an airless and coreless planet with a core mass fraction $<$4% or a water world with a significant (10-20%) water mass fraction. **Panel b**: Surface temperature maps of LHS1140 b from our Global Climate Model (GCM) simulations assuming an Earth-like atmosphere (1 bar N_2, 400 ppm CO_2; top) and a CO_2-dominated atmosphere (5 bar CO_2; bottom). The black line indicate the line of stability between liquid water and sea ice. The extent of the ice-free ocean strongly depends on the amount of CO_2 in the atmosphere. **Panel c**: Predicted transmission spectrum of LHS1140 b from 0.6 to 5.3 μm using the Planetary Spectrum Generator[7,8] (following the methodology of[9]) based on the output of the two GCM simulations (panel b). Simulated JWST/NIRSpec observations[10] with the G235H and G395H configurations are shown (degraded resolution $R \sim 20$). We estimate that 20 transits (10 G235H + 10 G395H) are needed to detect such atmospheres at 4σ.

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