The Search for Life on Exoplanets with JWST

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 ($\sim$500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: The characterisation of habitable exoplanets is the highest priority goal in exoplanetary science identified by the 2020 Decadal Survey. A large-scale JWST DDT program would be a unique opportunity for the community to pursue such a transformational goal in depth. We propose that a 500-hour JWST program be conducted for a comprehensive survey of the 20 most observable and diverse transiting exoplanets orbiting nearby M dwarfs in search for signatures of habitability and possible biological activity using transmission spectroscopy. Instead of focusing solely on terrestrial-size exoplanets, we propose that a more diverse and unbiased range of habitable environments be considered, including temperate super-Earths, ocean worlds, hycean worlds, as well as mini-Neptunes, in which diverse conditions for life have been predicted to be possible. Besides the transformational possibility of detecting a biomarker, the program will provide a legacy dataset for the community to robustly establish the prospects of characterising habitable exoplanets with JWST and lessons for future large missions focused on characterising Earth-twins. Such a program, early in the lifetime of JWST, would be timely and time-critical in order to harness the full potential of JWST to advance exoplanetary science. The contrary could be a missed opportunity.

Anticipated Science Objectives: A central question in the 2020 Astro Decadal survey [1] is: "Are there habitable planets harboring life elsewhere in the universe?" The survey states that laying out the pathways to habitable worlds is of highest priority in the field. While establishing the habitability or discovering a biosignature in an Earth-twin would require the capabilities of a future large mission as recommended by the survey, a diverse range of habitable exoplanets orbiting low-mass stars are within the reach of JWST. Therefore, the highest priority of JWST should be to maximise the characterisation of such planets to both (a) harness the potentially transformative discovery space within JWST's reach, and (b) build the foundation for future characterisation of habitable Earth-twins. In the recent past, studies of planetary habitability were primarily focused on Earth-size rocky exoplanets [2,3], which led to major investment of JWST Cycle 1 time on the TRAPPIST-1 system [4] but with limited success. This experience motivates a broader consideration of diverse habitable exoplanets that are more observable and provide better science return with JWST.

Therefore, we propose a multi-year 500-hour JWST survey with the primary goal to search for signatures of habitability (e.g. oceans, geosignatures, etc), and possibly life, in 20 potentially habitable exoplanets that are most conducive for atmospheric characterisation using transit spectroscopy. These will include habitable super-Earths, ocean worlds, hycean worlds, and even larger sub-Neptunes, with the potential environments spanning terrestrial-like, ocean-based, as well as cloud-based biospheres [3,5-7]. The survey will be implemented in three phases. The first phase will involve a reconnaissance program to survey all the targets with a limited number of transits each, designed to establish the presence/detectability of an atmosphere. Planets with atmospheric detections will be followed up in the second phase with more observations to robustly detect the dominant atmospheric chemical constituents. The most promising planets will be pursued in depth in the third phase to search for signatures of habitability and biological activity.

Urgency: The survey must be done now to maximise the impact of JWST.
Risk/Feasibility: The observations will be of standard transit spectroscopy of the best targets, so technical feasibility will not be an issue. This experiment needs a success rate of only 5% (1 in 20) to revolutionise the field. Conversely, a 0% success rate will provide robust constraints on the prospects for detecting life on exoplanets with JWST and future missions. The sooner we know this the better.
Timeliness: This is the highest priority area as per the 2020 Decadal survey.
Cannot be accomplished in the normal GO cycle: High-risk and multi-year.

[1] 2020 Decadal Survey: Pathways to Discovery in Astronomy and Astrophysics for the 2020s. Washington, DC: The National Academies Press.
[2] Kasting, J. F., Whitmire, D. P., & Reynolds, R. T. 1993, Icarus, 101, 108
[3] Meadows, V. S., & Barnes, R. K. 2018, Handbook of Exoplanets (Berlin: Springer), 57
[4] Gillon, M., Triaud, A. H. M. J., Demory, B.-O., et al. 2017, Nature, 542, 456
[5] Léger, A., Selsis, F., Sotin, C., et al. 2004, Icarus, 169, 499
[6] Madhusudhan, N., Piette, A., & Constantinou, S. 2021, Astrophys. J., 918, 1
[7] Seager, S., Petkowski, J. J., Günther, M. N. 2021, Universe, 7, 172