HabX2: a 2020 mission concept for flagship science at modest cost

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Philosophy: We will develop a flagship mission concept driven by compelling exoplanet science and important general astrophysics capability, of a scope and cost that leaves space in the NASA program for other astrophysics missions. Our approach is to maximize the science per dollar in a cost-capped environment using a single science theme to drive design. We see this activity as necessary and complementary to study efforts considering larger, more broadly focused flagship missions.

Starting Point: The central design question is what is the maximum habitable planet science that can be realized for a cost at various points in the range $2–$5 billion. We take as a starting point (hereafter"HabX2") a concept designed for direct imaging of Earth analogs *and* transit spectroscopy of M-dwarf habitable zone worlds. One key to controlling cost is to focus on implementation simplicity; the baseline concept is a stable, 3 m or larger, 280-200 K telescope, operating at L2 for 10+ years, with two spectroscopic measurement modes, one for direct imaging spectroscopy in the visible and near-IR with R~200, and one for continuous spectral coverage between ~200 nm and ≤5 μm (determined by the telescope temperature) with R~300-3000. To ensure responsiveness to the most important scientific priorities, and to leverage ongoing technology development efforts, implementation of the direct imaging spectroscopy mode as an "internal" or "external" occulter would be determined during prephase A development. Direct imaging spectroscopy would be the design driver for HabX2, with the continuous spectral coverage capability being implemented in a non-design-driving role. Ultra-light-weight mirror technologies, off-axis telescope implementations, and a range of telescope sizes, will be considered. We will evaluate the trade-off between mirror stability, telescope temperature, and longest wavelength not limited by the thermal background of a warm telescope, and also allowing the telescope to cool during the post-prime mission phase to enable spectroscopy from the near-IR to 5 μm. MCT detectors capable of working between 700 nm and 5 μm require only passive cooling.

Science: The exoplanet science case is centered on answering the over-arching question: ***Do temperate, terrestrial worlds outside of our solar system possess conditions that could support life?*** To answer this requires spectroscopic measurements of terrestrial exoplanet atmospheres; for this task, the HabX2 concept offers two important measurement capabilities.

- Direct Imaging Spectroscopy – This capability would allow both searching for and spectral characterization of temperate, terrestrial, habitable zone planets around nearby stars including potential detection of the O_2 and H_2O bands and imaging disks and planets in young planetary systems. The combination of a stable, optimized telescope and optimized implementation of the internal/external occulter would provide performance enhancements to build on the successes of WFIRST/AFTA.
- Transit Spectroscopy – In the post-JWST era, HabX2 would provide a critical capability to study atmospheres of T^3 (temperate, terrestrial, transiting) planets, with broad, continuous spectral coverage and repeated observations of long period

systems. T^3 planets, found by K2, TESS, and Plato, will be an important aspect of addressing the question of exoplanet habitability. The NIR capability provides access to deeper, broader molecular bands of CH_4, CO, and CO_2. Additionally, the transit spectroscopy capability of HabX2 will enable the study of atmospheric properties and processes of a wide variety of planets, which both enables comparative exoplanetology, and provides a context to better understand the atmospheric processes on potentially habitable worlds.

The HabX2 continuous spectroscopy capability from the UV to the IR is a versatile instrument with a wide range of science objectives ranging from probing the cosmic web to following up LSST (and other large survey) identification of transient and rare objects at low to high z. For example, the time domain and astrophysical spectroscopy capability of HabX2, extending into the UV, offer an important follow-on to Euclid and WFIRST by allowing pointed observations of specific targets found via those wide-field surveys. High NIR backgrounds will limit the capability of ground-based follow up of astrophysically interesting sources, meaning that the capabilities of HabX2 will play an important role in galaxy evolution studies in the 2030s. HabX2 will also be a key instrument in ongoing dark energy, dark matter, and galaxy evolution work in the post Euclid/WFIRST/JWST era.

We intend to undertake a vigorous study of the HabX2 concept with the objective of answering the following questions:

- What is the minimum mission cost for HabX2 that will answer the question: *Do temperate, terrestrial worlds outside of our solar system possess conditions that could support life?* In exploring this, we will create science merit functions and explore a range of mission architectures and notional design reference missions.
- What is the relationship between science grasp and cost in the $2 to $5 billion mission price range?
- What are the most compelling science cases, both exoplanet and general astrophysics, for a mission of this type in the post JWST, post WFIRST/AFTA world?
- What is the technology roadmap to implement HabX2?

The field of exoplanets is developing rapidly. Assumptions, including the basic one that temperate, terrestrial worlds are the best place to look for life, must be re-examined periodically as new data and new understanding develop.

In undertaking this study, we anticipate working with partners in NASA, academia, FFRDCs, and industry; our work will build on and complement the recently completed Exo-S and Exo-C studies by NASA's ExEP.