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The Next Generation of Observations of Planets Beyond Our Solar System

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Abstract

This presentation will give an overview of the planetary and exoplanetary observing capabilities of future astrophysics flagship missions that are under study in advance of the next Astrophysics Decadal Survey in the United States. This includes the UV-Optical-Infrared (LUVOIR) Surveyor, and the Habitable Planet Explorer (HabEx). Both missions are general-purpose space-based observatories with a wavelength range spanning from the far-UV to the near-infrared. The two missions differ in their levels of quantitative ambition, but either would enable revolutions in many areas of astronomy, including planetary science within and beyond our Solar System.

1. Background – The Astrophysical and Chemical Characterization of Exoplanets

Because LUVOIR and HabEx are both being considered for the next decadal survey, either must be capable of advancing our understanding of astronomical targets, including exoplanets, far beyond what will be achieved by the next two decades of observations from other space- or ground-based facilities. Either mission must move past the detection of potentially habitable worlds and their astrophysical characterization. Detection of such worlds is happening now with Kepler and ground-based measurements, and will continue with TESS (Transiting Exoplanet Survey Satellite), PLATO, and WFIRST (Wide Field Infrared Survey Telescope).

Any flagship mission under consideration for the timeframe beyond WFIRST that attempts to characterize exoplanet must also move beyond the chemical characterization of gas giants. This has begun with observations from Spitzer, Hubble, and ground-based telescopes and will see major advances with JWST (James Webb Space Telescope), ground-based Extremely Large Telescopes (ELTs), and WFIRST's exoplanet coronagraph.

2. The Future – Chemical and Astrobiological Characterization of Potentially Habitable Worlds

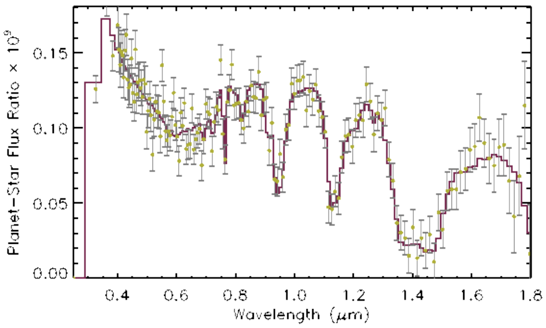

Figure 1: The spectrum of Earth, observed by a LUVOIR-/HabEx-like mission. This observation is at a SNR of 10 at 0.55 μm, assuming 30% throughput per channel. This spectrum would be consistent with any of the following scenarios: (1) a 10-hr observation of an Earth-like world 5 pc away with a 5m version HabEx; (2) a 30-hr observation of an Earth-like world 7 pc away with a 5m version of HabEx; (3) a 10-hr observation of an Earth-like world 12 pc away with a 12m version HabEx; or (4) a 30-hr observation of an Earth-like world 17 pc away with a 12m version of HabEx. *Figure courtesy Tyler Robinson* [1].

One of the main science objectives for these future flagship observatories will be to directly image rocky-sized planets in the habitable zones of other stars, measure their spectra (Figure 1), analyze the chemistry of their atmospheres, and obtain top-level information about their surfaces. Such observations will allow us to evaluate the habitability of these worlds, and search for potential signs of life in their spectra. We will review the specific observational strategies needed for astrobiological assessments of exoplanetary environments, including the wavelength range and spectral resolution required for these habitability analyses and biosignature searches.

3. The Connection Between Exoplanet Astrobiology and Solar System Planetary Science

We must consider the search for habitable environments and signs of life on exoplanets in the context of Solar System exploration, and vice versa. The selection of targets for these future exoplanet observations must be informed by our understanding of how planets work, which is constantly improving based on our exploration of worlds closer to home.

These links go in the other direction, as well. The history of exoplanet discoveries has upended expectations set by the knowledge of our Solar System. For example, the very first planets we discovered were so-called “hot Jupiters” that had a combination of physical and orbital properties unlike anything in the Solar System. The theories we have developed to explain the wealth of data from these discoveries has in turn influenced our thinking on the evolution of planets inside the Solar System, due to a new grasp of the ways that planets can migrate over time. Similar lessons are beginning to come from the chemical characterization of exoplanets, as well, and these lessons will accelerate with the dozens of transit observations by JWST. Based on this history, we should expect the unexpected when it comes to a future search for habitable environments and life. We plan to obtain spectra for up to dozens of rocky worlds in the habitable zone, and up to hundreds of worlds overall. The comparative planetology enabled by those data will allow us to test myriad hypotheses on global-scale planetary feedbacks such as the carbonate-silicate and ice-albedo feedbacks.

Finally, we must compare and contrast the strategies to search for habitable environments and life. The search for life on exoplanet will be remote, whereas most searches for life in the Solar System will be *in situ*, or will be remote measurements that are precursors to *in situ* measurements. This means that the detection techniques and associated instrumentation will differ dramatically. However, the fundamental science of astrobiology that underlies both endeavors is the same. Further, there is a similarity in the overarching frameworks that are arising in the communities focused on these various targets. Communities focused on each of these targets is now considering frameworks for astrobiological assessment that include a “follow the energy” approach, the complexity of individual molecules and of chemical networks, and the need to quantify our intuition on what constitutes a biosignature. These similarities allow us to share top-level strategies for the search for life, even if our detailed instruments and measurements exhibit significant differences.

4. The Search for Life Beyond Earth as a Global Endeavor

The expertise required to optimally perform this endeavor extends well beyond the capabilities of a single individual, team, or even nation. We need to fully incorporate lessons throughout the space sciences community – to better understand the stellar context of our observations, how the stellar forcing interacts with the planet, and how the planet itself contains myriad systems which interact. This means the inclusion of astronomers, planetary scientists, heliophysicists, and Earth scientists.

Accordingly, the search for another pale blue dot is one that should incorporate the talent integrated across our own pale blue dot. For example, the LUVOIR and HabEx missions have both included international participants in their study teams. Additionally, France’s Centre National D’Etudes Spatiales (CNES) is studying a high-resolution spectropolarimeter as one of LUVOIR’s instruments. These interactions will improve the quality of these studies, and build momentum for international collaboration as an element of these future flagship missions.

5. References

Robinson, Tyler D., Karl R. Stapelfeldt, and Mark S. Marley. Characterizing Rocky and Gaseous Exoplanets with 2 m Class Space-based Coronagraphs. *Publications of the Astronomical Society of the Pacific*, Vol. 128, pp. 025003, 2016.