Astro2020 Science White Paper

Thinking Big: How Large Aperture Space Telescopes Can Aid the Search for Life in Our Lifetimes

Thematic Areas: ☒ **Planetary Systems** ☐ Star and Planet Formation
☐Formation and Evolution of Compact Objects ☐ Cosmology and Fundamental Physics
☐Stars and Stellar Evolution ☐Resolved Stellar Populations and their Environments
☐Galaxy Evolution ☐Multi-Messenger Astronomy and Astrophysics

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Abstract: (optional)

In this white paper from *The Planetary Society*, we discuss briefly the capabilities needed to conduct what is perhaps the most scientifically compelling endeavor facing space science at this time: the successful search for life elsewhere. In many of the specific details we defer to the scientific experts who are submitting their own detailed white papers. We concentrate here on providing the context for NASA's search for life beyond the Earth writ large, and on reporting our assessment of public support for this science. We conclude with the combined implications for consideration by the leaders of Astro2020.

Introduction

The field of exoplanets has undergone a remarkable evolution since the last decadal, with thousands of planets discovered in our local neighborhood. Discovering life (or more precisely, compelling biosignatures suggestive of life) on one or more of these exoplanets would have significant and permanent consequences for humanity in multiple fields beyond astronomy: biology, planetary science, philosophy, religion, and more.

In this white paper from *The Planetary Society* (see **sidebar**), we discuss briefly the capabilities needed to successfully search for life elsewhere (deferring to the scientific experts who are submitting detailed white papers). We concentrate on providing the context for NASA's search for life elsewhere writ large and report our assessment of public support for this science. We conclude with the combined implications for consideration by the leaders of Astro2020.

The Planetary Society is an independent 501(c)(3) non-profit. Our mission is to empower the world's citizens to advance space science and exploration through: advocacy for space science and exploration investment; inspiration and education of people around the world; and development and funding of ground-breaking space science and technology. We are supported by over 50,000 members in over 100 countries and by hundreds of volunteers around the world.

Planets abound

There has been nothing short of a revolution in the field of exoplanetary astronomy in recent years. In 2000, the scientific community had catalogued only 58 exoplanets. By the time of the 2010 decadal survey, that number had grown to 573 though none were considered habitable. In the decade since, astronomers have confirmed an additional ~3500 exoplanets[1], 49 of which are considered potentially habitable at the time of this writing.[2] This explosion of exoplanet detections shows no signs of abating. In 2018, NASA launched the Transiting Exoplanet Survey Satellite (TESS) on a 2-year prime mission. This mission is expected to discover approximately 14,000 exoplanets, of which ~280 are expected to have a radius less than twice that of Earth.[3] Many more are expected to be discovered should TESS continue in an extended mission.[4] Statistical analysis of Kepler data suggests that 22% of Sun-like stars host Earth-sized planets in their habitable zone.[5] In short, the discovery of many more potentially habitable exoplanets will continue, presenting an ever-growing number of locations to search for signs of life.

Assessing Habitability Elsewhere: Observational Requirements and Strategies

The challenges of detecting biosignatures in planetary atmospheres are well known and discussed in significant scientific detail in other white papers submitted to Astro2020. We only reiterate the fundamentals here. Exoplanets are considered habitable when orbiting at a distance necessary to sustain liquid water on their surface with a radius two times that of Earth or less. Thus, the fundamental challenge is that astronomers must measure the spectral signature of a dim object (the exoplanet) next to an extremely bright one (the host star) that appear close together in the telescope's field of view (we set aside habitable moons, whose detection challenges are still greater). Given these conditions, a space telescope capable of measuring spectra for dozens of rocky planets in the habitable zone with statistically significant signal strength requires a large aperture and sensitive detector capability.[6] Fig. 1 shows a representative example from computations by C. Stark (private communication to H. Hammel in late 2018; see his decadal white paper for up-to-date assessments and detailed computations).

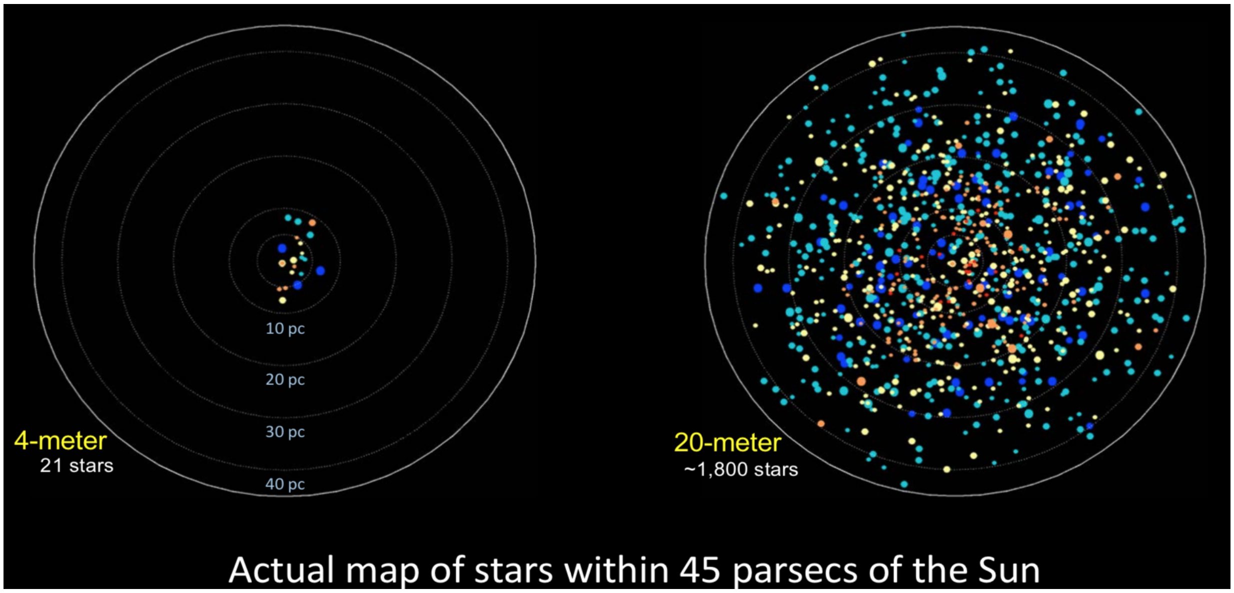

Figure 1. *The number of accessible star systems that could yield exoplanet spectra depends critically on telescope diameter. The number of potentially habitable planets is an even smaller subset of those shown.*

Carl Sagan, one of the founders of *The Planetary Society*, famously stated that "extraordinary claims require extraordinary evidence."[7] In this spirit, we assert that the extraordinary claim of a spectral biosignature detection on a distant exoplanet requires an unambiguous signal, ideally in combination with additional, complementary spectral biosignatures to reduce the possibility of a false positive. Evidence of this caliber requires significant apertures for future space telescopes. Fig. 2 shows two simulations as an illustrative example.

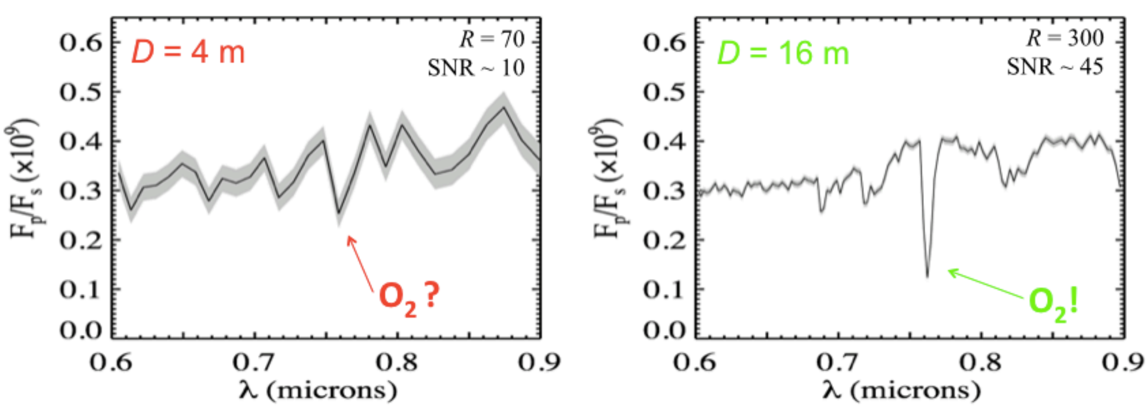

Figure 2. *Spectrum of an Earth at 10 parsecs, with 200 hours of observing time (source: http://luvoir.stsci.edu/coron_model). Only the detection on the right could meet "extraordinary evidence" criterion articulated by Carl Sagan (we note that O_2 alone is not an adequate detection; this is specifically about the signal-to-noise ratio).*

Assessing Habitability Nearby

In-situ searches for life on exoplanets are limited by the vast expanses between stars. Fortunately, the knowledge of habitable environments in our own cosmic backyard has greatly expanded in the same period as the exoplanet revolution. In particular, significant discoveries have been made regarding the habitability of ancient Mars and of modern ocean worlds in the outer solar system. On Earth, the concept of habitable environments has expanded to accommodate the discovery of thriving ecosystems in deep-sea thermal vents.

In-situ exploration of the martian surface has established that Mars hosted multiple habitable environments in its past[8,9] and may host a limited one now. NASA's rover missions and orbital spacecraft have taken initial steps to characterize the duration, location, and chemistry of these habitable environments. The upcoming Mars 2020 mission will collect samples from locations with strong biosignature preservation potential (including an ancient river delta, see Fig. 3) for eventual return to Earth. Once on Earth, the full suite of far more advanced scientific instrumentation here will be available to study these samples for biosignatures and further characterize ancient martian habitats.

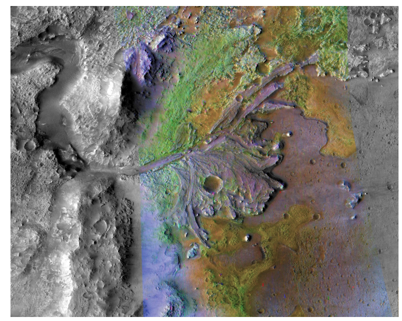

Figure 3. *The river delta within Jezero Crater, near the landing site for the Mars 2020 rover. Credit: NASA, JPL, JHUAPL, MSSS, Brown University.*

Further out in the solar system, the Cassini and Galileo missions established that several outer solar system moons contain large reservoirs of liquid water in potentially habitable conditions[10], particularly on Europa and Enceladus, but also possibly on Ganymede, Titan, and perhaps other large icy moons. The upcoming Europa Clipper mission will arrive at the Jupiter system by the late 2020s. It will study of Europa's ice shell and ocean in detail, mapping its surface in preparation for a future landed mission. These *in-situ* observations and others within our Solar System provide important constraints for interpreting data from exoplanetary systems and have expanded the definition of the "habitable zone" to include locations previously thought too distant from the Sun to support liquid water.

Rocket Power and Large Apertures

Simultaneously, significant progress has been made over the last decade in developing a new generation of rockets to bring large telescopes to orbit or provide lower-cost access that could capitalize on new developments in satellite technology. As an example, SpaceX's Falcon Heavy currently flies for a fraction of the price of other heavy lift vehicles. NASA's Space Launch System is planned to fly as early as 2020 with an upgraded version planned for the mid-2020s providing large fairing sizes and lift capability similar to that of the Saturn V. SpaceX's super heavy lift rocket—Starship—is planned to fly by the mid-2020s. Additionally, SpaceX and Boeing are on the cusp of launching astronauts to low-Earth orbit (LEO) as part of NASA's commercial crew program. Given the physical size requirements of the next-generation of space telescopes, ready access to LEO with astronauts may enable the in-space assembly of future large space telescopes (Fig. 4), reducing the complexity inherent in folding them to fit into fairings (*e.g.,* the James Webb Space Telescope). The mutually-beneficial partnership between NASA's human spaceflight and science mission directorates on the Hubble Space Telescope provides a useful model by which to pursue an ambitious joint project in space telescope science. Additionally, emerging capabilities to extend the capabilities of large telescopes (e.g. via coronagraphs) and of using satellite constellations to generate large apertures are technologies being developed right now with great potential in the next decade.[11]

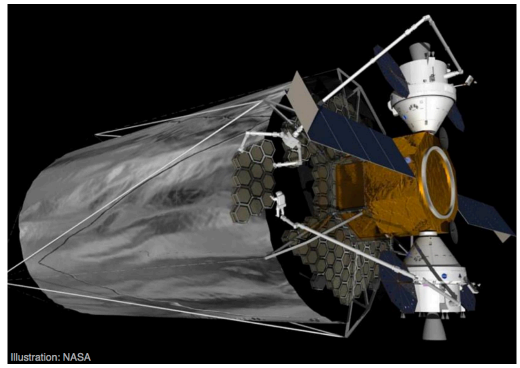

Figure 4. *In-space assembly of a future large space telescope. Source: N. Siegler; https://exoplanets.nasa.gov/internal_resources/1018/*

The threads of exoplanet discovery, advances in understanding planetary habitability, and launch vehicle and satellite development have come together and point toward a monumental goal: enabling the search for life at large scale with discoveries possible in a single generation – our generation. In particular for Astro2020, aperture size requirements for space telescopes capable of detecting biosignatures on exoplanets have moved from speculation to reality; likewise, the ability to realize those apertures is now within our grasp. The astrophysics community is positioned to make historic discoveries in the coming decades.

Search for Life and the Opportunity for Public Engagement

The search for life is one example of a diminishing number of cutting-edge scientific research that is communicable in a single sentence to a non-expert. Discussion of the effort and its implications naturally evokes an emotional response in people, reflecting the profound philosophical and theological implications of such a discovery.

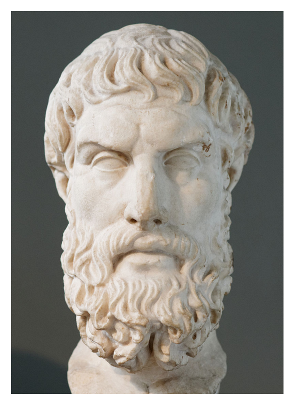

Figure 5. *Epicurus (341 – 270 BC). This Greek philosopher wrote, "there is an infinite number of worlds, some like this world, others unlike it."*

The concept of life elsewhere has been present in public consciousness since ancient times (Fig. 5) and has captured a permanent presence in the popular culture—particularly since the late 19th century. The persistence of the theme in fiction demonstrates the resonance it has with the public; it presents an opportunity for the scientific community to hook into an extant cultural fascination to educate and excite those who enable our exploration.

At the same time, much work is yet to be done by the scientific community to establish the scientific *bona fides* of the search for life and to establish its relevance to the public writ large. For example, a recent poll[12] showed that, when presented with a series of space exploration pursuits, the public rated the search for life as the third *lowest* priority, just above the human exploration of the Moon and Mars. In the same poll, however, "conduct[ing] basic scientific research to increase the knowledge of space" ranked third overall, suggesting that there is a significant public misconception regarding the *science* behind the search for life.

The Planetary Society's own member surveys demonstrate a similar misconception. Respondents rated the search for life as NASA's 4th most important priority, yet they placed the exploration of ocean worlds (whose prime scientific motivation is the search for life) as the highest priority. This paradox again points to a need for better communication and education.

The accessibility of, and cultural fascination with, the search for life is thus both a strength and a weakness. For decades the search for life has been conflated with fantastical stories of aliens coming to Earth in various forms or Earth explorers interacting with widespread alien civilizations. Not surprisingly, the scientific process that informs the actual search for life is lacking in these portrayals. The scientific community must take the lead in sharing the compelling and scientifically valid motivations behind the search for life (whether it be in the implications of discovering new metabolisms, new chemistries, or an overall understanding of humanity's place in the universe), and it must be pursued with as much effort as that of the search for life itself.

Conclusion

In the Astro2020 decadal survey, the astrophysics community is presented with a unique opportunity. One of the most profound questions we humans ask ourselves — "Are we alone?" — stands ready to be addressed in a systematic way. The scientific community can elect to survey the atmospheres of dozens of nearby exoplanets for subtle chemical imbalances or clues to surface environmental conditions that could indicate biological processes or at least potential habitability. We just need to build a sufficiently powerful space telescope.

At the same time, advances in planetary science as well as in large and low-cost launch vehicles will permit the opportunity for complementary exploration of habitable worlds (*e.g.*, Mars and ocean worlds) within our own Solar System. Such exploration is a priority for NASA and for the planetary science community. The public is likewise primed to support the search for life as a NASA objective, though work must be done to establish the validity of the scientific process directed at this search, after decades of fantastical representation created by entertainers.

Achieving the goal of finding evidence for life elsewhere is possible in our lifetimes, and success in conducting the search is a function of the collective determination and focus of the many stakeholders involved, including the space science community, politicians, educators, and the general public. There is no need to merely hope for a signal to come our way, or simply speculate whether life evolved more than once in the Universe. The astrophysics community has the capability to actively seek the signs of life elsewhere. Space-based telescopes are the tool. We just need to think big.

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