

Astro2020 APC White Paper

Title: The Carl Sagan Observatory: A Visionary Space Telescope

Type of Activity: Space-based Project

Principal Author:

Name: Heidi B. Hammel

Email: hbhammel@aura-astronomy.org

Institution: AURA

Phone: 202-483-2101

Co-authors: John Mace Grunsfeld (NASA GSFC Emeritus), Kenneth Sembach (STScI), Ann Druyan (self-represented), Scott Gaudi (OSU), Bradley Peterson (OSU), Jason Tumlinson (STScI), Matt Mountain (AURA)

Description: The search for life elsewhere is intimately linked to our knowledge of the grander Cosmos. As human beings on the only planet that we know for certain has life, this search is both profound and personal. In this Astro2020 Decadal Survey, our community has the opportunity to fundamentally address both our knowledge of the Cosmos and the story of life's emergence within it, if we have the courage to make science-driven bold choices. NASA has already explored the exciting scientific and technical landscape possible today with the studies for HabEx and LUVOIR. In this white paper, we highlight an optimum solution between the two extremes of these studies. This observatory will be capable of characterizing dozens of earth-like planets to search for life, as well as executing a forefront program of astrophysics needed to comprehend the story of life in the Universe. Our concept flows largely from a community-based study, *"From Cosmic Birth to Living Earths,"* that explored the capabilities of a large (12-meter class) space-based telescope (see [HDSTvision.org](https://www.hdsvision.org)). Such an observatory would revolutionize our understanding of the Universe, and lead to a statistically definitive answer to the question "are we alone?" within our galactic neighborhood. As demonstrated by NASA's current studies, this facility is achievable with a technical maturity that is already significantly more advanced than at comparable points in the development of Hubble or JWST. It is a mission we believe would be worthy of the title "The Carl Sagan Observatory."¹ We are at a unique point in the history of our species: we have within our grasp the ability to definitively answer "are we alone?". The Astro2020 Decadal Survey is deciding what the next generations of astronomers will be able to undertake, and now is the time to take that courageous step. As Carl Sagan said: *"The nature of life on Earth and the quest for life elsewhere are the two sides of the same question: the search for who we are."*

¹ We use "Carl Sagan Observatory" with the permission of Ann Druyan, a co-author of this white paper.

Introduction

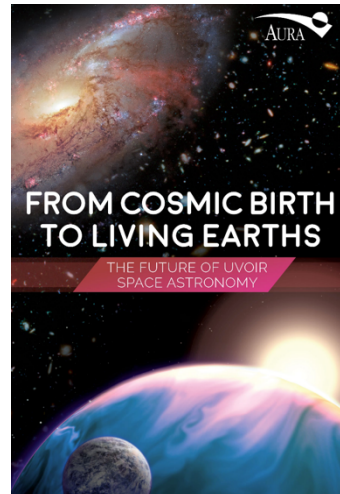
For the first time in human history we have both the tools and the means to answer some of astrophysics most important questions. Current observatories are enabling astrophysicists to make great strides in unravelling the mysteries of the Universe, yet one question remains unanswered: Are we alone? The technology to answer the question of life beyond earth is now at hand, both through exploration in our own Solar System and with telescopic characterization of planets around nearby stars.

The scientific community and the worldwide community of curious people are more than ready to take the next step in the search for life beyond Earth. For example, almost exactly four years ago a presentation on the potential power of a 12-meter space telescope (co-hosted by AURA and the American Museum of Natural History in New York City) captured the attention of many, including writer Dennis Overbye of the New York Times. He wrote (Overbye, 2014):

“In what they termed “a call to arms,” an organization of American university astronomers said last week that NASA should begin planning now to launch a sort of supersize version of the Hubble Space Telescope in the 2030s to look for life beyond Earth.

This ... telescope would be five times as big and 100 times as sensitive as the Hubble, with a mirror nearly 40 feet in diameter, and would orbit the sun about a million miles from Earth.

Such a telescope, the astronomers said, would be big enough to find and study the dozens of Earthlike planets in our nearby neighborhood. It could resolve objects only 300 light-years in diameter — the nucleus of a small galaxy or a gas cloud on the way to collapsing into a star and planets, say — anywhere in the observable universe.



The case for the telescope is laid out in “[From Cosmic Birth to Living Earths ...](#)”

In 2018, the National Academy of Sciences published the results of a community-led study on the next steps in exoplanet exploration. This study, the “Exoplanet Science Strategy,” clearly states:

“Ultimately, the exoplanet community needs to develop the means to study potentially habitable planets orbiting more Sun-like stars. Developing this capability will require bold investments and a longer time scale to bear fruit, but along the way it will foster the development of the scientific community and the technological capacity to understand a myriad of worlds that currently elude us. The requirements to pursue an Earth-Sun analogue imply an imager in space:



Finding: *A coronagraphic or starshade-based direct imaging mission is the only path currently identified to characterize Earth-size planets in the habitable zones of a large sample of nearby Sun-like stars in reflected light.*

Finding: *Recently acquired knowledge of the frequency of occurrence of small planets, and advances in the technologies needed to directly image them, have significantly reduced uncertainties associated with a large direct imaging mission.*

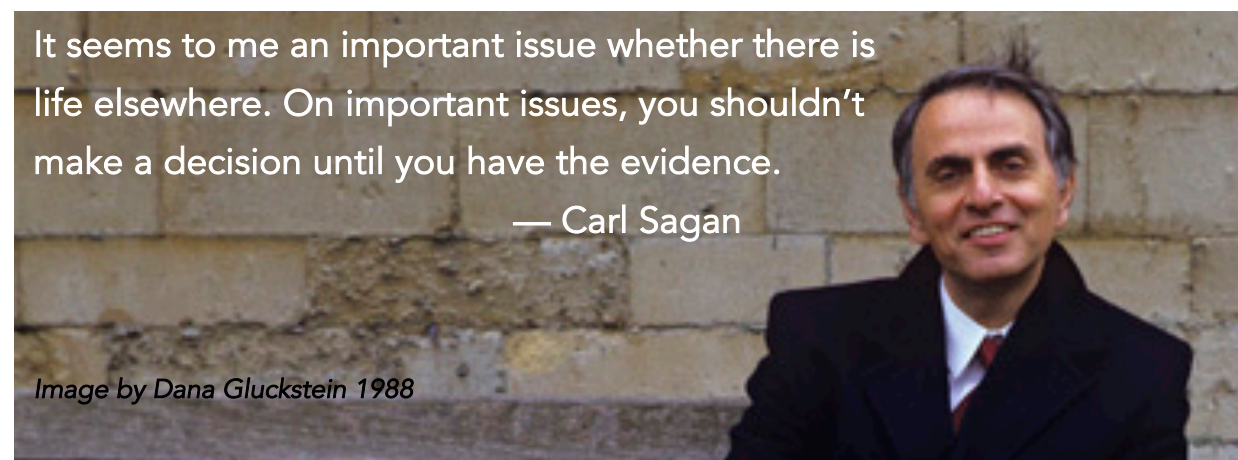
Recommendation: *The National Aeronautics and Space Administration (NASA) should lead a large strategic direct imaging mission capable of measuring the reflected-light spectra of temperate terrestrial planets orbiting Sun-like stars.”*

What we propose in this white paper is that the Astro2020 Decadal Survey prioritize and endorse the science case for an observatory that has the technical capability to provide reflected light spectroscopy of dozens of planets around nearby sun-like stars, an observatory that can answer some of the most fundamental questions about our Universe. We hope for an observatory that takes best advantage of the ideas developed in the detailed Astro2020 design reference mission studies, combined into an ambitious effort that can be accomplished in this next generation of projects.

The search for life elsewhere is the challenge of our time. This is the motivation to create a synthesis of the best concepts prepared in the reference missions developed to support Astro2020, along with the extensive groundwork laid down by years of previous studies. This is the inspiration to create an observatory that can search for signatures of life beyond Earth and explore the Universe. We propose to call this the Carl Sagan Observatory to honor the scientific curiosity and integrity of Carl Sagan in his quest to search for life in the Cosmos.

Key Science Goals and Objectives

The science goals for future large UVOIR space telescopes have been eloquently described by the LUVOIR and HabEx teams (Roberge et al. 2019 and Gaudi et al. 2019a). We briefly reiterate a few key points.



Life Elsewhere: As noted in [“From Cosmic Birth to Living Earths”](#) (CBLE14) our children are growing up knowing that there are planets around nearby stars, with more than 4000 planets confirmed as of this writing. **It is now within our power to leave a far more profound legacy for future generations: the knowledge — the actual evidence as Carl Sagan says — that not only are there other planets, but that some of these planets are just like Earth, with surface oceans and atmospheres with carbon dioxide, and possibly even life.**

Equally remarkable is the knowledge that all life, whether here on Earth or elsewhere, is made from atoms forged in the furnaces of stellar interiors. “These heavy elements — carbon, nitrogen, oxygen, iron, and others — were ejected from aging stars or in violent stellar explosions that forced most of these building blocks of life from the galaxies into cold, dark intergalactic space. The slow, gentle nudge of gravity brought them back, gathered them together into new galaxies, stars and planets” (CBLE14).

On at least one of these planets, Earth, these elements and starlight somehow nurtured life into being. We are now poised to answer the question: did this happen elsewhere? We are the first generation that can reach for this lofty and ambitious goal, because only now are other living Earths orbiting nearby Sun-like stars within our technological grasp. No matter how different life elsewhere may be from that on Earth, we will have at least this much in common: we are, as Carl Sagan noted, “star stuff.” The origins of life on Earth and elsewhere in our Galaxy are found in the history of our Cosmos. Thus,

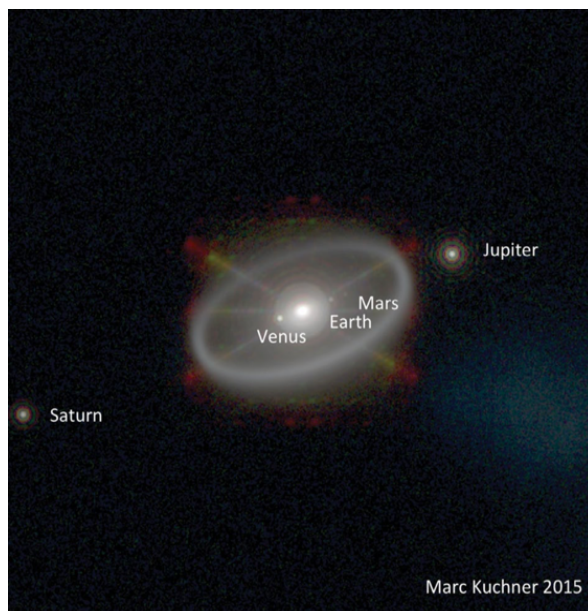
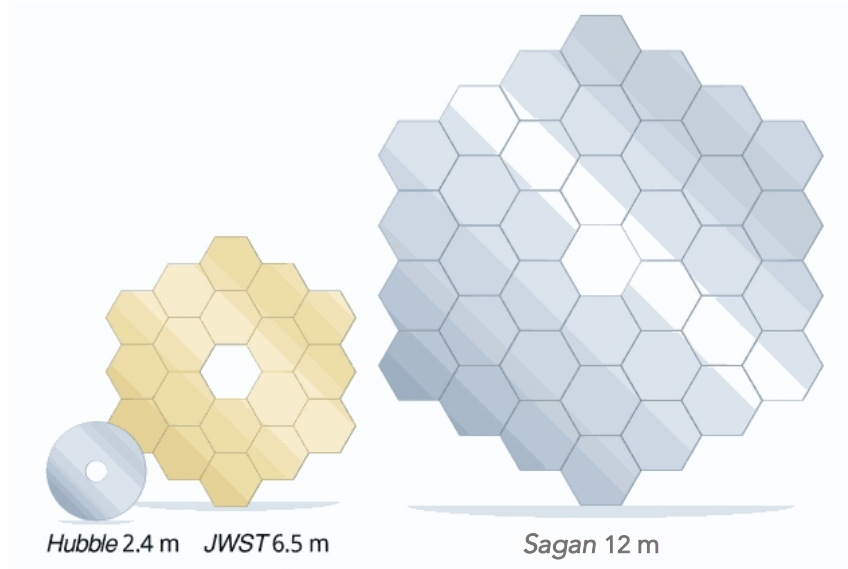
the astronomical search for life and its astrophysical origins in galaxies, stars, and planets are all woven together.

AURA's "Cosmic Earths to Living Earths" study concluded that to achieve this, and to also enable the next revolution in astrophysics, would require an aperture diameter of order 12 meters, which is perhaps not coincidentally within the suite of options studied by HabEx and LUVOIR (e.g., see APC white paper by Gaudi et al. 2019b).

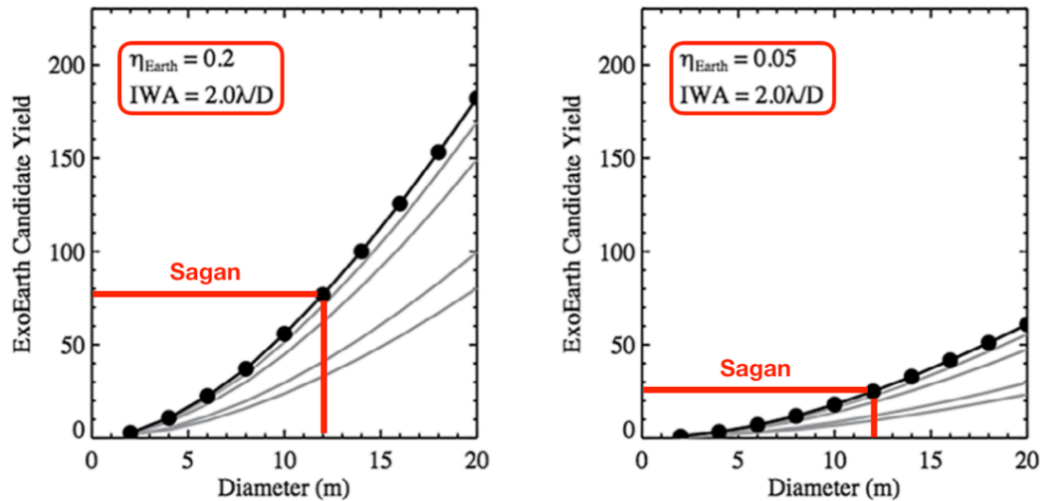
A 12-meter space telescope will be able to directly image solar systems like our own. More importantly, a 12-meter space telescope equipped with an appropriate coronagraph can characterize a significant number of Exo-Earths as shown below.

For a range of assumptions, including that the likely fraction of earth-like planets in the habitable zone (η_{earth}) varies between 0.05 to 0.2, a Sagan Observatory of this scale would have the capability to characterize dozens of Earth-like planets (see figure on next page).

The two subsequent NASA reference mission studies — HabEx and LUVOIR — were unified in science: there was an extensive collaboration between the two teams. The two teams landed on two different implementation methods, but what we really need is the observational capability.



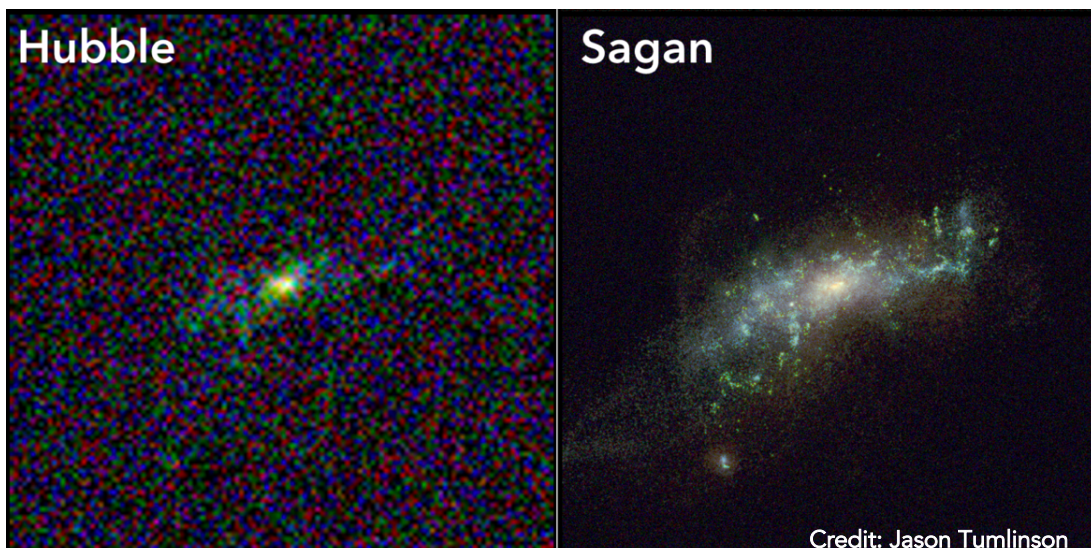
Simulated false-color (450-850 nm) image of a planetary system around a nearby G star (Beta Cvn) as seen by a 12-meter optical space telescope (credit M. Kuchner).



The number of candidate exo-Earths that can be detected in the habitable zones of Sun-like stars as a function of telescope aperture diameter, assuming one year of on-sky observations, and including time to acquire $R=70$ spectra centered at 550nm. Results are shown for two values of η_{Earth} . Assuming an inner working angle (IWA) = 2.0. Black curves are for an assumed exozodi background of 3 zodi. Gray curves show the impact of increasing exozodi levels to 5, 10, 50, and 100 zodi. If the same one year of observing time is spent only on discovery and not spectra, the yields may increase by as much as 40%
 Credit: C Stark

We assert that Astro2020 should endorse the idea of accomplishing the longstanding decadal and scientifically-compelling goal of finding the signature of life on another world. We also encourage Astro2020 to recognize that to do so requires high-resolution, high-sensitivity UV/optical capability.

Astrophysics: As shown by both CBLE14 and the LUVOIR study (Roberge et al. 2019), the discovery potential of a 12-meter telescope is enormous for a vast range of astrophysical problems beyond the search for life elsewhere. The large aperture provides imaging resolution and collecting area at an unprecedented scale.



With an extraordinary sensitivity to faint objects, a 12-meter Sagan Observatory will be able to study the smallest building blocks of galaxies back to the epoch of “first light.” It will be able to examine the “faintest light in the Universe” emanating from the diffuse gas that fuels all galaxies. It will be able to watch the motions of hundreds of galaxies around the Milky Way. It will be able to watch geysers on icy worlds in the outer solar system, and search the Kuiper belt for Planet X.

In all these domains of astrophysics, the Sagan Observatory will employ advanced technologies to reach far past the limits of our current imaginations about the Universe, true to the pioneering spirit of its namesake. With its 12-meter aperture, the Sagan Observatory will be able to resolve objects on the surface of Pluto, the separation between Earth-like planets and their parent stars, and, at cosmological distances, everything larger than 100 parsecs in galaxies over all of cosmic time.

Requested APC Content and Connection to Other White Papers

This section of our white paper is intentionally brief because we explicitly refer to the APC white papers created by the LUVUOIR and HabEx teams for all the details, rather than repeat them unnecessarily (Roberge et al. 2019; Gaudi et al. 2019a).

Technical Overview, Technology Drivers, Organization, Partnerships, and Current Status:

The technical basis and readiness to proceed with the development of a Sagan Observatory is well described in the details from the Astro2020 Design Reference Mission reports. For specific details from these NASA-funded studies, please see the APC white papers submitted by the teams for LUVUOIR (Roberge et al. 2019) and HabEx teams (Gaudi et al. 2019a), as well as that submitted by Gaudi et al. (2019b).

Cost Estimates: The cost category for this overall project, including science and operations, is “Space Facility - Large > \$1.5B” (in the \$10B class of the Great Observatories). To put that into perspective, we again quote from Overbye (2014):

“I used to think \$10 billion was a lot of money before TARP, the Troubled Asset Relief Program, the \$700 billion bailout that saved the banks in 2008...

Compared with this, the science budget is chump change, lunch money at a place like Goldman Sachs. But if you think this is not a bargain, you need look only as far as your pocket...

...all that NASA money — whether for planetary probes or space station trips — is spent on Earth, on things that we like to say we want more of: high

technology, education, a more skilled work force, jobs, pride in American and human innovation, not to mention greater cosmic awareness, a dose of perspective on our situation here among the stars.

Even if we never discover even a single microbe anywhere else, the money spent on the search for life out there will make life better for those of us stuck here on Earth.”

Schedule: Using as a guide the history of Great Observatory development times, and the extensive technology investments already made to implement a program for a 12-meter-class telescope, a launch date of 2034 should be possible. That this would be the 100th anniversary of the birth of Carl Sagan marks 2034 as an ambitious but achievable goal for an ambitious and achievable observatory.

As demonstrated by NASA’s current studies, a facility of this class and design exhibits a technical maturity that is already significantly more advanced than at comparable points in the development of Hubble or JWST.

The opportunity is for the astrophysics community is now — with the deliberations of Astro2020 — to decide whether to promote a schedule and budget for a project as bold as the Carl Sagan Observatory. As has been often noted, it is easier to get support from Congress for bold and transformative projects, then for small incremental programs of science. For reference, in the last Planetary Decadal Survey the scientific community promoted both a Mars Sample acquisition rover and a Europa mission even while explicitly noting that the Europa mission was outside the scope of the extant planetary budget envelope. Congress subsequently supported both ambitious missions, resulting in a near doubling of the NASA Planetary Science budget.

Summary

Sembach and Hammel (2019) closed their Astro2020 white paper with a thought worth repeating from Michelangelo di Lodovico Buonarroti Simoni, an Italian sculptor, painter, architect and poet of the High Renaissance who exerted an unparalleled influence on the development of Western art.

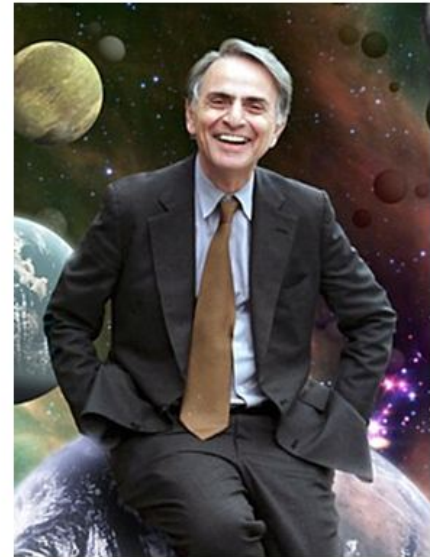
Michelangelo said: ***“The greatest danger for most of us is not that our aim is too high and we miss it, but that it is too low and we reach it.”***



The Astro2020 Steering Committee has the opportunity of a generation to not only pose the courageous question of “are we alone?” but also to endorse creation of a facility that can, for the first time in human history, provide a meaningful answer to that question. A 12-meter telescope would also revolutionize our knowledge of the full breadth and depth of a diverse swath of astrophysics, from the birth of the Cosmos to the creation of galaxies to the splendors within our own Solar System. This facility would be worthy of the coming generations of astronomers and astrophysicists, and would be worthy of the name, the Carl Sagan Observatory.

We close this white paper with a thought from Carl Sagan, who himself exerted an unparalleled influence on a generation of nascent space scientists as well as the broader public.

Carl Sagan said: **“If we long for our planet to be important, there is something we can do about it. We make our world significant by the courage of our questions and by the depth of our answers.”**



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