AN UPDATE ON NASA'S ASTRONOMICAL SEARCH FOR ORIGINS PROGRAM[1,2]

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Abstract— NASA`s Astronomical Search for Origins has been progressing along a roadmap first established in 1996. Key features of the roadmap included technological and scientific stepping stones linking major missions. This paper will provide an overview of the current Roadmap version published in 2003, overall status of the program and discuss top level evolution of the processes for linking these missions. More details on these issues will be presented by other speakers/panel members in this session.

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1. INTRODUCTION

NASA's Astronomical Search for Origins (ASO) has undertaken to answer two of the most profound and most challenging questions mankind has ever posed:

- *Where did we come from?*
- *Are we alone?*

Had the science fiction fables of the 50's and 60's proven real, these questions might not have been so elusive. Creatures or beings jetting in from Mars or Venus would have put that line of inquiry to rest, perhaps along with human civilization; but, our universe is not that simple. Instead, we find ourselves probing ever deeper into the interstellar reaches of our galaxy searching for signs of planets around other stars, and trying to understand what makes the galaxy, stars and planetary systems form the way they do.

In 1996, the first ASO Roadmap spelled out the challenges to scientific thinking and observation, and laid out a technological path to build the sequence of ground observatories and space missions that would be capable of making scientific measurements that would provide answers to our questions of our origins. The missions were difficult, but on the whole the path was straightforward and the steps achievable. At that time, by the way, science had evidence of about 5 extra-solar planets.

Like most of us as we go from being children to adults, we find we know much less than we thought we did. Today, some 116 planets are known (Figure 1). Having spent 7

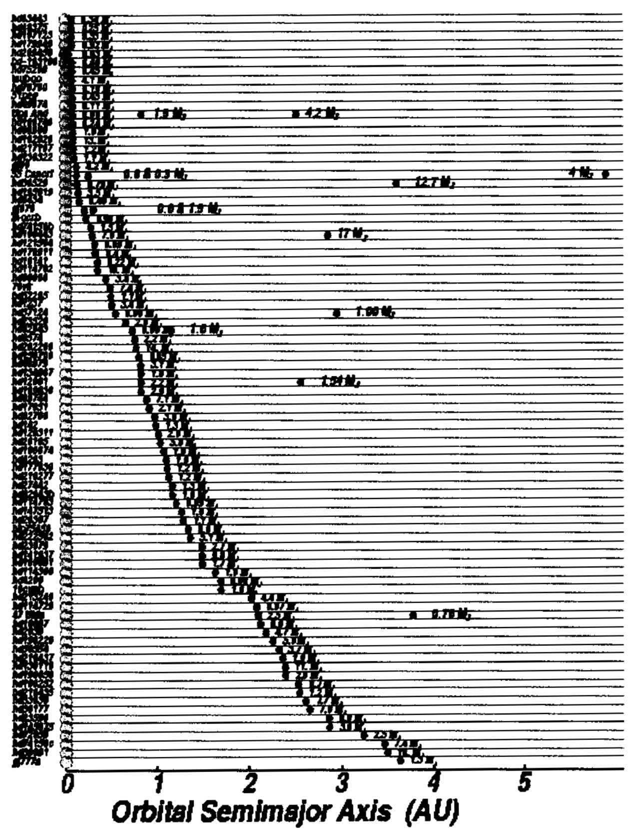

Figure 1, Exo-planet mass and Orbital Radius [Ref. 2]

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years and a few hundred million dollars in research and technology development, we now are quite clear that the ASO Roadmap leads us on a quest that is scientifically elegant and exciting, and technologically daunting. We will briefly touch on some of the highlights of recent evolutions in the plans and activities of the ASO program. Other papers and talks in this conference will go into more detail on the activities of several of the key ASO missions.

In its quest, ASO has set itself three Objectives [Ref 1]:

• The Emergence of the Modern Universe: ...to understand how today's universe of galaxies, stars and planets came to be.

• Stars and Planets: ...to learn how stars and planetary systems form and evolve.

• Habitable Planets and Life: ...to explore the diversity of other worlds and search for those that might harbor life.

The first of these goals as well as the star formation and early planet formation part of the second goal are addressed through several ASO missions, including the prolific Hubble Space Telescope, the Space Infrared Telescope Facility (SIRTF), the Stratospheric Observatory for Infrared Astronomy (SOFIA) carried aboard a specially configured Boeing 747 aircraft, and the James Webb Space Telescope (JWST) which plans to launch large ($25m^2$) deployable optics with near- and mid-infrared imaging and spectroscopic instruments in the 2011 timeframe.

The planetary system formation aspect of the second goal, as well as the third goal, are the focus of a set of science, technology and flight mission efforts being conducted in the ASO theme under the Navigator Program: *In Search of New Worlds*, and include the Keck Interferometer on Mauna Kea, the Large Binocular Telescope Interferometer on Mount Graham, the Space Interferometry Mission, and the Terrestrial Planet Finder.

And, astronomers' vision doesn't stop there, as plans are already being laid for missions decades in the future such as the Single Aperture Far-IR Telescope, an 8-10m telescope that could probe the early and distant star and galaxy formation, and eventually LifeFinder which would employ a set of 25m-class telescopes to search the atmospheres of distant planets for unambiguous tracers of life.

2. On-Going Projects – Great Success, Great Challenge

The most famous ASO project is the venerable Hubble Space Telescope. It has contributed beyond any initial conception to the explosive growth of knowledge in the field of astronomy and cosmology. Now, as it approaches the end of its design life, one more mission is planned to service the telescope and install new instruments. Unfortunately, the design feature that has been one of HST's greatest strengths, its serviceability by the Space Shuttle, now has seemingly come to an impasse due to the concerns around Shuttle safety. The current plan is to conduct the one planned servicing mission, but on a schedule delayed by the demands of the Shuttles safe return to flight. NASA's policy of providing a safe deorbit of any space hardware which might survive reentry and pose a safety threat may, however, not be able to rely on the Shuttle as originally planned. Studies are underway to devise means of attaching a deorbit vehicle to the HST through robotic approaches. These activities are compelling and difficult, and occupy much of the program's contingency capability as the program moves toward its next generation of space observatories.

As one Great Observatory struggles to leave the stage, the Space InfraRed Telescope Facility (SIRTF), the last of the Great Observatory series, strides to center stage to begin what promises to be another era of astronomical breakthroughs. Launched in August 2003, SIRTF is performing flawlessly as it works to complete on-orbit checkout of the observatory and its instruments preparing for the beginning of full science operations in 2004. Another paper in this session will provide a complete update on SIRTF as it embarks on its mission of scientific discovery.

3. Projects Moving Into Implementation

Several other projects within the ASO theme have made big strides forward since the last Roadmap was published. The Kepler Mission was selected through the Discovery Program, and is being prepared for a launch in 2008 on a mission to detect planets around other stars down to earth-size through the photometric transit technique. Kepler [Ref. 6] is designed to survey the extended solar neighborhood to detect and characterize hundreds of terrestrial and larger planets in or near the habitable zone. It utilizes a 0.95-meter aperture differential photometer with a 105 deg^2 field of view to continuously monitor photometric variations of 5-40 X 10^{-5} for ~100,000 stars. In addition to the basic science returned, these observations are important to the mainstream NASA planet finding missions discussed later because they help define the requirements for the search, including identifying common stellar characteristics of host stars, defining the volume of space needed for the search (the frequency of terrestrial planets, $\eta_\oplus$), and identifying target stars for these high-powered deep searches.

The Space Interferometry Mission (SIM) has completed an incredibly difficult set of technology developments to a level that enables it to move forward through NASA's mission development process from a definition phase (Phase A) to the design phase (Phase B). This marks a significant step forward for one of the ASO strategic missions. SIM is a boom mounted interferometer operating in the optical/NIR. SIM was recommended by the National Research Council decadal survey in 1991 [5] and reaffirmed in 2001 [4]. SIM has selected its spacecraft prime contractor (TRW), its instrument contractor (LMMS), and brought on board the science team, including a dozen leaders in the field of exo-solar planets, to help guide the project through its future development. It is planned to begin implementation in 2006 for a launch in late 2009.

SIM will provide the exquisite precision and sensitivity needed to detect planets of just a few earth masses in 1-5 AU orbits around stars from 4 to 30 light years away. SIM will push the limits on the mass of planets around nearby stars into the range predicted for the rocky as opposed to gas giant planets. SIM will provide 1μas astrometry for narrow angle deep searches, and 4μas for wide angle broad surveys. The measurement technologies required to accomplish this have been developed through a combination of efforts involving industry, academia and the JPL project team, and will be the topic of a paper in this session.

The James Webb Space Telescope, a follow-on to SIRTF and HST that will operate in the infrared, has also completed necessary enabling technology development and moved into Phase B. JWST will deploy 25m^2 optics to become the first of a new breed of extremely large telescopes in space. Astronomers in the last 50 years have made wondrous discoveries, expanded our understanding of the universe and opened humanity's vision beyond the visible portion of the electromagnetic spectrum. To further our understanding of the way our present universe formed following the Big Bang requires a new type of observatory with capabilities currently unavailable in either existing ground-based or space telescopes. Simply put, a goal of the James Webb Space Telescope (JWST) is to observe the first stars and galaxies in the Universe.

JWST faces many technology challenges, but perhaps the greatest is the development of lightweight deployable optics that can be launched into space and made to achieve the required optical performance. A very aggressive and broadly based effort was undertaken as a collaborative effort of several government agencies in addition to NASA to develop approaches to solve these problems. JWST has recently selected its mirror material, beryllium, and its development contractor, Ball Aerospace. This and other aspects of JWST will be the subject of another paper in this session.

4. All Roads Lead to TPF

Out near the planning horizon of the ASO theme lies the mission intended to nail the question: "are we alone," the Terrestrial Planet Finder (TPF). TPF has been endorsed by NRC decadal survey as their 3rd priority major space initiative, appropriate for a mission which will only formally start development late in the decade. It was said to be "the most ambitious science mission ever attempted by NASA." [4] In addition to imaging planets, TPF will undertake to obtain spectroscopy on their atmosphere to investigate the kinds of spectral signatures that could be indicators of biogenic origin. Again quoting the NRC report, "the discovery of life on another planet is potentially one of the most important scientific advances of this century, let alone this decade, and it would have enormous philosophical implications" [4]

With the kinds of system envisaged, TPF could make observations that would **detect** a planet in 2 hours, **detect** an atmosphere in 2 days, and **characterize** the planet in 2 weeks (Fig 2). Large optics, cryogenic detectors, precision wavefront control, and either formation flying interferometers or large coronagraphs will present daunting technical challenges. Over the past 2 years, TPF has developed both a Technology Roadmap and a Precursor Science Roadmap to layout the plan for activities required prepare TPF for a project new start.

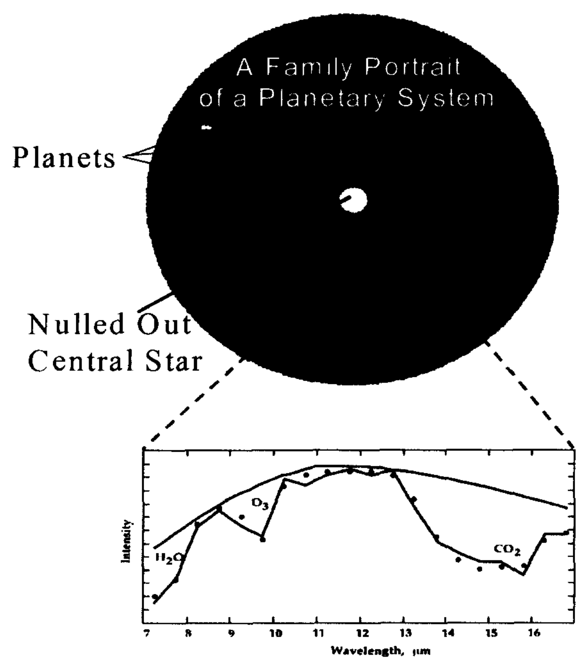

Figure 2, Simulation of Planetary System

A large technology development effort of on the order of $35-40M/year has been undertaken to develop architectural concepts and component and system-level technologies. At the same time, $5-10M/year is focused on precursor scientific inquiry through observation and theory work to help sharpen the scientific questions and provide the background knowledge to inform the tradeoffs leading to architecture choices. Such things as $\eta_{\oplus}$ (frequency of terrestrial planets), the level of extra-zodiacal light emitted from dust disks around stars which would obscure planetary signals, and the nature of biomarker signatures in planetary atmospheres will have great influence on how TPF is designed. Two architectural classes, visible coronagraphs with ~10m apertures, and IR interferometers with 40-100m baselines of either structure mounted or precision formation flying spacecraft are being carried toward a selection of a flight approach in about 2007. The activities planned over the next several years will be described in a paper later in this session.

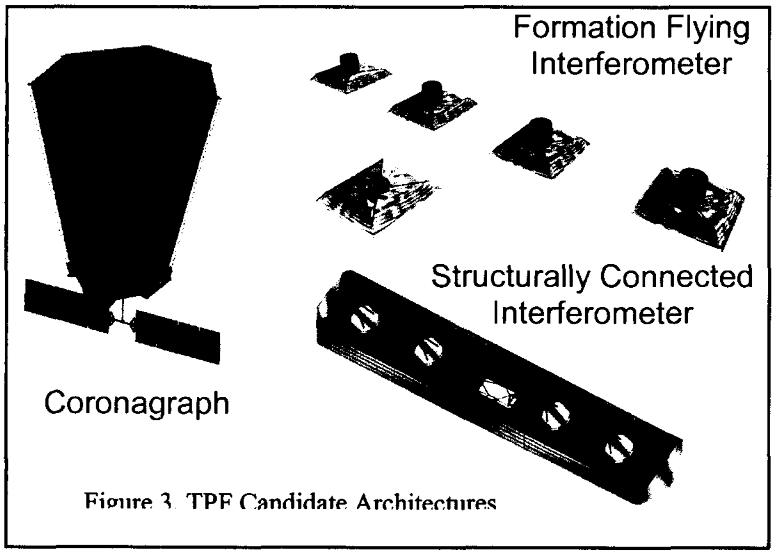

Figure 3. TPF Candidate Architectures

5. Beyond the Horizon

Not content to just undertake the incomparably difficult, the science community in the Origins Roadmap [1], have thrown out a challenge beyond the current horizons of technology. Four missions define this long-term vision of the Origins program. A large (10m) single aperture far-infrared telescope, SAFIR, and a large UV-Optical HST follow-on mission have been identified in the Roadmap for the next decade. Beyond that are the visionary missions for the far future. The first of these is Life Finder (LF), which would follow up on the discoveries of TPF with higher spectral resolution studies needed to identify unambiguously the signs of life on other planets. LF might consist of a TPF-like array of 25-m telescopes, based on technologies developed for other non-planet finding missions in the Origins theme.

The other mission — sometime in the 21st century — is Planet Imager (PI), which could actually spread a number of pixels across the face of a planet around another star, and allow us to look for continents and oceans. We know from the physics that this would require something like a constellation of ~40-m visible-light telescopes operating as an interferometer with a baseline of a few hundred kilometers. Such instruments, while currently almost unimaginably difficult to build and deploy, not to mention beyond the reach of any known funding source, would nonetheless open up a new frontier of exploration unparalled since the first ships navigated in the blind to our new world.

The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administrations.

6. References

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