Technology Development for Future Very Large Observatories[1,2]

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Abstract—The future very large observatories planned as part of the Astronomical Search for Origins will require significant advances in focal planes, large apertures, active and adaptive wavefront control and distributed thermal management systems. The Vision Missions and the needed technologies will be briefly described.

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1. INTRODUCTION

The Origins Theme of the Space Science Enterprise seeks the answers to two questions-"Where did we come from?" and "Are we alone?"- simple to understand, challenging to investigate, and profound in implication. The observations necessary to take the next steps toward answering these questions require continually advancing technologies and the Origins Technology Program addresses these needs. In the near term, the priority is to mature the technologies required for Space Interferometry Mission (SIM), James Webb Space Telescope (JWST) and Terrestrial Planet Finder (TPF). Looking forward, the challenging Vision Missions currently under study for future formulation include the Single Aperture Far-Infrared Observatory (SAFIR), New Large Aperture Optical-UV Telescope (NLAOUT), Life Finder (LF), and Submillimeter Evolution of the Cosmic Structure (SPECS). Many of the Origins missions share technology elements with the Beyond Einstein Initiative of the Structure and Evolution of the Universe (SEU) theme, also in SSE, that focuses on answering fundamental questions regarding the connections between space, time and matter.

Examination of these very large space observatories yields an ambitious set of needed technological capabilities; many areas require a considerable advancement on the state-of-the-art represented by the missions currently in implementation. The Technology Program seeks to incorporate the legacy of technologies developed for previous missions into each near-term Origins mission, which in turn will provide a technological foundation for missions farther out on the horizon. The first two missions described, SAFIR and NLAUOT, are considered for the 2015-2020 horizon for launch. The remaining are considered to be beyond the 2020 timeframe due to their demanding requirements.

2. UPCOMING MISSIONS

SAFIR

The Single Aperture Far-Infrared observatory will have a 10m class primary mirror operating at wavelengths of 20 to 800 μm. In order to achieve the highest possible signal to noise ratio, the thermal emission from the telescope and its optics must be reduced by cooling the telescope and its optics to close to 4K. The size of the aperture represents a significant advancement over the 0.85m, 5K Space Infrared Telescope Facility (SIRTF), and cryogenic temperature reached by the aperture will be significantly lower than the 35k the 6.5m, 18 segment primary aperture of JWST. The scientific program of SAFIR, planned for launch in the 2015-2020 timeframe, includes investigation of the formation of the very first stars, the origin of present-day galaxies, the formation of solar systems, and Kuiper Belt objects that may be remnants of the planet formation process.

NLAOUT

This 4-8m aperture telescope succeeds the 2.5m Hubble Space Telescope (HST), also termed Space Ultraviolet Observatory (SUVO) and Next Hubble Space Telescope (NHST), operating at ultraviolet and optical wavelengths. The research program includes investigation into formation

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of the first stars and heavy elements, the structure of the early universe, the emergence of stellar systems and the evolution of proto-planetary dust and gas disks into planetary systems.

Life Finder

Life Finder builds on the large, cryogenic apertures, as well as IR detector and cryocooling technologies, of SAFIR to realize a nulling IR interferometer with multiple 25m cryogenic apertures capable of detecting spectroscopic signs of life on habitable planets identified by TPF. Like TPF, the research program of LF is very focused due to its ambitious nature; LF must detect, for example, relevant methane and nitrous oxide signatures.

SPECS

The Submillimeter Evolution of the Cosmic Structure is envisioned as a submillimeter interferometer consisting of three 15-25m, 4K telescopes with a 1 km baseline. This space-based interferometer would observe the first and most remote galaxies in the universe, and investigate collapsing protostars and planetary system formation in the youngest galaxies.

3. TECHNOLOGY NEEDS

Detectors

The primary technology improvement needed to support Origins missions is detector performance. The development of very large (10^3-10^4 pixels) arrays of direct detectors for far infrared to mm wavelengths will yield dramatic gains in system performance. Advancement is needed for a number of elements of promising focal plane architectures, which include impurity band photoconductor and Transition Edge Sensor (TES) bolometer detectors, associated multiplexors, readouts, and cryocoolers; development of full-up working systems that include all aspects of the focal plane assembly are expected to yield the most significant advances in this area. In the ultraviolet regime, new solid state devices are critical, for example the cryogenic Superconducting Tunnel Junctions (STJ) sensors that allow energy resolution in conjunction with two-dimensional imaging. Detector development plans must consider both flight related environmental and resource performance issues, as well as monitoring and maintenance of production infrastructure that can be costly and unique to Origins applications.

Large Apertures

A second critical technology need is for accelerated production methods and improved architectures for large, often deployable or perhaps even constructable, apertures for space based telescopes and interferometers. For target mirror masses of 1000 kg, an 8m diameter mirror (e.g. SAFIR) can have an areal density no larger than 20kg/m^2, and this figure of merit decreases to by an order of magnitude at 25m diameter for LF and SPECS. This value includes all support structures, thermal control systems, which must be deployable, and actuators needed to maintain the mirror figure. The reflector must be able to hold its figure at cryogenic temperatures under both active and passive cooling conditions, in spite of the reduced mass density, and it is expected that as apertures increase, active primary surface control and downstream correction will play an increasingly important role. More useful figures of merit such as the ratio of stiffness to mass, which describes the structural efficiency, are emerging due to the increasing likelihood that volume constraints will begin to dominate. Further the production rate for these mirrors must be consistent with the timetable for assembly, test, and integration of the telescope.

Cryogenic Thermal Control

With the exception of NLAUOT, each of the apertures for the described upcoming missions must be cooled to cryogenic temperatures in order to reduce the background radiation of the instrument. A number of different technologies have been identified as necessary to build these future cold telescopes. Planned near-term missions cool their large telescope systems to 35 to 50 K using deployable sun shade and passive radiator systems. Reaching the required 4K temperatures passively becomes drastically more difficult and active cooling is an expected necessity, driving development of higher efficiency cryocoolers with increased heat-lift capacity. Thermal management techniques are undeveloped in this range; heat pipes for this temperature range do not exist at all, and high thermal conductivity tends to be associated with large cross sectional areas of metallic materials, clearly inconsistent with the need for light-weighted apertures. In addition thermal control systems must provide the temperature stability required for high sensitivity measurement. Associated technologies are needed to reduce the power dissipation of active components on the cold telescope and to minimize the heat leaking from the warm spacecraft.

Wavefront Sensing and Control

Wavefront correction is needed to produce high-quality wavefronts from very large apertures that are light-weighted at the expense of stiffness. This technology area encompasses all methods for creating a stable wavefront, and for maintaining the wavefront in the operational environment, which includes changes in temperature, gravity gradients, induced vibrations, etc. Correction may be implemented on the primary reflector, supporting structural elements, the secondary and at additional downstream locations. Distinct metrology approaches may be needed at various control element scales, and many of these metrology methods themselves require development. Once the wavefront sensing and metrology have yielded information on the system state, system modeling and correction algorithms are needed to implement control, as are high-precision and high-dynamic range actuators for effecting that correction.

4. CONCLUSIONS

The long-range goal of the Astronomical Search for Origins and Planetary Systems (ASO) theme is to detect and

characterize planets in orbit around nearby stars. Upcoming missions under study are described in the Origins Roadmap 2003 and the Space Science Mission Vision Statement. The Origins Technology Program identifies and develops the capabilities needed to accomplish these goals.

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BIOGRAPHY

Jennifer Dooley *is a research scientist at the Jet Propulsion Laboratory, where she has been working in the area of Large Apertures. She started in this field by supporting the development of the Dual Anamorphic Reflector Telescope, and other novel membrane telescope architectures. She began working at JPL in 1997 on magnetostrictive materials for use in cryogenic actuators and dampers. Since she has supported a number of missions in implementation and formulation, from the cryogenic testing of the SIRTF telescope to serving as a technology contributor to the SAFIR concept study team. She has a BS in Applied Physics from Caltech and an MS & PhD from Carnegie Mellon University, where she did research on magnetostrictive materials and developed a transmission electron microscopy technique for high-resolution mapping of magnetic domains within the materials.*