ORIGINS

T E C H N O L O G Y

HST has been — and will continue to be, well into this decade — the flagship observatory of the Origins Program. However, the time has come to "pass the torch" to a new generation of landmark observatories that will lay the foundation for astrophysics in this century. The first of these new observatories are SIM, NGST, and TPF. They will introduce optical/IR space interferometry, large-aperture folded optics, and constellations of interferometrically connected, large-aperture telescopes flying in formation. Bringing these missions to fruition poses enormous technological challenges. That is why the Origins Program is investing in the development of technologies focused on these missions, including component technology development, ground testbeds, and flight technology demonstration.

For now, most of the attention and technology resources are directed at SIM, NGST, and TPF, which need to progress toward launch in the next dozen years. But we cannot ignore our "seed corn" — technological investments in the more distant future, when observatories will need to be even more capable. For this reason, we are also proposing a Large Telescope System Technology Initiative (LTSI). This initiative is aimed at developing technologies needed for very large-aperture telescopes — with 10 times the collecting area of NGST and 100 times the collecting area of HST.

Taken together, the focused technology for near-term missions, technology investment for missions of the future (LTSI), and technology capabilities needed for emerging astrobiology form the foundation of the Origins technology program defined in this section.

SPACE INTERFEROMETERS, LARGE-APERTURE OPTICS, AND CONSTELLATIONS OF LARGE APERTURES INTERFEROMETRICALLY CONNECTED WILL REVOLUTIONIZE ASTROPHYSICS IN THIS CENTURY.

Independent of any specific instrument concept, the basic laws of physics set minimum requirements for the apertures that must be used to make the high-spatial- and high-spectral-resolution observations needed to accomplish the scientific Goals and Objectives of Origins. Relative to the benchmark of the largest ground-based telescopes and the 8-m NGST, terrestrial-planet spectroscopic characterization requires a tenfold increase in aperture area and low-resolution direct imaging requires an additional 25-fold increase in area. Such large collection areas probably preclude using missions with single telescopes. Rather, such missions will likely use constellations of large telescopes flying in formation and operating as interferometers. The basic building blocks for these systems will be diffraction-limited optical collectors with diameters of 20 to 40 m.

Through continued refinement and additional advances in active optical wavefront control, the technology developed for NGST can also be utilized for other 10-m-class telescopes that operate at shorter visible and UV wavelengths.

One of the most important motivations for going into space is the opportunity to cool the optics to cryogenic temperatures hundreds of degrees below room temperature. This allows another theoretical performance limit to be achieved. The telescope's ability to detect faint IR targets is then determined only by its size and the brightness of sources in the sky. The overwhelming thermal emission from the telescope has been eliminated. Most of the cooling is accomplished by putting the telescope in the shadow formed by a large sunshield. The temperature in the shadow will be sufficiently cold for most applications. If additional cooling is required, some form of active cryogenic refrigeration will be needed. The expectation is that this sunshield will be a very large gossamer structure, probably twice as large as the telescope. NGST, for example, will have a kite-shaped sunshield that could cover a tennis court.

The technological problem is not just how to build bigger telescopes and sunshields, but how to make them practical and affordable systems for space. The major added concerns are how to fold and pack a precision structure into the confined payload space of the launch vehicle and how to keep the total weight within the launcher's ability to deliver mass to orbit. Once the desired location in space is reached, the optics, instruments, and supporting structure must be unpacked, unfolded, aligned, focused, and stabilized to a precision equal to a small fraction of the wavelength of light — typically a few millionths of an inch. This process must be automated or, perhaps in the case of very large systems, accomplished with the help of astronauts. As the optics cool to cryogenic temperatures, the alignment and focus must be adjusted to compensate for the thermal contraction of all the parts.

This photo shows a to-scale version of a possible deployable sunshade currently being evaluated for NGST. Future telescopes will be much larger, but also must be very lightweight.

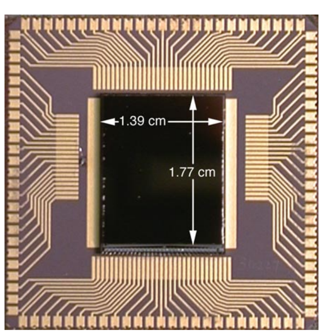
One remedy to all the problems introduced by precision physical structures is to eliminate as much of the structure as possible. The overall size of the optical systems envisioned for Origins will be hundreds and, eventually, many thousands of meters. These systems will consist of many individual optical apertures that are arranged to collect the light, combine it, and form very high-resolution images. As the maximum system dimension passes 100 m, maintaining the positions and alignments of this aperture array with physical structure becomes impractical and unaffordable. The alternative is to control each aperture independently, in free flight, as part of a precision constellation. This architecture for complex optical systems — the separated-spacecraft array — is a challenging and exciting vision.

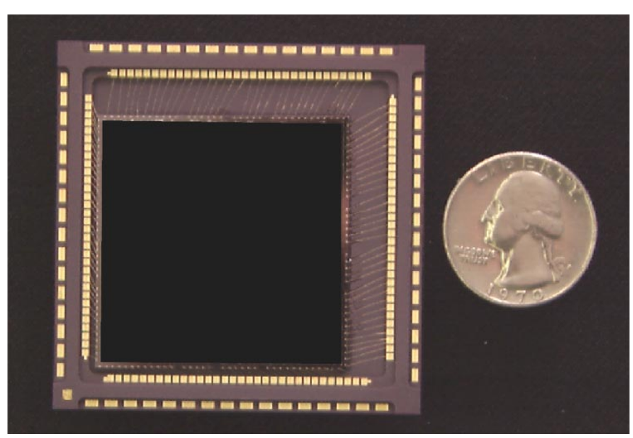
For the astronomers, the single most important technology issue is the photodetector, the device that transforms the collected light energy into an electrical signal. In the same sense that a microphone cannot improve the sound it receives and often adds noise and distortion, the photodetector always degrades, to some extent, the inherent performance of the optical system that feeds it. If the detectors are very good, the degradation is hardly noticeable. If they are poor, the capability in the rest of the system is seriously compromised. Improvements in sensitivity or size can make enormous gains in the type of scientific observatories enabled.

LARGE TELESCOPE SYSTEM TECHNOLOGY INITIATIVE

In order to achieve the combined capabilities needed for the next generation of much larger, deployable space telescope arrays, we propose the LTSI. This initiative will produce the materials, structures, and active controls for a 25-fold increase in diffraction-limited aperture areas. LTSI will solve the problems of passive and active cryogenic cooling of extremely large space structures; it will improve the critical deficiencies in available photodetectors; and it will address the issues of robotic or human-assisted deployment of these new telescopes from affordable launch systems. In order to provide focus to these efforts, they will be guided by the key technology needs of the next set of Origins missions, SUVO, FAIR, and the farther-term vision for detailed characterization of extrasolar planetary systems, the LF and PI missions.

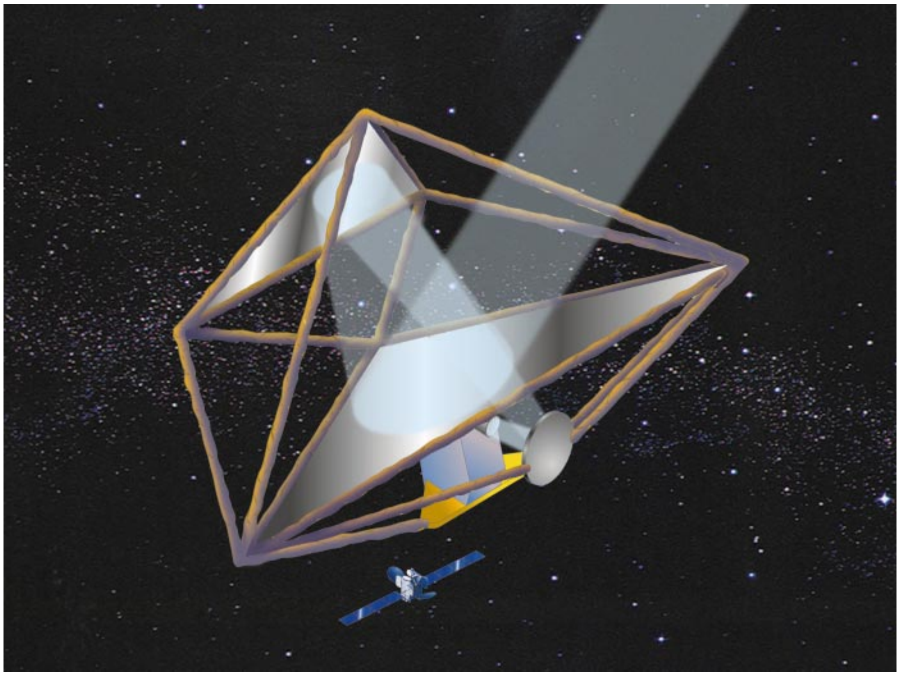
New, sensitive, large-format detector arrays at IR and visible wavelengths are a critical part of the revolutionary advances in our ability to study the Universe.





DETECTOR SYSTEM TECHNOLOGIES

The greatest benefits from detector improvements will come from larger visible and infrared focal-plane arrays for NGST and TPF, the creation of high-sensitivity imaging arrays that operate at far-infrared wavelengths for FAIR, and the perfection of high-energy, possibly energy-resolving, photon-counting devices and arrays for SUVO's spectral domain.



Imaging planets around other stars will require precision flying of constellations of large-aperture telescopes to achieve suitable resolutions and sensitivities.

Large infrared-detector arrays are under development for NGST and early concepts are being investigated for far-infrared arrays and superconducting devices that resolve both the image location and energy of individual UV photons. Significant improvement in UV quantum efficiency is critically important.

Improvements in detector performance frequently lead to a related need to improve the supporting cryocooler technology. While higher-temperature detectors offer some new options, it is clear that reliable, low-power, vibrationless cryocoolers for the 5–10 K range are needed. Small instrument cryocoolers based on both mechanical compression and gas adsorption are being investigated for this application. It also appears that some of the new energy-resolving detectors must operate in the millikelvin temperature range. The special techniques used to achieve extremely low temperatures are being adapted for space applications.

WE PROPOSE A LARGE TELESCOPE SYSTEM TECHNOLOGY INITIATIVE TO BUILD A TECHNOLOGICAL CAPABILITY "TOOL CHEST" FOR ORIGINS MISSIONS IN THE SECOND DECADE OF THIS CENTURY.

SPACE OPTICS

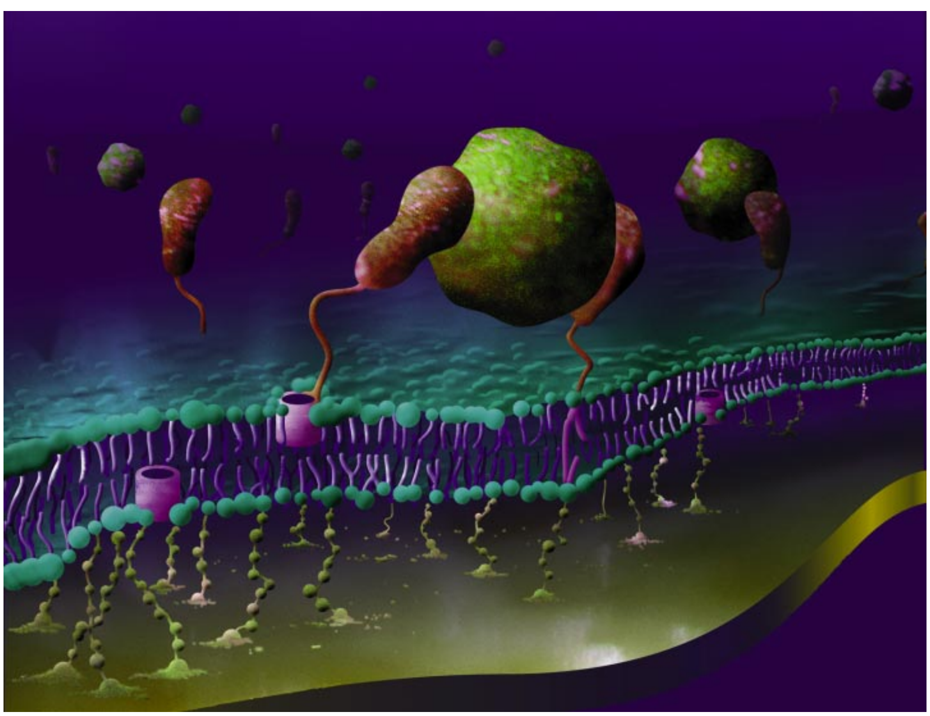
The single largest and heaviest component of a telescope is its primary optical element, typically a precisely shaped concave mirror that can weigh many tons. For space applications, the optical performance must be nearly perfect and the mass must be minimized.

The critical metric is the areal density of the fully loaded primary mirror (optical surface and substrate, reaction structure, actuators, wiring, and auxiliary cooling paths): 100–200 kg/m^2 is typical for conventional telescopes. The NGST mirror technology program expects to set the state of the art between 10 and 15 kg/m^2 in a few years. Similar technology will probably be used for TPF and SUVO. For larger observatories, starting with FAIR, areal densities of 1 kg/m^2 or less are needed. Ultimately, even more aggressive architectures with much larger (hundreds of meters) aperture diameters and much lower areal densities will be required to achieve the sensitivity and resolution for planet imagery and spectroscopy. The technology for these apertures is the focus of a proposed program called the Gossamer Spacecraft Initiative.

As the areal density is reduced, nearly perfect optical performance must be preserved. Expressed in terms of the fundamental resolution limit set by the wave properties of light, the optics must be diffraction limited. The required precision is proportional to wavelength and, therefore, systems designed for the infrared have larger allowable surface errors than visible-light optics. Initially, the goal is to maintain diffraction-limited performance at cryogenic temperatures for operation at infrared wavelengths. Eventually, the desire for visible-light planetary images will require technology for diffraction-limited performance at visible wavelengths with the largest, lowest-areal-density, optical collector arrays.

The expectation is that the residual errors in the primary optical surface will be actively corrected by shape control of the optical surface and by ancillary active optical elements elsewhere in the system. Technology programs are in place to develop the wavefront sensing and control components needed for these active optics systems.

These optics technologies and their lower-accuracy precursors have direct applicability to the needs of other Space Science themes and NASA Enterprises. For example, the technology for low-surface-accuracy telescopes produces excellent RF, microwave, and submillimeter antennas. High-frequency active microwave systems (radars), applicable to Earth Science and Structure and Evolution of the Universe (SEU) missions, may also benefit from this technology. Successful development will provide a "technology push" for SEU submillimeter and radio astrophysics missions. Finally, deep space and planetary optical communications links would be enabled by very large, low-cost collectors.



The ability to detect extremely small living organisms will come from new biosensors that are themselves the size of molecules. Shown here, AMBRI's ICS biosensor sends out antigens (orange "arms") to detect the presence of bacteria, viruses, and biochemicals (green "blobs").

PRECISION SPACECRAFT CONSTELLATIONS

We expect that TPF and subsequent interferometer systems (LF) will be composed of arrays of optical apertures that are each carried by an individual free-flying spacecraft. The light from each aperture is fed to a central station that combines the beams into the desired format. During observations, these spacecraft constellations must be controlled as if they were connected by a rigid structure. The allowable position errors are less than a centimeter over distances of hundreds or thousands of meters. To achieve this level of precision, long-distance range and angle measurement systems are being developed. Each spacecraft must also be equipped with a precision maneuvering system that allows it to accurately correct very small position errors. Between observations, the entire array must autonomously reposition and realign itself for the next target with efficient use of both fuel and time. The ST-3 mission is being designed to validate these precision separated-spacecraft array technologies in a complete system.

DEVELOPMENTS IN INFORMATION TECHNOLOGY WILL PERMIT HIGH-FIDELITY MODELING OF SYSTEMS THAT CANNOT BE TESTED OR BUILT ON THE SURFACE OF EARTH.

TECHNOLOGY FOR RESEARCH IN ASTROBIOLOGY

Previous research related to astrobiology has utilized traditional laboratory and field techniques. We expect that this situation will change dramatically as NASA's astrobiology program expands. New techniques and technologies for rapid and efficient genetic sequencing, "containerless" prebiotic chemistry, information visualization, and extensive virtual collaboration will be needed.

SUPPORTING TECHNOLOGIES

The technological difficulties of the optical system can, to some extent, be offset by improvements in launch vehicle capabilities. Greater payload volume is at least as important as more payload mass. Thus, improvements in launch vehicle technology and cost are a very desirable adjunct development for Origins.

HST owes its tremendous scientific productivity to critical repairs, maintenance, and science upgrades that have been performed by astronauts. As the complexity of the Origins observatories continues to grow, long-term success may require continued human intervention. The key will be flight systems and related technology for servicing observatories that are not located in low-Earth orbit.

Advances in information technology will also have substantial adjunct value for the Origins Program. We expect that in the far term, information technology will have a profound impact on both the science return and the implementation of these missions. Sophisticated autonomous operations and preliminary data analysis are obvious examples of the impact of this technology. Full-up system testing is likely to be impossible. Gossamer structures and separated-spacecraft arrays will not work on the ground and, therefore, cannot be completely tested under the load of Earth's gravity. The substitute will be testing of subsystems that are evaluated by very high-fidelity computer models of the whole system. Implementation of these computer models, both in hardware and low-cost software, will be a key contribution of the information technology revolution.