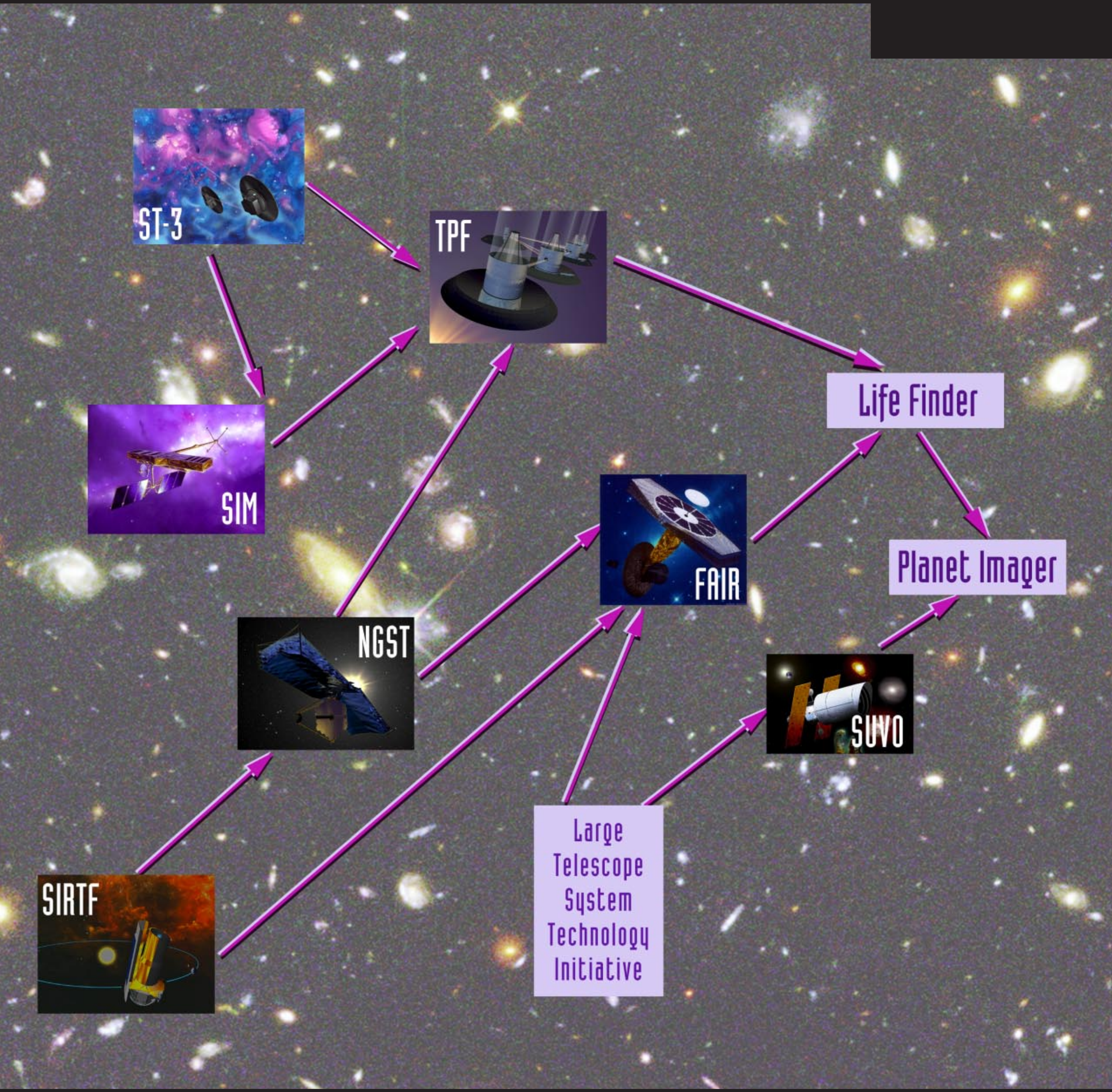

ST-3
TPF
Life Finder
SIM
FAIR
Planet Imager
NGST
SUVO
Large
Telescope
System
Technology
Initiative
SIRTF

ORIGINS

M I S S I O N   C A N D I D A T E S

A hallmark of the Origins architecture is that each major mission builds on the scientific and technological legacy of previous ones while providing new capabilities for future missions. Only in this way can the complex challenges of the theme be achieved at reasonable cost and acceptable risk. For example, the techniques of interferometry developed for KIA and SIM will be combined with the infrared detectors used on SIRTF and the telescope technology needed for NGST to enable TPF to look for habitable planets.

EACH MAJOR MISSION BUILDS ON THE HERITAGE OF THOSE THAT PRECEDED IT AND LEAVES A LEGACY FOR THOSE THAT WILL FOLLOW.

Beyond TPF will come a still more capable spectroscopic mission, the Life Finder (LF), which will make detailed studies of any life found on the planets that TPF discovers. The Filled-Aperture Infrared (FAIR) telescope would operate between TPF and LF to carry out its own science program and to develop the 25-m telescopes needed for LF. The technology of FAIR might also be used as a building block for the elements of a kilometer-baseline interferometer used at far-infrared wavelengths for cosmological studies. The Space Ultraviolet/Optical (SUVO) telescope will build on the technology developments of NGST and will itself pave the way for more challenging UV/Vis telescopes of the future.

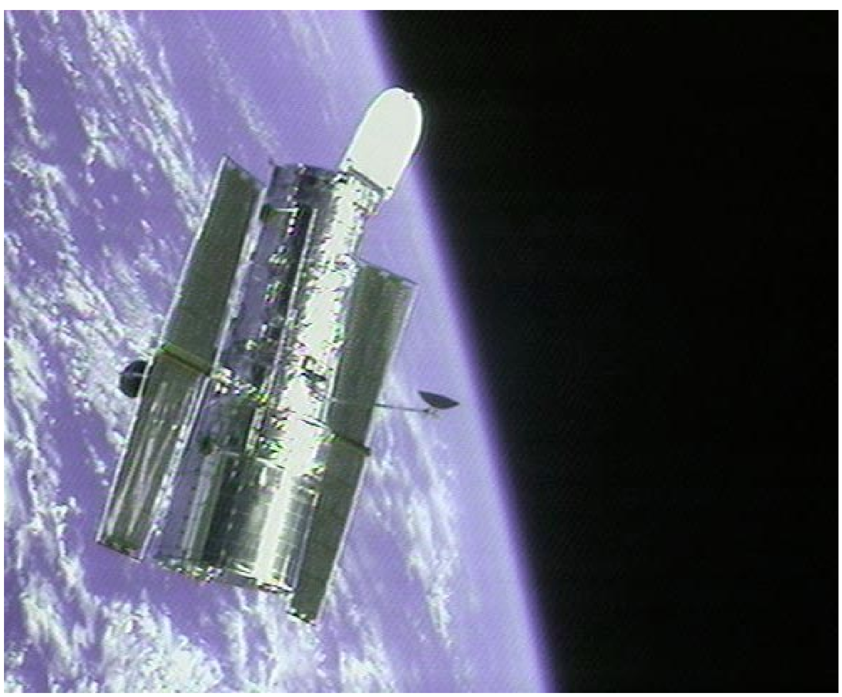
OPERATIONAL MISSIONS

Foremost among the current Origins missions is the HST, which was launched in April 1990, but — thanks to regular upgrades of its instruments via Space Shuttle servicing missions — remains NASA's most productive scientific program. This impressive record of achievement will continue into the second decade of HST's operation, with the installation in late 2000 of the Advanced Camera for Surveys (ACS) and a new active cooling system intended to reactivate the NICMOS near-infrared imaging system. The subsequent and final Space Shuttle mission, planned for 2003, will install both the highest-performance UV spectrograph ever flown in space (COS) and the first truly panchromatic imaging system ever flown in space, the Wide-Field Camera 3 (WFC3).

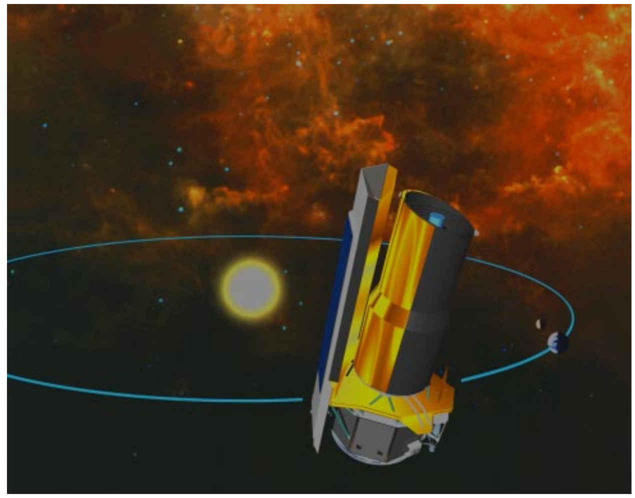
The importance of HST to the scientific community is matched by the pivotal role that the mission has played in educating the public about science. The observatory may be the best-known scientific facility in history, with its results used in classrooms around the world.

The most recent Origins mission to be launched is the Far-Ultraviolet Spectroscopic Explorer (FUSE), which is exploring the Universe at shorter wavelengths than are accessible by HST. In particular, FUSE is determining the abundance of deuterium, an

HST continues to be one of the most productive scientific instruments ever built.



isotope of hydrogen that was formed in the Big Bang, which will constrain our understanding of conditions in the very early Universe. FUSE will also investigate hot interstellar gases, in order to understand the life cycle of matter between the stars as gas cycles between stellar death and rebirth. A highlight of the FUSE mission is its highly visible role in the Maryland Science Center in Baltimore, which is visited by over 600,000 persons per year.



SIRTF will offer unsurpassed sensitivity at both mid- and far-infrared wavelengths to explore almost all aspects of astrophysics.

MISSIONS TARGETED FOR OPERATION BY 2002

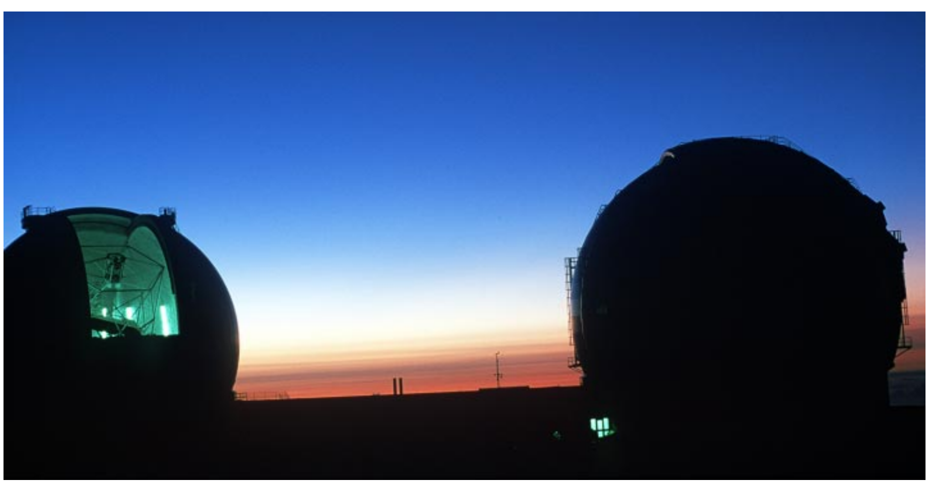
The SIRTF mission will be the fourth of NASA's Great Observatories and will use infrared wavelengths to achieve Origins' scientific goals. In particular, SIRTF will contribute extensively to the understanding of the formation of stars and planets and will investigate the evolution of luminous galaxies. A particular characteristic of the observatory will be its Legacy Program, in which very large and scientifically important research programs will be rapidly made available to the entire scientific community. The broad applicability of infrared technology is highlighted in the mission's extensive E/PO program.

While SIRTF will have unsurpassed sensitivity throughout the infrared wavelength regime, the Stratospheric Observatory for Infrared Astronomy (SOFIA) will complement the space mission with much better spatial and spectral resolution for the detailed study of bright objects. SOFIA can continually upgrade its

SOFIA consists of a 2.5-m telescope in a 747 aircraft that flies above almost all the atmospheric water vapor that blocks most infrared radiation from reaching ground-based telescopes.

instrumentation and will serve as a critical training ground for new generations of instrument builders. A key scientific goal of SOFIA will be the investigation of the conditions within the interstellar medium from which stars and planets form. This flying observatory will also have an ambitious E/PO program, with active involvement of teachers and students directly with the observatory itself.

The KIA will combine the infrared light collected by the world's two largest optical telescopes, the twin 10-m Keck telescopes in Hawaii, to undertake a variety of astrophysical investigations. Foremost among the questions to be studied will be the location and amount of zodiacal dust within other planetary systems. The KIA will also incorporate four smaller outrigger telescopes to detect the gravitational effects of planets with masses as low as Neptune's on the positions of their parent stars. This first in-depth census of planets will be an important contribution to our understanding of the evolution of planetary systems.



The twin Keck telescopes on Mauna Kea will be linked together as an interferometer (KIA) to search for planets.

MISSIONS TARGETED TO ENTER DEVELOPMENT PHASE IN 2003–2007

Extrasolar planets are a reality: More than 30 planet-sized objects have been indirectly detected around neighboring stars and the list of them is growing rapidly. But techniques available today from the ground are capable of detecting only the most massive objects, perhaps the mass of Saturn. The KIA will push this mass limit significantly lower, possibly to the mass of Neptune. However, space-based techniques will be required to detect objects whose mass approaches that of Earth and allow the first in-depth search for objects that are similar to our home planet.

SIM will be the first observatory capable of detecting planetary bodies having a few times the mass of Earth in orbit around nearby stars. Thus, SIM, by answering the question “Are there other worlds like our home planet?” will take a major step forward in answering one of the Origins Theme’s defining questions: *Are we alone?* SIM will extend the Keck census of nearby planetary systems into the range of the rocky, terrestrial planets for the first time, permitting scientists to refine their theories of the formation and evolution of planets like Earth. This census will form the core of the observing programs for subsequent missions that will investigate in detail the nature of these newly discovered worlds.

The SIM mission will usher in the era of optical interferometry from space. SIM will make highly accurate measurements of stellar positions to look for planets and to explore a broad range of fundamental astrophysical phenomena.

SIM TECHNOLOGIES

Technology	*Builds on past missions*	*Leaves legacy for future missions*
Interferometry	*KIA, ST-3*	*TPF, LF, far-IR interferometer*
Nulling	*KIA*	*TPF, LF*

In addition to its scientific goals, SIM will develop key technologies necessary for future missions, including constructive and destructive (nulling) interferometry and the precise, active control of optical pathlengths.

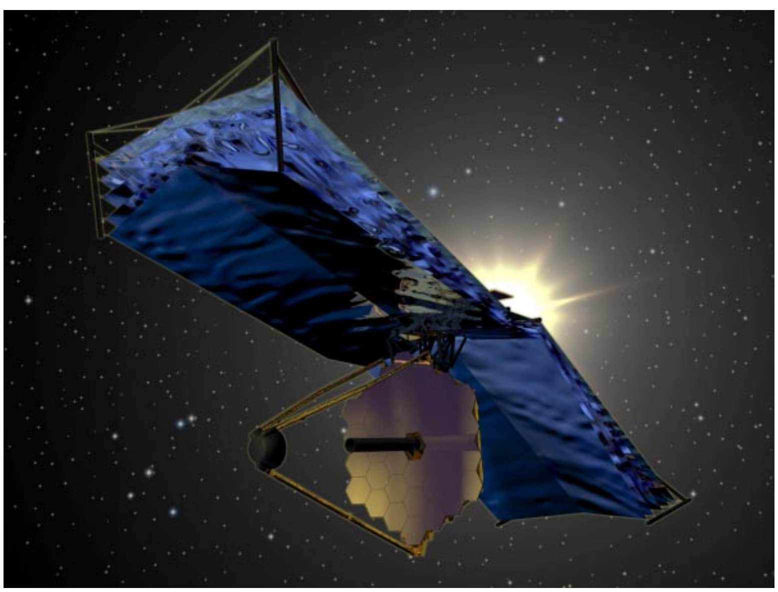
Beyond the detection of planets, SIM's extraordinary astrometric capabilities will permit the determination of accurate positions throughout the Milky Way Galaxy. This will permit a far more precise determination of distances to major populations of stars, as well as delineate in detail the large-scale motion of the Milky Way.

The next step after HST will be NGST, which will have more than three times the diameter of HST's mirror and about an order of magnitude more light-gathering capability. Because the prime science goals for NGST are to observe the formation and early evolution of galaxies, NGST's greatest sensitivity will be optimized for near- and mid-infrared wavelengths, where the expansion of the Universe causes the light from very young galaxies to appear most prominently. NGST will also be a powerful general-purpose observatory capable of undertaking important scientific investigations for a very wide range of astronomical questions, including those that are central to the Origins Theme.

NGST TECHNOLOGIES

Technology	*Builds on past missions*	*Leaves legacy for future missions*
Large, passively cooled optics	*SIRTF for passive cooling*	*TPF, LF, SUVO, FAIR*
Cryogenic coolers	*HST-NICMOS, FIRST, Planck*	*TPF, LF*
IR detectors	*SIRTF, SOFIA*	*TPF, FAIR*

NGST is expected to have a telescope diameter of 8 m and be celestial-background-limited between 0.6 and 10+ µm. NGST will incorporate imaging and spectroscopic instruments to cover this entire wavelength regime and will have a requirement to be diffraction-limited at 2 µm. With these capabilities, NGST will be a particularly powerful tool for investigating fundamental processes of stellar formation and early evolution, as well as the later stages of their evolution. In both cases, dust almost completely blocks our ability to observe the visible and UV light from rapidly evolving stars, so that detailed observations must be carried out at longer wavelengths.

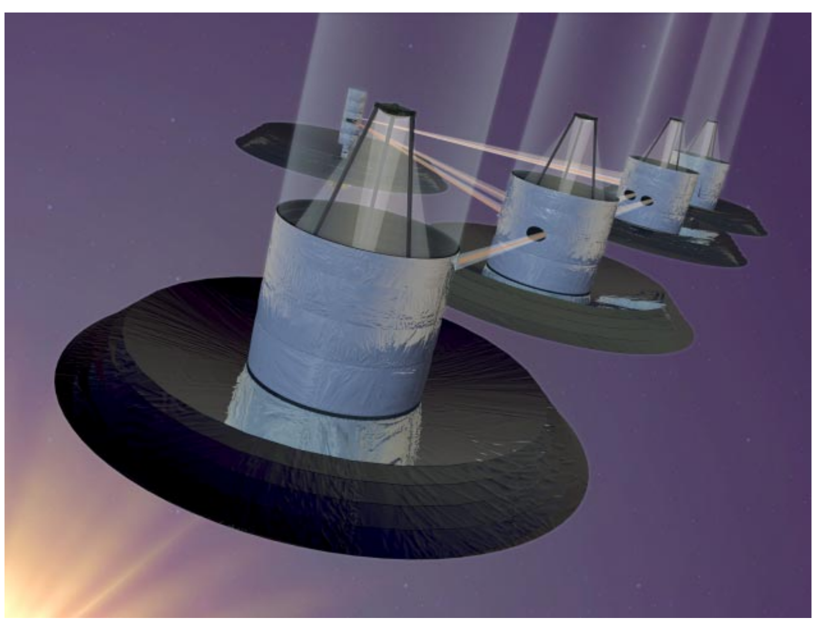


The NGST 8-m telescope cools behind its sunshade so that emission from the telescope will not swamp weak astronomical signals.

The European Space Agency (ESA) and the Canadian Space Agency (CSA) have agreed to contribute scientific instruments and spacecraft subsystems to the NGST project to enhance the overall capabilities of the observatory.

With the technology developed to build large apertures via the NGST program, the ability to carry out interferometry in space via SIM, and demonstrating formation flying of a spacecraft constellation via Space Technology–3 (ST-3), the next major step for the Origins Theme will be to combine these two capabilities into TPF. This mission will greatly expand our understanding of the origin and evolution of planetary systems, but more importantly, TPF offers the prospect of revolutionizing humanity's perception of its own place in the Universe by identifying habitable and possibly even life-bearing planets orbiting other stars. TPF will be able to find planets around neighboring stars that are like Earth in essential respects: warm, with water and an oxygen-containing atmosphere. The highly chemically reactive nature of oxygen is such that, if it is present in significant amounts, it is likely that there is some nonequilibrium process that is maintaining it. That nonequilibrium process is very likely to be life.

The separated-spacecraft architecture of TPF allows an adjustable baseline for applications ranging from planet detecting and characterization to milliarcsecond general astrophysics imaging.



TPF TECHNOLOGIES

Technology	*Builds on past missions*	*Leaves legacy for future missions*
Large, passively cooled optics	*SIRTF, NGST*	*FAIR, LF*
Formation flying	*ST-3*	*far-IR interferometer, LF*
Interferometry and nulling	*SIM, KIA*	*far-IR interferometer, LF*
IR detectors and cryocoolers	*NGST, Planck* *SIRTF, SOFIA*	*far-IR interferometer, LF*

TPF will use spatial interferometry to make images of planets in orbit around stars out to distances of 50 light years. The observatory's spectroscopic system will then observe the most promising of these worlds to seek the characteristic spectral signatures of water, carbon dioxide, oxygen (in the form of ozone), and methane.

As currently envisaged, TPF consists of four 3.5-m free-flying telescopes, each passively cooled to 35 K, and a central beam-combining facility. Planet detection and characterization will use a nulling interferometric mode at wavelengths from 7-20 µm with spectral resolution of ~20. TPF will also be able to operate as a general-purpose imaging interferometer at wavelengths from 3 to 30 µm with spectral resolutions as high as 300. With a maximum baseline of 1 km, TPF will offer angular resolution better than 1 milliarcsec to investigate astrophysical phenomena such as planet-forming protostellar disks and the energetic cores of active galaxies.

ESA has been actively studying an infrared interferometer referred to as either Darwin or the Infrared Space Interferometer (IRSI), with essentially the same science goals as TPF. Scientists and technologists at ESA and NASA are discussing ways in which the preliminary architecture studies can lead to effective collaboration on a joint mission. The ST-3 project is a technology demonstration mission that will use two or three spacecraft to form an interferometer with separations as great as 1 km to demonstrate critical technologies for TPF.

MISSIONS TARGETED TO ENTER DEVELOPMENT PHASE IN 2008–2013

A long-term Origins goal is the detailed study of life and its evolution in ecosystems beyond the Solar System. Achieving that goal will require observations beyond those possible with TPF. For example, searching the atmospheres of distant planets for unambiguous tracers of life such as methane (in terrestrial concentrations) and nitrous oxide would require a spectral resolution of ~1000, utilizing a version of TPF with 25-m telescopes. While the LF interferometer is beyond the horizon of this Roadmap, the FAIR mission, consisting of a single 15- to 25-m telescope, could serve as a building block for LF, while carrying out a broad range of scientific

The ST-3 mission will demonstrate the precision formation flying needed for separated-spacecraft interferometers such as TPF.

programs more ambitious than those of NGST and SIRTF, including: Probing the epoch of energetic star formation in the redshift range $1 < z < 10$ at a wavelength regime that can easily detect continuum and cooling-line emission from dust-enshrouded primeval galaxies, with an angular resolution capable of isolating individual objects at or below the limits of the Hubble Deep Field; investigating the physical processes that control the collapse and fragmentation of molecular clouds to produce stars of various masses by mapping cold, dense cores at <100-AU resolution at the peak of their dust emission and using gas-phase tracers such as H_2, H_2O, CO, OI, and NII; learning about the era of cometary bombardment that may have limited the early habitability of Earth by making high-spatial-resolution maps of the distribution of ices and minerals in the Kuiper Belts surrounding nearby stars; and studying the nature of the recently discovered objects in the Kuiper Belt of our own Solar System that may be remnants of our own planet-formation process.

FAIR TECHNOLOGIES

Technology	*Builds on past missions*	*Leaves legacy for future missions*
Large, passively cooled optics	*NGST*	*LF*
IR detectors and cyrocoolers	*NGST, FIRST, Planck*	*LF, far-IR interferometer*

The full exploitation of these wavelengths demands the sensitivity and high spatial resolution that only a very large, actively cooled telescope (<10 K) can provide. The proposed observatory would consist of a single filled aperture, 15 to 25 m in diameter, and would require the development of telescope technologies far lighter than those under consideration for NGST.

A successor to HST, SUVO operates at ultraviolet and optical wavelengths. SUVO, which will produce forefront science in all areas of modern astronomy, will be focused on the era from redshifts $0 < z < 3$ that occupies over 80 percent of cosmic time, beginning after the first galaxies, quasars, and stars evolved into their present forms. The science to be addressed in the post-HST era includes studies of dark matter and baryons, the origin and evolution of the elements, and the major construction phase of galaxies and quasars. Key unanswered questions include: Where is the rest of the non-baryonic Universe? What is the interplay of the dark and luminous matter in the Universe? How did the intergalactic medium collapse to form the galaxies and clusters? When were galaxies, clusters, and stellar populations assembled into their current form? What is the history of star formation and chemical evolution? Are massive black holes a natural part of most galaxies? A large-aperture telescope in space (SUVO) will provide a major facility in this century for solving these scientific problems.

SUVO TECHNOLOGIES

Technology	*Builds on past missions*	*Leaves legacy for future missions*
Large optics	*NGST, HST*	*Visible-light complement to LF, PI*
UV/optical detectors	*HST, FUSE, Galex*	*PI*

SUVO will build on the technology breakthroughs of NGST, but will demand novel UV and optical detector capabilities. The UV spectrograph and associated cameras will deliver more than a hundredfold increase in both throughput and multiplex efficiency over current instruments. SUVO will require a spectral resolution of R = 30,000 to 50,000 for primary science and R = 1000 for faint-object "survey mode," with an angular resolution of 0.3 arcsec or better over a band from approximately 1150 to 3200 Å. The technology inherent in SUVO, i.e. large, lightweight optics and metrology adequate for UV wavelengths, will help with a long-term Origins goal of making follow-up observations of planets discovered by TPF. SUVO could also be complementary to LF (see below). If equipped with an advanced coronagraphic capability, SUVO could search for weak spectral features at visible wavelengths due to oxygen or chlorophyll.

THE FAR FUTURE

Two missions define the long-term vision of the Origins program. The first of these is LF, which, as described earlier, would follow up on the discoveries made by TPF with the higher spectral resolution needed to identify unambiguously the signs of life on nearby planets. LF might consist of a TPF-like array of 25-m telescopes developed for the FAIR mission. The second mission — still farther in the future — is PI, which could actually resolve the disk of a distant planet and allow us to look for continents and oceans. We know from the laws of physics that such an objective would require a constellation of ~40-m visible-light telescopes operating as an interferometer with a separation of a few hundred kilometers. LF and PI would extend the reach of biologists, geophysicists, and atmospheric chemists to ecosystems far beyond Earth. The technologies we invest in for missions like FAIR and SUVO represent a down payment on these distant dreams.

HOW THE ORIGINS MISSIONS AND R&A RESPOND TO THE INVESTIGATIONS IN THIS ROADMAP.

INVESTIGATION	KIA	SOFIA
1. Fate of baryonic matter		
2. Early galaxies		
3. Chemical evolution		● Significant contribution
4. First stars with planets	● Contribution	
5. Multistar-systems formation	● Contribution	
6. Evolution of planetary disks	● Contribution	
7. Planet-forming disks around young stars		● Contribution
8. Planet detection and characterization	● Significant contribution	
9. Ultimate outcome of planet-forming process	● Significant contribution	
10. Climatological/geological effects on habitable zone		
11. Early Earth biosphere development		
12. Define biosignatures for remote sensing		
13. Relative importance of sources of organics on early Earth		● Significant contribution
14. Paths to the first protocell		
15. Environmental limits for life		
16. Detection of microbes on other planets		

● *Significant contribution* ● *Contribution*

MISSION

	SIRTF	SIM	NGST	TPF	FAIR	SUVO	R&A
			● (black)			● (red)	
	● (black)		● (red)	● (black)	● (red)		
			● (red)		● (red)	● (red)	
		● (red)	● (red)	● (red)			● (black)
			● (black)	● (black)	● (red)		
	● (black)		● (red)	● (red)	● (red)		
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