National Aeronautics and Space Administration

ASTROPHYSICS LONG-TERM PROGRAM

PROJECT CONCEPT SUMMARY:

Large Ambient Deployable Infrared Telescope

OCTOBER 1980

FOREWORD

This document is one in a series describing projects of current interest in NASA astrophysics planning. Some of these projects were originally suggested by the Space Science Board of the National Academy of Sciences and the Outlook for Space Study Group. Others have been suggested by various internal working groups. Still others have been suggested by individual scientists or scientific groups both within NASA and in the broad astrophysics community. The descriptions presented in these volumes are based on technical studies or preliminary assessments done by NASA's Ames Research Center, Goddard Space Flight Center, Marshall Space Flight Center, and the Jet Propulsion Laboratory. Since the projects are at various stages in the planning process, the level of detail presented gives our current best estimate of the scientific objectives and technical characteristics. Where variations such as alternative strawman payload combinations have been studied, these are presented, and their effects on the overall project are discussed. Specific spacecraft, and other systems or subsystems, are identified or implied in many cases to illustrate that a concept for conducting the project exists. Such identification does not reflect a commitment on the part of NASA to utilize such hardware should the project be implemented. Similarly, in the actual implementation of any particular project, details will inevitably change. Our objective in assembling these documents has been to produce a set of concise project descriptions in a uniform format. They are intended to serve as a basis for discussion within the astrophysics community and to help determine how individual missions can best be accommodated within NASA's overall astrophysics program.

This document was prepared by Michael W. Werner and James P. Murphy of Ames Research Center.

Franklin D. Martin

Franklin D. Martin
Director, Astrophysics Division
Office of Space Science

LARGE AMBIENT DEPLOYABLE INFRARED TELESCOPE

PROGRAM SUMMARY: A 12-m diameter, segmented IR telescope
Deployed and revisited by the Space Transportation System (STS)
Multiple Experiments

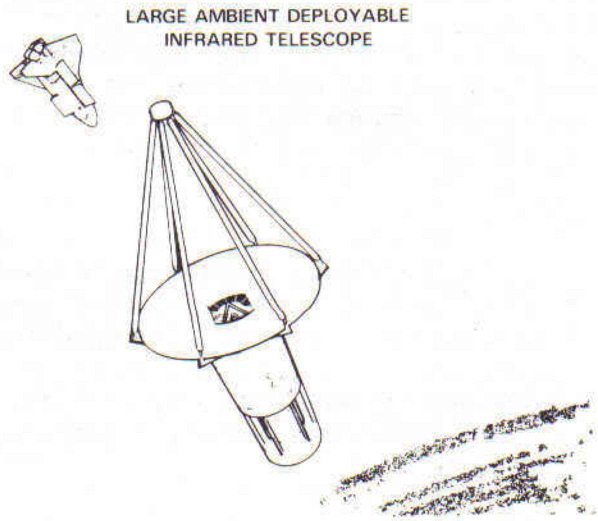
ORBIT: Inclination: 28° to 50°
Altitude: 700 km

MISSION DURATION: 10 years or longer

ORBITED MASS: 25,000 kg (12-m size)

OBJECTIVES:

To conduct infrared astronomical investigations outside the Earth's atmosphere using an STS-launched telescope with a large aperture (10 to 30-m diameter), which will provide improved spatial resolution and energy-collecting capability for the study of a wide variety of astrophysical phenomena throughout the infrared spectral region.



TYPICAL SCIENCE INVESTIGATIONS:

(1) High-spatial-resolution studies of the structure of distant galactic nuclei, of regions of star formation, and of circumstellar shells in our galaxy

(2) Very high-spectral-resolution studies of chemical abundances in stars and in the interstellar medium of our own and distant galaxies

(3) Investigation of the evolutionary status of protostellar objects by probing the velocity distributions and excitation conditions in the clouds of dust and gas from which they are forming

(4) Studies of mass motions associated with the ejection of matter by stars and extragalactic objects, such as quasars and dust-obscured galactic nuclei

(5) Studies of the composition and properties of small, distant, solar-system objects such as cometary nuclei and the satellites of the outer planets.

Investigations will be performed at wavelengths out to 1 mm. The short-wavelength limit for diffraction-limited performance is not yet defined and will be determined by a combination of scientific, technical, and cost considerations. It is anticipated at present that the telescope will perform excellently down to wavelengths at least as short as 30 μm. A telescope of comparable size which is intended primarily for submillimeter ($\lambda > 100$ μm) observations is described in a companion booklet prepared by the Jet Propulsion Laboratory. It is possible that the two concepts will eventually be merged to produce a single instrument.

MISSION DESCRIPTION:

The baseline design has a 12-m-diameter aperture collector and can be placed in orbit by a single STS mission. The optics consists of segmented sections with a backup structure self-deployed in orbit to form a free-flyer.

LARGE AMBIENT DEPLOYABLE INFRARED TELESCOPE

After assembly and checkout, data-collection operations will be conducted by the ground science team. A variety of instruments will be included on each flight to permit a wide range of scientific studies. The instrument cryogens will be resupplied and instrument change-out accomplished through periodic visits by the STS.

STATUS:

Deployable large telescopes, capable of being carried on the STS, have been studied by the military. The specific designs have been for other purposes, but the technology appears to be applicable to a deployable telescope for infrared astronomy.

A technology assessment activity for a 10 to 30-m-diameter telescope is presently under way at NASA Ames and JPL. Preliminary results of this activity show that a 10 to 20-m self-deployed telescope is feasible with near-term technology. A larger 15 to 30-m telescope can be carried in one shuttle load, but must be assembled using the Remote Manipulator System. More advanced lightweight mirror technology is also required. Active segment sensing and position control is required for either size for diffractionlimited operation at the shorter wavelengths.

SCIENCE

Rationale

Large apertures improve the capabilities of astronomical telescopes in two ways: increased spatial resolution (linearly dependent on aperture diameter) and increased sensitivity (dependent on aperture diameter squared). The large ambient deployable telescope, with a nominal 12-m diameter, would produce an order-of-magnitude improvement in spatial resolution and a two-order-of-magnitude increase in collecting area, in comparison with the 1-m airborne and balloon-borne telescopes which are now available for observations between 30 μm and 300 μm. The increased angular resolution would permit the study of the structure of objects such as the nuclei of galaxies, and, in our own galaxy, regions of star formation and circumstellar shells. These objects are generally obscured in visible light by dust, which becomes increasingly transparent as one goes to longer infrared wavelengths. Thus, a very large aperture infrared telescope is an extremely powerful tool for studying the structure of a broad class of objects. It must be placed above the atmosphere to avoid the absorption that makes ground-based observing impossible through most of the infrared spectral band. The increased collecting area would facilitate the use of high-resolution spectroscopy for the study of chemical abundances (via infrared forbidden lines) in dust-obscured regions in our own and other galaxies. Very high-spectral-resolution studies of Doppler profiles of atomic and molecular lines in the infrared would provide an unparalleled opportunity to study velocity distributions associated with the accretion of matter by protostellar or prestellar objects, ejection of matter by stars, and mass motion in extragalactic objects, such as quasars and dust-obscured galactic nuclei. Combining the large collecting area and the high spatial resolution will permit these spectroscopic studies to be carried out on very fine spatial scales, which will be of crucial importance to our understanding of these phenomena.

Objectives

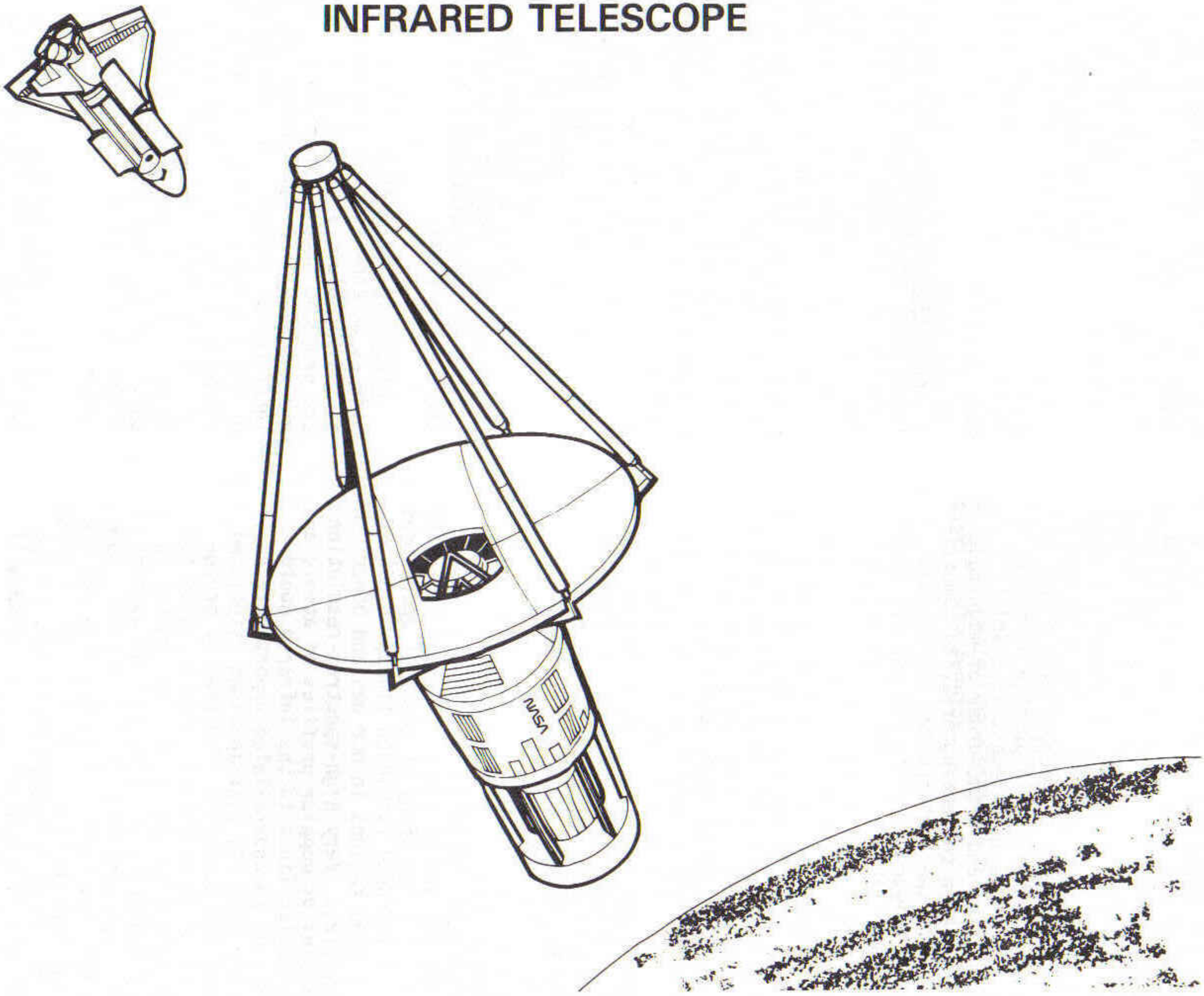
An infrared telescope with a diameter of 10 m or more would not only address many specific problems already recognized but would also be a general-purpose astronomical telescope capable of discovering new and unanticipated phenomena. The objectives listed below are a few examples that are presently known to be particularly well suited to such an instrument and particularly important to resolving current astronomical problems.

Formation of Stars. An understanding of this process requires that the composition, dynamics, and structure of dense clouds of dust and gas be determined on a scale small enough to spatially resolve individual protostars, and regions where stars are forming, at wavelengths long enough to see through the surrounding dust. Apertures of 10 m or larger are essential for the required spatial resolution, and the large collecting area will provide sufficient signal to determine the velocity profiles needed to distinguish in-falling from out-going matter. The study of atomic and molecular emission lines from such regions will provide information about the excitation and state of motion of the gas and these in turn can be related to the evolutionary status of the forming stars.

Circumstellar Shells. Planets and life as we know it could not have formed if heavy nuclei (atomic mass >4), which are produced in the interiors of stars, had not been injected somehow into the interstellar medium. An understanding of the processes involved in this enrichment of the interstellar medium from the atmosphere of old stars can be aided by the study of velocity profiles of shells of material surrounding evolved stars, such as giants, supergiants, and novae.

Galactic Structure and Evolution. The high angular resolution of the large ambient telescope will permit the study of nearby galaxies on spatial scales

LARGE AMBIENT DEPLOYABLE INFRARED TELESCOPE



which are only a small fraction of the distance from the sun to the center of our galaxy. This along with the large collecting area will permit many important studies in the area of galactic structure and evolution. Variations in metal abundance with position in an external galaxy, which would be the result of positional gradients in the rate and type of star formation over the lifetime of the galaxy, can be studied by comparing the infrared-line emission from ionized regions at different positions in the galaxy. Star formation at the current epoch can be studied by observations of particular atomic and molecular transitions which are tracers of shockwaves that may trigger star formation in the interstellar medium.

Quasars, Galactic Nuclei. Studies of the structure of such objects, of their composition, and of trends in both structure and composition should help to determine how these objects have evolved. Of special interest are: (a) the dynamics and structures of Seyfert galaxies and quasars which exhibit short-term variability suggestive of faster-than-light signal propagation and/or extremely concentrated energy sources and (b) exploration of the connection between peculiar galaxies which have unusually luminous nuclei ($L>10^{10}$ solar luminosities, chiefly at infrared wavelengths), but appear otherwise normal, and the rarer, but much more luminous ($L>10^{12}$ solar luminosities), quasars and Seyfert galaxies.

Solar-System Studies. A 12-m space telescope would resolve the disks of Jupiter and Saturn into > 100 spatial resolution elements at far-infrared wavelengths and thus could be used in combined spatial and temporal studies of the planetary atmospheres. These studies would include observations in the vibrational-rotational transitions of important molecular constituents such as CO_2, NH_3, and H_2. The large collecting areas will permit photometry and spectrophotometry of faint outer solar system objects, including asteroids, cometary nuclei, and the satellites of the outer planets, which may represent the best available samples of material from the primitive solar nebula. Finally, a 10-m-diameter or greater telescope, diffraction limited at 30 µm, could resolve and detect a Jupiter-type planet in an orbit with a radius > 5 astronomical units around a late-type star within a few parsec of the Sun.

Measurements

Measurements of several types would be required to achieve the scientific objectives described above. Photometry and spatial mapping would be carried out with angular resolution varying from 0.5 arc-sec at $\lambda = 30$ µm to 20 arc-sec at $\lambda = 1$ mm. Spectral resolving power of at least 10^5 is needed throughout the 10^- µm to 1-mm range. This could be attained either through the use of conventional spectrometers or with heterodyne techniques.

With currently available detectors, the large ambient telescope would reach its ultimate sensitivity limit (i.e., be background-noise rather than detector-noise limited) over much of the infrared spectral region for both broad-band and moderate-to-high spectral-resolution observations. Improvements in detector sensitivity will permit background-limited performance at even higher resolution. The anticipated development of detector arrays will dramatically increase the efficiency of the telescope for both mapping and spectroscopy by permitting simultaneous measurement of many spatial and/or spectral resolution elements.

Typical Payload Complement

In addition to the deployable 10 to 30-m telescope and its guidance system, a typical payload might include:

(1) Multiband photometers, or infrared cameras based on detector arrays,

for photometry and mapping

(2) Several spectrometers, including grating instruments for low- to moderate-resolution work and interferometers and heterodyne receivers for higher resolution spectroscopy

(3) Polarimeters for use with both the photometers and the spectrometers

(4) Cryogenics for cooling the instruments.

MISSION DESCRIPTION

Launch Phase

The Large Ambient Deployable IR Telescope will be compatible with direct mounting in the Space Transportation System (STS) bay (no pallets). Upon achieving the proper orbit, the cargo-bay doors will be opened and the telescope deployed.

Mission Duration

The mission duration will be 10 years, with periodic visits (1 to 2 - yr intervals) by the STS for replenishment of cryogens for the cooled detectors, instrument changeout, and any required repairs.

Missions

The Large Ambient Deployable IR Telescope will be operated as a multiuser observatory; several instruments will be flown so that a number of teams of scientific investigators and guest observers will share the use of the telescope facility. In addition, it will be feasible to change or modify instruments during the periodic resupply visit by the STS.

Operations

The first operation after achieving orbit will be deployment of the telescope. After the cargo-bay doors are opened, the stowed structure is first tilted to a vertical position, then the various segments of the large collector are unfolded and locked into place. Finally, the entire self-contained telescope is separated from the STS. Checkout of the telescope facility will be conducted from the ground; however, the STS will remain on station until checkout is complete so that any unforeseen problems can be resolved. After checkout, the telescope will be commanded to start its program of astronomical observations.

GENERAL CHARACTERISTICS

Deployable large telescopes, capable of being carried by the STS, have been studied by the military. The specific designs have been for other purposes, but the technology appears to be applicable to a deployable telescope for infrared astronomy. A technology assessment activity for a 10 to 30-m telescope is presently under way at NASA-Ames and JPL. Preliminary results of this activity show that a 10 to 12-m telescope is feasible with near-term technology. The general characteristics of such a system are as follows:

The 12-m telescope would operate over the 2 μm $<\lambda<$ 1000 μm wavelength range with diffraction-limited performance down to at least 30 μm. Passive cooling would be used to achieve an optics temperature around 200 K. A sunshade would not be required as long as the sun and moon are kept greater than 60° off-axis. The optics system would be a two-mirror Cassegrain with a parabolic primary. The primary mirror would consist of seven 4-m glass segments, attached to a graphite-magnesium backup structure. The segments, backup structure, and spacecraft would fit in the Shuttle bay and be self-deployed on reaching orbit. The secondary mirror would be approximately 0.5m in diameter and made of lightweight beryllium. The secondary mirror would be capable of space chopping. Active control of the primary mirror segments would be required to achieve diffraction-limited operation at 30 μm wavelength. Three position actuators per segment are required to control the required degrees of freedom. Position error signal could be derived either from capacitative edge sensors operating between the segments or from a laser trilateration system operating periodically on retro-reflectors mounted on the front surface of the segments. Control moment gyros would be used to provide retargeting capability and stability during observations. A focal-plane star sensor aligned to the science instruments would provide attitude information during observations and updates to a package of gyroscopes. Total weight for a 12-m telescope including optics, backup structure, and spacecraft subsystems is estimated to be 25,000 g.

MISSION OPTIONS

A telescope with a primary mirror up to 30 m in diameter has been studied, however, a number of difficulties brought out by the studies show that this requires more advanced technology than the 12-m system described above. Thus considerable additional work is required before such large sizes can be seriously considered.

PROGRAM ASSESSMENT

Studies of the break points in cost and technology are currently under way. These studies will determine the shortest wavelength at which the telescope can operate and will define in more detail the required technology development.

TECHNOLOGY READINESS

Although a 12-m telescope appears feasible, several technology areas need further investigation and development. These are summarized below:

(1) Deployment: Telescopes up to 12 m in diameter can be packaged with a backup structure and self-deployed. Larger diameters require assembly using the Remote Manipulator System.

(2) Optics: Light weight 4-m glass segments can be fabricated using "frit" bonding technology. These segments are compatible with a 12-m system. More advanced, lighter weight segments would be required for a larger telescope. Candidate materials for lighter weight segments include aluminum, glass, beryllium, and others. More work is required on fabrication, handling, polishing, and testing techniques for the mirror segments.

(3) Optical System Control: Control of the segment positions is required at the shorter wavelengths because of deformations of the backup structure. Several different concepts appear feasible for sensing and control of the segment positions. Trade offs and analysis are required to determine which concept is the most attractive. For larger telescopes (>12 m) control of the figure of each segment may be required because of thinness of the lighter weight segments.

(4) Dynamic Structure Analysis: A large structure, such as would be needed, has very complex dynamic modes because of its inherently flexible structure and low damping. Additional analysis is necessary to examine the problems of assuring maintenance of optical precision during disturbances caused by slewing, attitude control, etc.

REFERENCES

Murphy, J. P., Kiya, M. K., Werner, M., Swanson, P. N., Kuiper, T. B. H., and Batelaan, P. D., "A Large-Aperture Space Telescope for Infrared and Submillimeter Astronomy", SPIE Paper 228-11, presented at the SPIE Technical Symposium East, Washington, D. C. , April 7-11, 1980.