The NASA Space Infrared Telescope Facility

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Abstract.. The NASA Space Infrared Observatory Facility (SIRTF) is a cryogenically cooled space observatory being developed for use in the early years of the next century. SIRTF will carry an 85 cm primary optic cooled to 5.5K and instrumentation covering the wavelength range from 3 μm to 180 μm. Placement into a heliocentric orbit at a significant distance from the Earth and careful attention to thermal and cryogenic design will allow 250 liters of superfluid helium to provide a lifetime in excess of 2.5 years. The instrumentation for SIRTF will include imaging 3 μm to 180 μm and spectroscopy from 5 to 100 μm.

More than 75% of the observing time on SIRTF will be available to guest investigators selected from the scientific community. Within the general observer program, SIRTF is developing a "legacy" science program of major investigations to take best advantage of the unique capabilities and relatively short lifetime of the SIRTF observatory.

SIRTF began definition phase funding in November of 1996. Industry partners have been selected for design and development of SIRTF and design activity began in September 1996. The development phase is expected to begin in the second quarter of 1998 leading to a launch in mid 2002.

1. Mission Description

The Space Infrared Observatory Facility is an 85-cm cryogenically-cooled observatory for infrared astronomy from space which will be the key infrared component of NASA's astrophysics program. It will be launched with a Delta rocket into a heliocentric orbit trailing the Earth, where it will be free of the viewing restrictions and heat loading associated with geocentric orbits. Operations will also be greatly simplified, and major parts of the sky will be available for long-term continuous viewing. Data from SIRTF will be processed and disseminated through the facilities of the Infrared Processing and Analysis Center (IPAC) located on the campus of the California Institute of Technology.

Using new design concepts, the telescope will be launched warm and then cooled when in orbit, while the three focal plane instruments will be cooled by liquid helium at launch and throughout the mission. This new architecture permits the launch of a large aperture telescope in a very lightweight configuration, bringing SIRTF within the launch capabilities of the Delta vehicle. The observatory will provide a 14K helium bath to cool the scientific instruments, and

the helium boil-off will be used to cool the telescope to the 5.5 1{ required for the longest wavelength observations planned. Radiative cooling will keep the outer shell of SIRTF below 50 K which reduces the parasitic heat load 011 the cryogen to a very low level and allows only 250 liters of liquid helium to provide the 2.5 year lifetime. SIRTF will have a pointing accuracy of a few arcsec and stability of a fraction of an arcsec for long periods. Precision offsets will allow targets to be placed 011 spectrograph slits wit h sub-arcsecond accuracy.

A scientifically interesting feature of the heliocentric orbit is that toward the end of its nominal mission SIRTF will enter an interplanetary dust cloud, discovered with IRAS, which follows the Earth in its orbit (Dermott, et al. 1994).

2. Instrumentation

SIRTF will contain three science instruments: the Infrared Array Camera (IRAC), the Infrared Spectrograph (IRS) and the Multi-band Imaging Photometer (MIPS). Together, these instruments provide imaging and spectroscopic capability from 3 to 180 μm. Each instrument is equipped with state of the art large format detector arrays. To simplify operations and reduce mission cost only one instrument will be operated at a time. In addition, all the instruments have been designed with very few moving parts and a minimum number of operation modes.

The instruments are packaged radially around the telescope focal plane and share the unvignetted field of view through a fixed array of pick-off mirrors and entrance apertures, as shown in Figure 1. The two IRAC entrance apertures and the three MIPS apertures are aligned perpendicular to the direction toward the Sun so that long strips of the sky can be conveniently mapped by moving the telescope line of sight at a constant solar elongation.

2.1. IRAC

The IRAC is a four channel camera designed for simultaneous wide field imaging at 3.5, 4.5, 6.3 and 8 μm with 25% bandwidth. Two adjacent fields of view in the SIRTF focal plane feed the array detectors through dichroic beam splitters and band pass filters as shown in Figure 1. The characteristics of IRAC are summarized in Table 1.

Table 1. IRAC Specifications

Band[a]	Field	Array Size	Type	Pixel	Sensitivity[b]
3.5 μm	5′x5′	256X256	InSb	1.2″	2.6 μJy
4.5 μm	5′x5′	256X256	InSb	1.2″	3.3 μJy
6.3 μm	5′x5′	256X256	Si:As BIB	1.2″	18 μJy
8 μm	5′x5′	256X256	Si:As BIB	1.2″	31 μJy

[a] $\lambda/\Delta\lambda$=4 for all 11<111 ,1.

[b] 5σ, 500 seconds

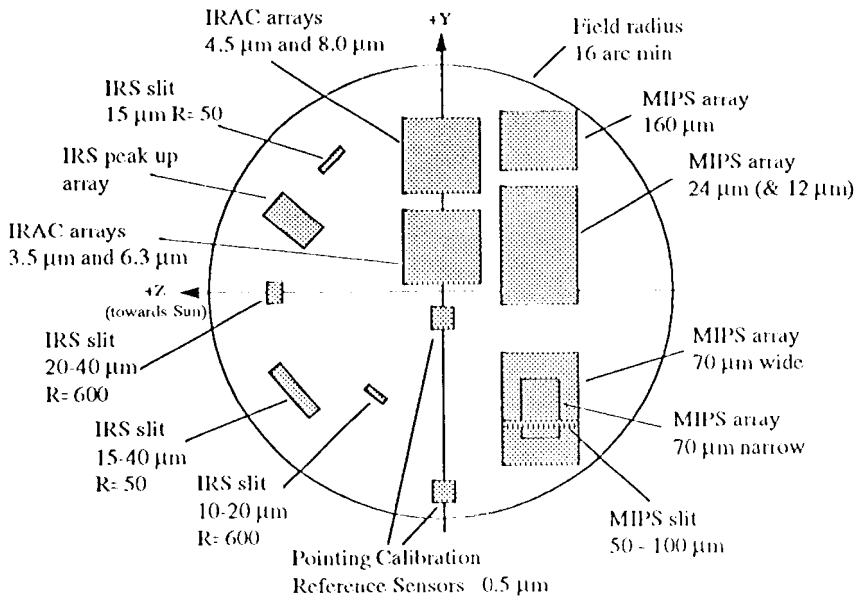

Figure 1. Proposed arrangement of entrance apertures in the SIRTF focal plane. Locations of the quadrant arrays of the Pointing Calibration Reference Sensors are also shown.

2.2. IRS

The IRS is composed of four optically and mechanically separate spectrometer modules. The two low resolution modules have long slits and produce a one dimensional image along the slit. The high resolution modules have short slits and operate in echelle mode producing an image of 7 to 10 spectral orders on their array detectors. The short wavelength, low resolution module uses a portion of its detector array as a 10 μm imager to aid in source acquisition.

The optical and mechanical design of each IRS module is optimized for reliability and ease of fabrication, assembly and test. Each module contains a single detector array and there are no moving parts and no adjustable parts in any module. The IRS characteristics are summarized in Table 2.

Table 2. IRS Specifications

Band	$\lambda/\Delta\lambda$	Slit Size	Array Size	Type	Sensitivity[a]
5-15 μm	50	3.6″x60″	96X128	Si:As BIB	550 μJy
15-40 μm	50	9.7″x145″	128x128	Si:Sb BIB	1500 μJy
10-20 μm	600	4.8″x12″	128x128	Si:As BIB	3×10^{-18} w/m^2
20-40 μm	600	9.7″x24.2″	128x128	Si:Sb BIB	3×10^{-18} w/m^2

[a] 5σ 500 seconds

2.3. MIPS

MIPS consists of a single module containing five optical trains that can be operated in any of three modes: a) simultaneous imaging at 24, 70 and 160 μm, b) fine sampled imaging at 70 μm for super-resolution processing and c) low resolution spectroscopy from 50 to 100 μm for spectral energy distribution measurements. A single axis tilting mirror selects the appropriate optical train for the desired mode and modulates the signal for good photometric performance with the germanium detectors, The tilting mirror also implements an efficient 'nap while scan' mode in which the telescope slews slowly along a track parallel to the alignment of the MIPS input apertures while the tilting mirror executes a sawtooth motion to 'freeze' a series of sky images on the detector arrays. A 12 μm channel is being considered to aid in star detection for pointing reconstruction.

Table 3. MIPS Specifications

Band[a]	Field	Array Size	Type	Pixel	Sensitivity[b]
(12 μm	0.5′x5.3′	13x128	Si:Sb BIB	2.4″	100 μJy)
24 μm	1.2′x5.3′	11 OX128	Si:Sb BIB	2.4″	24[1 μJy
70 μm	5.3′ x5.3′	32x32	Ge:Ga	9.4″	1.0 mJy
70 μm	2.6′x2.6′	32x32	Ge:Ga	4.0"	1.6 mJy
160 μm	0.5′x5.3′	2x20	Ge:Ga*	16″	7.5 mJy
50 100 μm	0.3′x2.6′	16x32	Ge:Ga	9.4″	6.6 mJy

[a] $\lambda/\Delta\lambda$ = 4 for imaging bands, R=20 for 50-100/111) SED mode

[b] 5σ, 500 seconds, confusion limited @ 160 μm

● SIICSSVCI Ge:Ga

3. Scientific Capabilities

The capabilities of SIRTF were built around four scientific themes to define and focus the designs of the facility and instruments. While the resulting capabilities can be applied to a wide range of studies, a description of some applications within the four themes is a useful illustration of SIRTF's power. Figure 2 compares SIRTF's sensitivity to some astronomical objects.

Brown Dwarfs and Super Planets Two surveys at 3-8 μm of 300 deg^2 separated by 2 years, using about 250 days, could find $\sim$ 50 brown dwarfs within $\sim$ 65 pc of the Sun through proper motion selection, even if brown dwarfs make up < 20% of the dynamic mass of the halo. Spectroscopic follow up of this survey might study H_2O, NH_3, CH_4 with 5-15 μm low resolution spectroscopy.

One 111111 dred nearby stars could be surveyed for super-planets in about 25 days of observation. SIRTF can be expected to separate a super-planet 20 AU from its star at 10 pc.

Using its large separation from Earth, SIRTF will be able to perform MACHO parallax measurements at 3.5 μm by timing MACHO events which have been previously detected with ground based measurements (Gould 199 4). Monitoring of the MACHOS will take very little observing time.

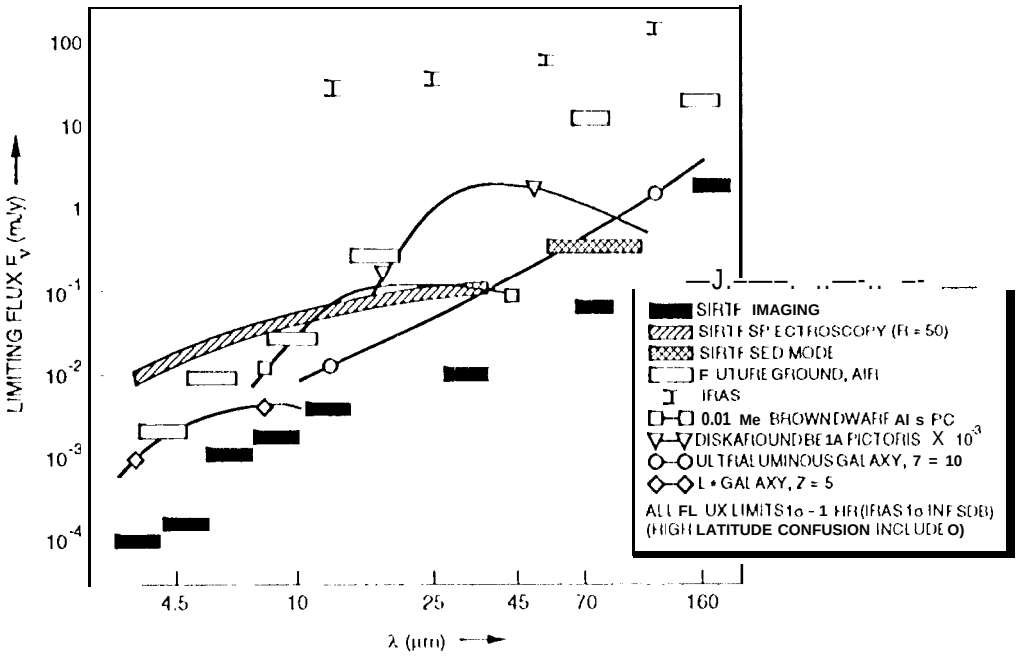

Figure 2. Comparison of the expected sensitivity of SIRTF with other facilities and the brightness of several astronomical sources.

Protoplanetary and Planetary Debris Disks A protoplanetary disk census at 6.5 - 160 μm in several nearby star formation regions will require $\sim$ 60 hours/5 deg^2 to yield $\sim$ 100 sources with luminosity $> 10^{-3} L_{(\odot)}$ at 500 pc. Low and high resolution spectra from 5 - 100 μm of resulting PPD sources requires 1 hour/source for 10σ spectra.

A debris disk survey at 24 to 160 μm of 1000 stars will require 21 days and would see typical disks at 20 pc and β Pic type disks at 1 Kpc. High resolution imaging of the debris disks requires about 50 hours/disk.

Photometry of Kuiper belt objects at 70 μm requires about 2 hours to reach 0.25 mJy 5σ to detect a 15 Km diameter object.

Early Universe A deep survey of 0.2 deg^2 at 3-8 μm is expected to detect $\sim$ 600 L* galaxies at Z= 3 for an investment of 35 days observation time. 3.5, 4.7 and 8 μm colors provide good separation by redshift for selection of objects for follow up spectroscopy and can be used for statistical redshift data.

A confusion limited survey of 1 deg^2 at 3.5, 8, 24, 70 and 160 μm will take about 30 days to reach deep into the confusion for study of the extragalactic background.

Ultraluminous Galaxies and AGNs A survey to 1 mJy 5σ at 70 μm with a target of 10^5 ULIR galaxies and AGNs would cover 5 to 50 deg^2, depending on the actual distribution of ULIRGs and AGNs, and consume 5 to 50 days. Simultaneous coverage at 24 and 160 μm would be obtained. A redshift survey of 100 of the resulting sources with $F_{70\mu m} > 10$ mJy would take about 1 hour

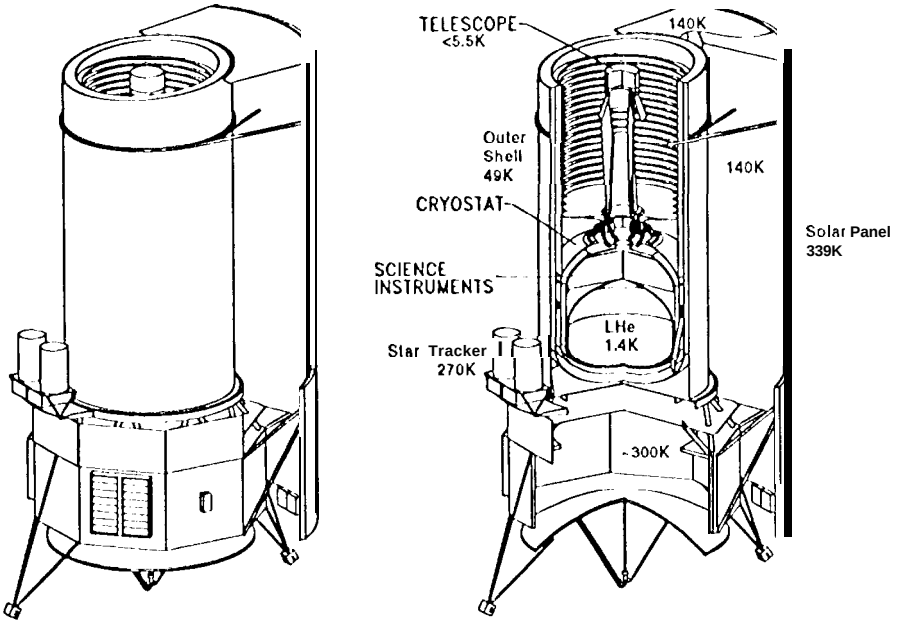

Figure 3. The current configuration of the SIRTF facility showing some expected operating temperatures.

per source for a 5 - 40 μm spectrum with R=50. An excitation study of 100 sources from the survey would take about 2 110111"s per source for 10 40 μm spectra with R= 60[).

4. Design Status

The general form of the SIRTF flight system has now been settled (Figure 3). Cryogenic and thermal designs appear suitable for attainment of required life time and critical telescope and instrument temperatures. The outer shell temperature is predicted to be low enough that helium consumption is dominated by cold instrument power dissipation, not parasitic< An engineering test bed model of a beryllium primary mirror suitable for the SIRTF telescope has been fabricated and successfully tested below 10K. The rest of the test bed telescope is nearing completion. An engineering model of the IRS echelle module has been produced and used successfully at the Palomar 200 inch telescope. Spacecraft components and spacecraft systems design for SIRTF do not press any limits of current technology and no problems are anticipated other than producing a satisfactory flight system within budget.

5. Observation Programs and Community Participation

SIRTF observational programs will be defined and conducted by both Guaranteed Time Observers (GTO's: instrument teams, interdisciplinary scientists,

project and facility scientists) and by the general scientific community. The general community will use 75% of the SIRTF observing time through a General Observer (GO) program and a Legacy Science program. The SIRTF Legacy Science program is intended to augment and enhance the specific, target-oriented observation programs proposed by (; '1 'O's and GO's by providing a mechanism to perform and archive observations that are expected to have long-term, high priority scientific value to the community as a whole. Each legacy program will probably involve a time allot.atioIl of order 500 hours or longer and will enjoy no proprietary period for the data so that follow 011 observations can be defined and executed with minimum delay. Legacy science teams and programs will be competitively selected well in advance of the launch of SIRTF to insure adequate preparation time for rapid implementation of observation programs once SIRTF is launched. Legacy programs could occupy as much as 40% of the first year of SIRTF observations.

The community is participating in definition of the SIRTF observation programs through a series of workshops organized by the SIRTF Community Task Force. These meetings are typically held at the winter meetings of the American Astronomical Society and annual meeting of the Division for Planetary Sciences of the AAS.

Current news about the SIRTF facility development, science program, operational issues and current time lines for project milestones and the issuance of Announcements of Opportunity for observers can be found on the World Wide Web by using the URL: http://sirtf.jpl.nasa.gov/sirtf/home.html

6. Preject Status and Schedule

The industrial partners for SIRTF development and construction have been selected. Ball Aerospace Systems Division will develop and produce the Sill'1'l' telescope and cryogenic system. Lockheed Martin Missiles and Space will develop and produce the SIRTF spacecraft and will integrate the observatory system. NASA approved the start of the SIRTF definition phase (phase B) in November 1996. An eighteen month phase B is anticipated with phase C/D development starting in the spring of 1998. Launch is expected in the last half of 2002.

The Third SIRTF Community Science Planning Workshop will be held in January 1997 at the Toronto AAS meeting. Release of the SIRTF Legacy Science NRA is anticipated in the spring of 2000 with legacy science selection following in the fall of 2000, The General Observer NRA release and subsequent science selection is expected in the last half of 2001. "

Discussion

Dr. H. Okuda: 1. What kind of survey works do you anticipate for SIRTF observations? 2. What is the cooling time to equilibrium of the warm launch t('1('s('0])('?

Dr. Gautier: 1. We anticipate that a number of survey type programs will be proposed in the legacy science program and that a substantial amount of the