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SIRTF: The Fourth Great Observatory

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ABSTRACT

The Space Infrared Telescope Facility (SIRTF), the fourth of the Great Observatories, will look through a new window on the universe. Using SIRTF, the astronomical community will be able to explore the infrared universe with a depth and precision complementary to that achieved by NASA's other Great Observatories—the Hubble Space Telescope (HST), the Advanced X-ray Astrophysics Facility (AXAF), and the Compton Gamma Ray Observatory (GRO).

SIRTF will achieve unprecedented infrared sensitivity by fully utilizing a new generation of infrared detector arrays. The new detectors, combined with an 85-cm cryogenic telescope, will allow SIRTF to provide scientific capabilities so impressive that SIRTF was designated the highest priority major new mission for all US astronomy in the 1990s.

This paper will provide a review of the SIRTF program—the science, mission design, facility, and the instruments. Emphasis will be placed on those features of the program which will allow us to realize the great scientific potential of the Observatory in a resource-constrained environment.

INTRODUCTION

SIRTF has been recognized as a key element in the NASA astrophysics program for over a decade. The Observatory has been restructured and redefined to be consistent with the new NASA paradigm of *faster/better/cheaper*. Innovations have played a major role in defining the new SIRTF. The science focus is sharply defined, the mission implementation uses a unique solar orbit, the Observatory has adopted a unique architecture, the science instruments use state-of-the-art infrared arrays, and finally, an implementation approach is being employed which creates a partnership between JPL and industry.

In the fall of 1993, NASA was under great pressure to change the way large projects were conducted. In particular, costs had to be reduced and development times had to be shortened. In this environment SIRTF

was redefined, resulting in the current concept, which provides a substantial part of the originally envisioned scientific capability at a fraction of the cost.

The scientific capabilities of SIRTF have been guided for over a decade by a Science Working Group (SWG) selected in 1984. The SWG reassessed SIRTF's scientific capabilities in the light of the pressure to reduce the mission scope and decided to rebuild SIRTF's scientific requirements around the needs of four specific science programs: Brown Dwarfs and Superplanets, The Early Universe, Protoplanetary and Planetary Debris Disks, and Ultraluminous Galaxies and Active Galactic Nuclei. These four areas were singled out as of particular importance for SIRTF by the National Academy of Science's decadal review (the Bahcall Report), which in 1990 designated SIRTF as the highest priority major new mission for US astronomy.

The mission objectives of examining as efficiently as possible the infrared sky led to the adoption of an innovative heliocentric (solar) orbit for SIRTF. The Observatory will be launched on a Delta launch vehicle, and will be placed in an Earth-trailing 1-AU orbit. This orbit eliminates viewing restrictions due to Earth occultations, reduces thermal heat loads associated with proximity to the Earth, and simplifies operations by having the Observatory in a slowly changing location that accommodates flexible scheduling for commanding and for data transmission. Data from SIRTF will be processed and disseminated to the science community using the Infrared Processing and Analysis Center (IPAC) located on the campus of Caltech.

The architecture of the Observatory is substantially different than that used in previous infrared missions. The telescope will be launched warm and cooled on-orbit, in large part by radiation to space. This architecture enables the launch of a large-aperture (0.85-meter) telescope in a very light-weight implementation. Using radiative cooling significantly reduces the quantity of cryogen needed over a 2 1/2-year mission life. The resulting mass reduction is essential to using a Delta class launch vehicle. The Observatory will provide a 1.4 K helium bath

environment for the science instruments. Two hundred and fifty liters of helium will be used to provide the environment for the instruments, and the helium boil-off will be used to reduce the telescope temperature from the 50 K that radiative cooling would provide to the 5.5 K required to make the longest wavelength background-limited observations. A major challenge for the Observatory will be the provision of a pointing control system (PCS) that has pointing accuracy of a few arcsec and stability of a fraction of an arcsec over long periods.

SIRTF will employ three instruments for the collection of scientific data. The Infrared Array Camera (IRAC) will provide imaging at 4 wavelengths between 3 and 8 μm . The Infrared Spectrograph (IRS) will provide both low- and high-resolution spectra between 5 and 40 μm , and the Multiband Imaging Photometer for SIRTF (MIPS) will provide long wavelength imaging between 12 and 180 μm . Each instrument will employ state-of-the-art detector arrays representing improvements of several orders of magnitude over previous infrared sensors used in space astronomy missions.

SIRTF will use a unique implementation approach that includes a teaming arrangement between JPL, industry and the science community. The Observatory will be built by industry based upon a design developed jointly with JPL and the science community. Once selected by a competitive process, industry team members will become part of the SIRTF team, and will work together to meet project commitments. The project must be accomplished within a fixed budget, which will require an unprecedented degree of cooperation. To conserve resources, the plan is to accomplish the majority of the work in a short period of time to minimize time-related costs. Clear responsibilities will be established to minimize redundant or overlapping efforts. The result is expected to be a demonstration of how, using the new paradigm of *faster/better/cheaper*, NASA can continue to conduct significant scientific missions using state-of-the-art technology with uncompromised performance.

SCIENCE OBJECTIVES

The flavor of SIRTF's scientific programs can be inferred from four examples, one drawn from each of the four scientific theme areas. SIRTF will be able to detect "brown dwarfs" — objects too low in mass to shine like stars — if they are common enough to constitute a significant fraction of the mass in the

solar neighborhood. SIRTF will also be used to carry out an ultra-deep survey of a small region of the sky to study galaxies as they appeared when the Universe was about one-tenth of its present age. SIRTF can study the composition of the dust in solar system like structures around other stars and compare it with that of the dust in the outer portions of our own planetary system. Finally, SIRTF can peer into the central regions of the most energetic objects known in the Universe, to tell us whether they derive their power from large numbers of stars, from accretion of material onto black holes, or from as yet unidentified physical processes.

These examples illustrate SIRTF's possible contributions to the study of the four science themes chosen to define the mission requirements. Of course, a mission optimized for these four programs will have broad applicability to a much wider range of astrophysical investigations, and the mix of science to be carried out from SIRTF will be defined closer to launch by a peer-reviewed selection of investigations. Finally, in addition to its great power for the study of known scientific problems such as those defined above, SIRTF's great gain in observational capabilities gives this mission very high potential for unexpected discoveries.

MISSION DESIGN

Orbit Selection

SIRTF requires an orbit that is far from the Earth's thermal and radiation environment. A solar orbit was chosen among three options. A circular high-Earth orbit (HEO) with an altitude of 100,000 km would place the Observatory beyond the trapped radiation environment, but this option was rejected because of the high energy required to circularize the transfer orbit from low-Earth altitude. The L2 libration point is also ideally suited for astronomical observations. It is a dynamic equilibrium point about 150-million kilometers from Earth along the Sun-Earth line where the Sun-Earth gravity is balanced by the centrifugal force. But it too was rejected because it requires a propulsion system and precise navigation and maneuvering throughout the mission lifetime. The solar orbit that was selected is actually an escape orbit from Earth. Given the proper injection energy and direction from the launch vehicle, the Observatory is given a push to barely escape Earth gravity, but not enough energy that it leaves Earth rapidly. After separation from the launch vehicle, the Observatory does not require any propulsion for targeting and

maneuvering, thus eliminating the need for a propulsion system on board, and a navigation team before and during flight operations.

Figure 1 gives a view of the solar orbit from the ecliptic pole. Earth is fixed at the origin of this rotating coordinate system, and the Sun is at 150-million kilometers along the negative x-axis. The Observatory is about 0.32 AU from the Earth at the end of a 2 1/2-year mission. The loops in the figure are a result of the eccentricity of the solar orbit. At aphelion, the Observatory is moving away because it is moving slower than the Earth, and vice versa at perihelion.

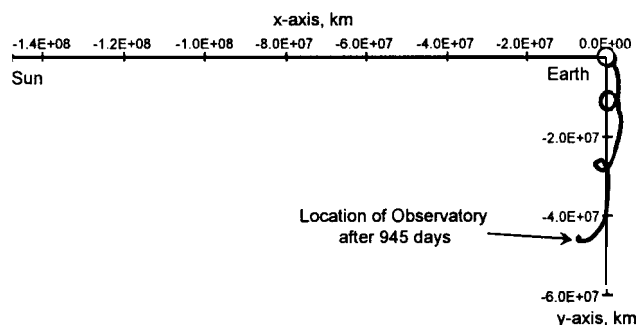


Figure 1. Solar orbit-ecliptic pole view in rotating coordinates

Launch Vehicle

Because of performance and cost considerations, the Observatory will be launched by a Delta 11 vehicle. There are two versions of the Delta II that are suitable for SIRTf. The 7920 is a two-stage vehicle with nine strap-on solid boosters. The 7925 is the same as the 7920 with an upper-stage for high-energy missions. The selection between the 7920 and the 7925 is essentially a trade between payload mass capability and volume. The 7925 can inject about 1200 kg into the solar orbit whereas the 7920 can inject 775 kg. On the other hand, the upper stage in the 7925 uses almost half the payload volume in the standard 9.5-ft fairing. Initial assessment indicates that the flight system can satisfy all mission requirements and stay under the mass limit of the 7920 capability. The 7925 can be a backup option with the standard 10-ft diameter fairing and adding 2 ft in length.

Unlike planetary launch opportunities, the solar orbit does not have a restriction on time of year to launch. However, the time of year to launch affects which part of the sky can be observed first. One added advantage of the solar orbit is that it does not require a parking orbit to achieve a precise escape orbit. Using a direct ascent orbit increases the payload

capability of the 7920 by about 70 kg and is included in the 775-kg capability.

Command, Telemetry, and Tracking

One disadvantage of the solar orbit is that it slowly drifts away from the Earth and therefore requires a High-Gain Antenna (HGA) to communicate with the Earth. A fixed HGA mounted at the bottom of the Observatory is chosen for simplicity and risk-free operations. As a result, observations must be interrupted to downlink data to Earth. The HGA antenna is supplemented by Low-Gain Antennae (LGAs) for emergency and low-rate communications.

SIRTf will use the Deep Space Network (DSN) for command, telemetry, and tracking. The nominal stations to be used are the 34-m High-Efficiency (HEF) stations. The stations and the transponder provide X-band communications. Current plan for commanding is once per week using the Low-Gain Antennas at 2 kbps. Uplink can be performed during an observation as well as simultaneously with downlink. Telemetry downlink is planned once every 12 hours. The Observatory supports several data transmission rates. A downlink rate of 45 kbps is used with the LGAs during the first 80 days of the mission when continuous monitoring is required and Sun-Earth-Probe angle prevents use of the HGA. The nominal downlink rate is 2.2 Mbps. Near the end of the mission, the 70-meter DSN stations may be required to maintain the 2.2-Mbps rate. Otherwise, the downlink rate maybe dropped to 1.1 Mbps. The maximum downlink rate of 2.2 Mbps is the current limit of the DSN telemetry decoding equipment on the ground.

Unlike Earth orbital and interplanetary missions that require frequent tracking updates and precise orbit determination, the only navigation requirement for the solar orbit is to have sufficient knowledge of the Observatory location for DSN antenna pointing. Two-way Doppler provides tracking data. At X-band frequencies, acquisition of the Observatory location by the 34-m antenna requires an angular knowledge of 0.03 deg. Once an initial Observatory location is established, it is possible to predict several months into the mission without further tracking data.

OBSERVATORY DESIGN

SIRTf is composed of three major systems: the Cryo-Telescope Assembly (CTA), the Spacecraft (S/C), and the Science Instruments (SIs). The CTA consists of a cryostat containing a 250-liter superfluid

helium tank and an instrument chamber for housing the SIs, a telescope assembly of 0.85-m aperture, and all of the thermal shields and radiators necessary to achieve the required cryogenic operating temperatures in orbit. The S/C consists of the usual subsystems for command and data handling, power generation and distribution, telecommunications, pointing control, and reaction control. The launch mass of the Observatory is 750 kg.

Warm Launch/Cryo-Telescope Assembly

SIRTF employs an innovative architecture which differs fundamentally from the approach taken on previous cryogenic space telescopes (such as the Infrared Astronomy Satellite (IRAS) and the Infrared Space Observatory (ISO)), and that offers significant size and mass reductions. The conventional approach surrounds the telescope, vapor cooled shields, superfluid helium tank, and instruments in a vacuum vessel that is launched cold. Following launch, a vacuum cover is opened to allow infrared radiation to enter the telescope. The need for a large vacuum vessel adds unnecessary weight and bulk. In the warm launch approach employed by SIRTF, only the superfluid helium tank and the instruments are contained in a vacuum vessel—the telescope, vapor cooled shields, and outer shell are all outside of the vacuum vessel, and are launched warm. The resulting compact cryostat is housed beneath the telescope assembly, as shown in Figure 2.

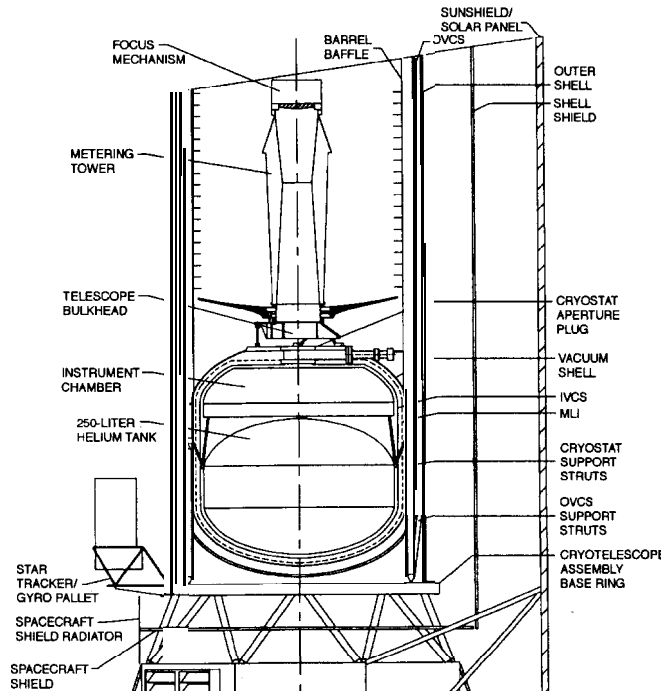


Figure 2. Cryo-Telescope assembly

Once in orbit, the telescope, outer shell and intermediate shields cool by passive radiation to space until the outer shell reaches approximately 50 K. The CTA is shielded from the Sun by an insulated sun-shield which is covered with solar cells for power generation. After the telescope has passively cooled to 50 K, a conductive thermal link connecting it to the outer shell is opened, and the telescope is further cooled by superfluid helium vapor to an operational temperature of 5.5 K. A small vacuum cover (called the cryostat aperture plug) is then opened, admitting infrared radiation into the instrument chamber. Initial cooldown to 50 K is expected to take about 7 days; final cooldown of the telescope to 5.5 K may require an additional 2 weeks.

Surrounding the cryostat and the telescope is a vapor-cooled shield that contains an annular aperture radiator, and this is further surrounded by the outer shell of the Observatory. Between the sun-shield and the outer shell is an important v-shaped intermediate shield that contains a large aperture radiator. This shell-shield intercepts nearly all of the heat (30 W) that leaks through the insulation of the sun-shield, and radiates it out to space. Similarly, a shield between the cryostat and the S/C intercepts the parasitic heat from the S/C and radiates it to space.

The warm launch architecture exploits the geometry of the solar orbit, where the anti-Sun side of the Observatory always views cold space—Earth is never a heat source. The superfluid helium cryogen is thus used primarily to carry away the heat dissipated by the S1 focal planes (8 mW); parasitic heat from the spacecraft and solar panel is intercepted and radiated to space passively. As a result, a 2.5-year mission duration is achieved using only 250 liters of cryogen, compared to 2140 liters used to achieve a 1.5-year mission duration on ISO.

Telescope

The proposed SIRTF telescope (shown in Figure 3) is a Ritchey-Chretien design, diffraction limited at 6.5 μ m. Major advances in technology enable this 0.85-m aperture telescope to weigh less than 50 kg. Optical parameters at both cryogenic and ambient temperature are contained in Table 1. An ambitious technology demonstration program was undertaken by NASA to produce an all-beryllium telescope meeting the SIRTF requirements. The primary mirror assembly of this telescope has been completed and is currently under test. The remainder of the telescope is scheduled to be completed and tested this year.

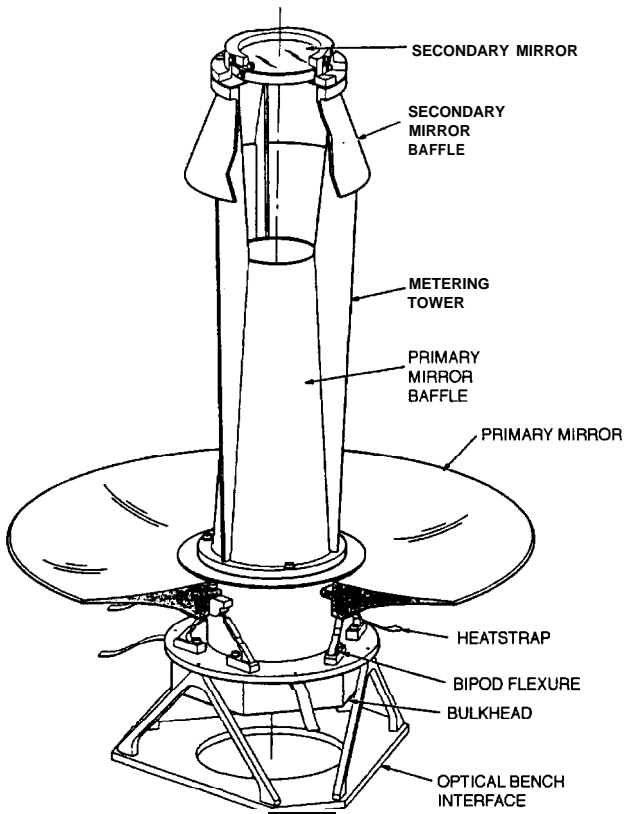


Figure 3. Telescope assembly with test optical bench interface

Spacecraft

A block diagram of the S/C is shown in Figure 4. Because the SIRTf orbit is far from Earth, a reaction control system is required to desaturate the reaction wheels used by the PCS. Gaseous nitrogen has been selected for this system, and a propellant tank is located in the center of the spacecraft bus. Reaction control thrusters are located on outriggers to maximize the available torque, and to minimize the likelihood of contamination of the cold CTA surfaces.

The surface of the sun-shield is populated with solar cells that generate 300 W average power at end-of-life. Average power usage is expected to be 250 W.

Pointing Control System

One of the more challenging requirements of the SIRTf S/C is to achieve a high performance and flexible pointing control capability with an affordable design. The PCS provides the capability to safely and accurately point the line-of-sight of the telescope at a science target, and to either stabilize the line-of-sight or perform controlled scans across the sky. The PCS is also used to orient the high-gain antenna toward Earth for telecommunications links.

Table 1. Optical parameters at 5.5K and 293K

Optical Parameter Description	Cryogenic Temperature (5.5K)	Room Temperature (293K)
System Parameters		
Focal Length	10,200 mm	10,213.26 mm
f/#	12	12
Back focal length (PM vertex to focus)	340 mm	340.442 mm
Field of view (diameter)	32.0 arc min	32.0 arc min
Spectral bandpass	3 μ m - 200 μ m	3 μ m - 200 μ m
Aperture Stop		
Location	at primary mirror	at primary mirror
Diameter of OD obscuration	850 mm	851.105 mm
Diameter of ID obscuration	320 mm	320.416 mm
Linear obscuration Ratio	0.3765	0.3765
Primary Mirror (hyperbola)		
Radius (concave)	-2040 mm	-2042.652 mm
Conic constant	-1.00284	-1.00284
Clear aperture	same as aperture stop	same as aperture stop
f/#	1.2	1.2
Secondary Mirror (hyperbola)		
Radius (convex)	-274.524	-274.881
Conic constant	-1.526131	-1.526131
Clear aperture (OD)	135 mm	135.176 mm
Clear Aperture (ID)	38.846 mm	38.846 mm
PM to SM spacing	896.361	897.526
Note : $\Delta L/L$ for Be is 0.3%		

The PCS is required to point the line-of-sight of the telescope in absolute coordinates to an accuracy of 5-arcsec rms radial. This ensures that the desired target will fall within the field-of-view of a visible light quad cell detector located in the focal plane, or a 10-micron peak-up array, which is part of the IRS Science Instrument. Once a target is found in one of these two "targeting" arrays, a precision offset is executed to locate the target onto one of the science arrays or spectrograph slits to an accuracy of 0.4 arcsec rms radial.

Once the target has been placed onto the desired science detector, the PCS can maintain the line-of-sight of the telescope stable to 0.6 arcsec rms radial over a duration of 500 seconds. Alternatively, the line-of-sight of the telescope can be scanned across the sky at selectable rates from 2 to 20 arcsec/sec. Scanning is used primarily in conjunction with the MIPS instrument, which contains an internal scan mirror on a flyback mechanism that can "freeze frame" a scene on the science detector over short integrations (typically 5 seconds) and thereby step across the sky, imaging in a mosaic fashion.

Table 3. Projected IRS Performance

Module	Band μm	Detector Type	Detector Format (pixels)	Spectral Resolution ($\lambda/\Delta\lambda$)	Slit Size (pixels)		Pixel Size (arcsec)	Sensitivity 500s/5 σ
					d	x-d		
Short Lo [†]	5–7.5	Si:As(BIB)	128 x 128	50	2	30	1.8	100 μJy
	7.5–15			50	2	30	1.8	550 μJy
	10(peak up)*			2	32	30	1.8	3x10 ⁻¹⁸ W/m ²
Long-Lo [†]	14–21	Si:Sb(BIB)	128 x 128	50	2	30	4.8	1500 μJy
	21–40			50	2	30	4.8	1500 μJy
Short Hi	10–19.5	Si:As(BIB)	128 x 128	600	2	5	2.4	3x10 ⁻¹⁸ W/m ²
Long Hi	19.5–38	Si:Sb(BIB)	128 x 128	600	2	5	4.8	3x10 ⁻¹⁸ W/m ²

* The required image quality is achieved only over 32 by 30 pixels. A FOV of up to 3' x 1.5' maybe possible with reduced image quality.

[†] The grating operates in more than one order with order-sorting filters. The slit lengths shown are per order: d: dispersion direction (slit width); x-d: cross-dispersion direction (slit length). It is likely that the exact FOV of the **peak-up, and the slit length of the Lo modules, will change somewhat as the optical design is further developed.**

Table 4. Projected MIPS Performance

Operating Mode	Band (μm)	Detector Type	Detector Format (pixels)	Spectral Resolution ($\lambda/\Delta\lambda$)	Field of View (arcmin)	Pixel Size (arcsec)	Sensitivity 500s/5 σ (μJy)
1	12	Si:Sb(BIB)	13x128	4	0.5 x 5.3	2.4	100
	30	Si:Sb(BIB)	11 OX 128	4	4.1 x 5.3	2.4	150
	70	Ge:Ga	32X 32	4	5.3 x 5.3	9.4	530
	160	Ge:Ga(stressed)	2X20	4	0.5 x 5	15	7500
2	70	Ge:Ga	32X 32	4	2.6 x 2.6	5	870
3	50-100	Ge:Ga	32X 32	20	0.3' x 5.4"	9.4	3500

of the instrument chamber volume. The focal plane parameters and projected performance of the IRS are shown in Table 3.

MIPS Description

The MIPS instrument comprises a single cold optical assembly which contains five distinct optical trains that can be operated in one of three data gathering modes: 1) image in three bands simultaneously, 2) image with high magnification at 70 μm , and 3) low-resolution spectroscopy from 50 to 100 μm . A single axis scan mechanism is included to modulate the signal on the Germanium detectors to provide good photometric performance, and to select among the three instrument operating modes.

The instrument utilizes a Si:Sb array of identical design to that in the IRS. In addition, two gallium-doped germanium (Ge:Ga) arrays are used, one with

32 X 32 pixels that respond up to 120 μm , and the other with 2 X 20 pixels, each subjected to a mechanical stress to extend its photo conductive response to 180 μm . The cold assembly is packaged into a 90-degree wedge of the instrument chamber volume. The focal plane parameters and projected performance for MIPS are summarized in Table 4.

ACKNOWLEDGMENTS

The “warm launch architecture for cryogenic space telescopes was developed by Dr. F. J. Low (University of Arizona), and his contributions to the SIRTf concept are gratefully acknowledged. The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under an agreement with the National Aeronautics and Space Administration.

detectors must operate at approximately 15 K. The mid-infrared band Si:As and Si:Sb Blocked Impurity Band (BIB) array detectors require approximately 5 K and 3 K, respectively, and the far-infrared stressed Germanium photoconductor array detectors require the lowest operating temperature—approximately 1.5 K. Somewhat higher maximum allowable telescope temperatures are permitted in each case ranging from 100 K to 5.5 K.

The instruments access the focal plane of the SIRTf telescope through individual flat “pickoff” mirrors, whose positions are fixed in the shared telescope field of view. The fields of view of the various instrument apertures projected onto the sky are shown in Figure 5. Only a subset of these fields is active at any time, depending on the selected instrument and the operating mode of that instrument as described below. Also shown in Figure 5 are Pointing Calibration Reference Sensors (PCRS), which are quad cell detectors used to calibrate the instrument alignment with the spacecraft star tracker.

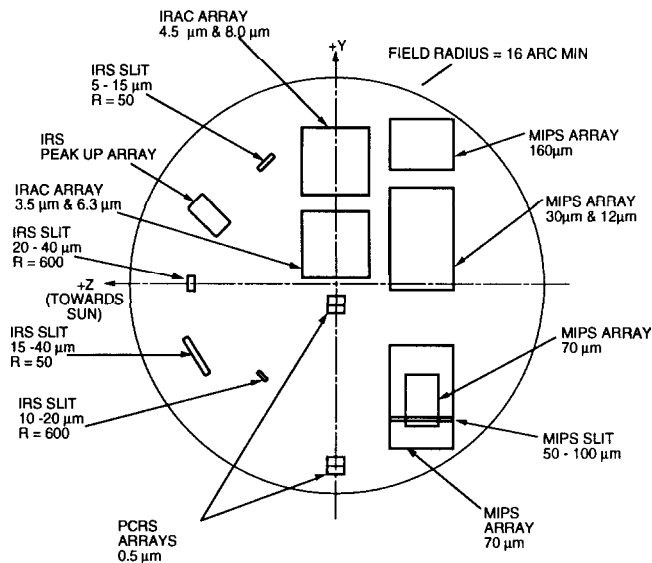


Figure 5. SIRTf focal plane arrangement

IRAC Description

The Infrared Array Camera (IRAC) is a four-channel imager packaged in a single module. Simultaneous wide-field images at 3.5, 4.5, 6.3 and 8.0 μm are possible with 25% bandwidth at each wavelength. Two adjacent fields of view in the SIRTf focal plane support the four channels in pairs as shown in Figure 5.

Infrared radiation enters the instrument via two pickoff mirrors which feed similar channels, each consisting of a beam splitter and a pair of lenses and fold mirrors. Radiation shortward of 5 μm reflects off the beam splitters and is focused on the InSb arrays; radiation longward of 5 μm passes through the beam splitters and is brought into focus on the Si:As BIB arrays. Filters in front of each array determine the central wavelength and bandwidth of each channel.

The IRAC occupies an approximately 30-degree sector of the instrument chamber volume. Key to the compact packaging is the use of silicon asphere refractive optics. The focal plane parameters and

projected performance of the IRAC are shown in Table 2.

IRS Description

The IRS is comprised of four separate cold optical assemblies or “modules” which are independent of each other both optically and mechanically. Two of the modules produce one-dimensional, low-resolution spectra with a one-dimensional image along the slit. The other two produce two-dimensional echelle-format moderate-resolution spectra with 7 to 10 spectral orders on the array. In addition, a portion of one of the low-resolution short-wavelength modules is used to produce 10-mm “peak up” images to aid in identifying sources and to help calibrate the Observatory pointing system.

The optical design of each module is optimized to achieve reliability and ease of fabrication, integration and test. There are no moving parts in the IRS module. Each module contains one infrared detector array, with either an arsenic-doped silicon (Si:As) blocked impurity band detector (BIB) or an antimony-doped silicon (Si:Sb) BIB detector. All four assemblies are packaged into slightly less than a 180-degree wedge

Table 2. Projected IRAC Performance

Band (pm)	Detector Type	Detector Format (pixels)	Spectral Resolution ($\lambda/\Delta\lambda$)	Field of View (arcmin)	Pixel Size (arcsec)	Sensitivity 500s/5 σ (μJy)
3.5	InSb	256 x 256	4	5.1 X 5.1	1.2	2.6
4.5	InSb	256 x 256	4	5.1 X 5.1	1.2	3.3
6.3	Si:As (BIB)	256 x 256	4	5.1 X 5.1	1.2	18.1
8.0	Si:As (BIB)	256 x 256	4	5.1 X 5.1	1.2	30.9

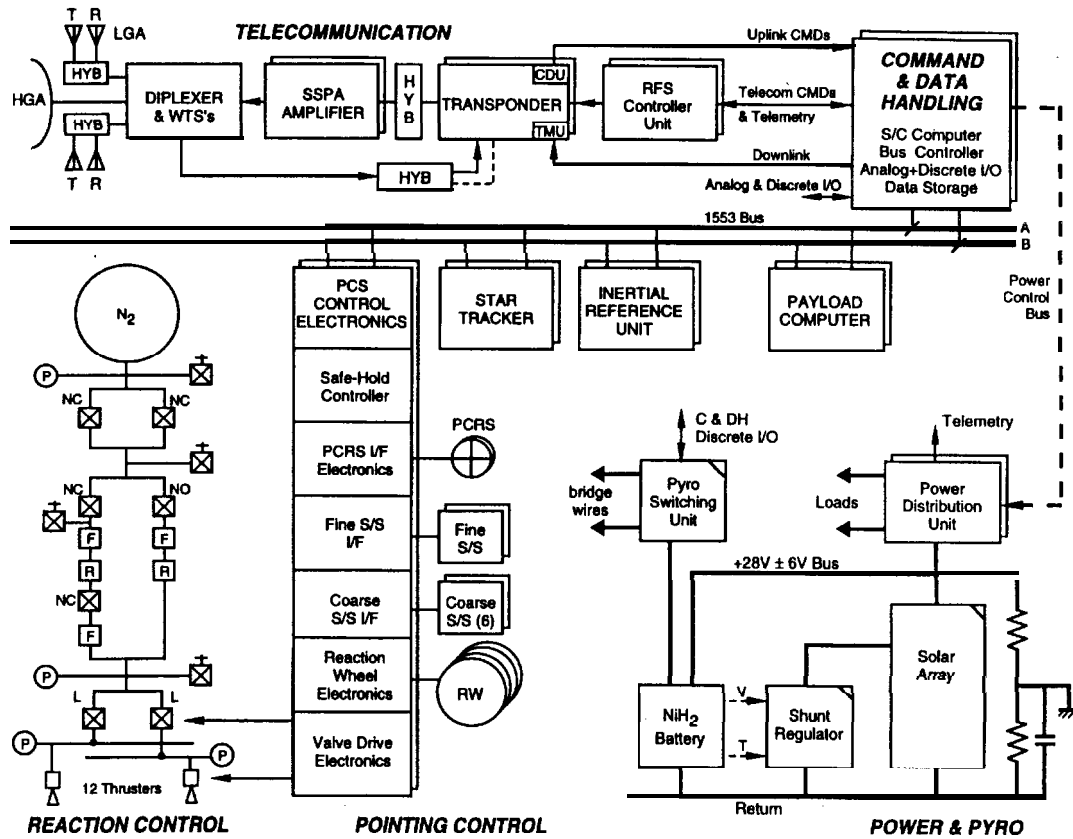


Figure 4. Spacecraft Functional Block Diagram

SCIENCE INSTRUMENTS (S1)

SIRTF contains three science instruments, each of which is developed under the direction of a Principal Investigator (PI). The three instruments are the IRAC, the IRS, and the MIPS. These instruments, taken together, provide a wide variety of imaging and spectroscopic modes from 3 to 180 μ m. To simplify operations and reduce overall mission costs, SIRTF is designed such that only one instrument is operated at a time.

Each instrument consists of both cryogenic sensor subassemblies and warm electronics subassemblies. These are interconnected by electrical signal cables which pass through the various insulating layers of the CTA.

The cryogenic subassemblies share a cylindrical (21-cm-high x 42-cm-radius) instrument chamber which is located within the cryostat, as shown in Figure 2. These cryogenic subassemblies perform all optical processing of the telescope input beam and deliver the resulting signal to the infrared detector arrays, which produce a low-level analog output signal. For both reliability and cost reasons the number of mechanisms in the cryogenic instrument subassemblies has been kept to a minimum (two).

The instrument warm electronics subassemblies provide all the necessary electronic housekeeping for detector operation and readout, including bias voltage and clock generation, analog-to-digital conversion, compression, formatting, and presentation to the spacecraft for storage and subsequent transmission to Earth. Cost, mass, and power savings are achieved by appropriate sharing of general-purpose computing, power conditioning, and other electronic functions among the instruments. Instrument warm electronics modules are located within the S/C bus.

In each instrument the most critical performance-determining components are the infrared detectors and their associated cryogenic readout circuits. Each instrument team has successfully conducted a detector and readout development which has drawn on a variety of industrial, academic, and governmental organizations. In all cases, SIRTF instrument detectors have a long technology development pedigree and represent the state-of-the-art in infrared detector technology.

The operating temperature of both the detectors and the telescope place unique demands on the cryogenic system. As the wavelength of operation increases, required operating temperature decreases. At the shorter infrared wavelengths the InSb array