Space InfraRed Telescope Facility (SIRTF) enters development

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ABSTRACT

The *Space InfraRed Telescope Facility* (SIRTF), the last of NASA’s “Great Observatories,” is entering its development phase. Ongoing advances in infrared detector technology, coupled with innovative choices in orbit and system architecture, have maintained the vitality of SIRTF’s scientific capability at a small fraction of the original development cost. The great sensitivity of SIRTF and its high observing efficiency promise to yield a rich legacy of science results. SIRTF is on a fast-track development schedule, with launch in December 2001. While the current baseline calls for a minimum 2.5-year cryogenic lifetime, recent programmatic and engineering developments suggest that a 5-year lifetime is within reach. More than 75 percent of the SIRTF observing time will be available to the general community.

We summarize the scientific capabilities and the technical specifications for the mission, including descriptions of the three-instrument payload. We will focus on the SIRTF science operations concepts, and describe SIRTF’s seven observing modes -- the means by which the community will interface with the Observatory. The pre- and post-launch user services available at the SIRTF Science Center will also be presented. We include a listing of events likely to be of interest to potential SIRTF users between now and launch.

Keywords: SIRTF, space telescopes, infrared astronomy

1. MISSION OVERVIEW

After a quarter century of dreams and designs, the *Space InfraRed Telescope Facility* (SIRTF) begins formal development in 1998, with launch scheduled for December 2001. SIRTF represents the final element in NASA's suite of "Great Observatories," and a scientific and technical bridge to NASA’s ambitious new *Origins* program. Congressional approval of SIRTF in 1997 provided an emphatic exclamation mark to NASA's completion of the space-based initiatives recommended in the National Academy of Science's review of decadal priorities for astronomy and astrophysics in the 1990s -- the “Bahcall Report” [1]. SIRTF's technical capabilities, in combination with the compelling scientific basis for studying the Universe at infrared wavelengths, virtually assures that its legacy will favorably compare with those of the *Hubble Space Telescope,* the *Compton Gamma-Ray Observatory*, and the imminent results from the *Advanced X-Ray Astrophysics Facility*.

The political ramifications of an increased interest by the US electorate into expanding federal budget deficits in the early 1990s forced the original $2.2 billion version of SIRTF (as measured by development costs) to be rescoped twice to its current $0.45 billion cost. But as an illustrative example of the impact that ingenious engineering can have on scientific capability, one would be hard pressed to find an example whose benefits will exceed those from SIRTF. A companion conference paper (Fanson *et al.*) in these Proceedings describes the technical details of the Observatory, and elaborates on some of these “better science through engineering” concepts chosen for SIRTF and summarized below. It is these engineering choices that have served to maintain most of the scientific vitality and potential of SIRTF, despite an 80 percent reduction in development cost.

The first breakthrough was to escape from geocentric thinking and place SIRTF into an Earth-trailing heliocentric orbit, such that it drifts away from Earth at the rate of ~ 0.1 AU/year. For cooled infrared missions, this choice of orbit presents a far more benign thermal environment than any geocentric orbit. One of the consequences of this orbit – one that will vastly simplify SIRTF scheduling and operations – is the substantial reduction in Sun-Earth-Moon avoidance constraints. SIRTF’s view of the celestial sky will be limited by only two pointing constraints: (i) the Observatory cannot point closer than 80° in the forward Sun direction, for (obvious) thermal reasons; and (ii) it cannot point more than 120° away from the Sun direction, because of the need to illuminate the solar panels.

SIRTF’s window of visibility on the celestial sky will form an annulus, perpendicular to the ecliptic plane, of 40° width. A region of the sky will be minimally visible to SIRTF twice a year, for ~ 40 days each period (at the ecliptic equator). The visibility periods increase to about 120 days per year at an ecliptic latitude of 30°, to ~ 200 days at $\beta \sim 60°$, and reach constant viewing at the ecliptic poles. About a third of the sky will be instantaneously visible to SIRTF at any given time.

On-board, solid-state memory will permit SIRTF to use a store-and-dump philosophy of data transfer to the ground. The high-gain antenna on SIRTF is fixed, and so the spacecraft will interrupt its science program once or twice a day to repoint to Earth and downlink the data. Telemetry will be provided through NASA’s Deep Space Network, with nominal one-hour downlink passes scheduled every 12 to 24 hours. Taken together, the orbit and telemetry requirements suggest that SIRTF should reach 90% overall astronomical observing efficiency. (Slew and settling times are assumed to be part of the execution of astronomical observations.)

The second clever technical development is an implementation of a “warm-launch architecture,” whereby SIRTF’s telescope assembly is launched at ambient temperature and allowed to radiatively (passively) cool in the deep recesses of space. Only the focal-plane instruments and the compact cryostat are enclosed in a vacuum shell, leading to yet another positive (and cost-reducing) feature – easier ground-based testing and integration. In this design, the in-orbit parasitic heat load to the cryostat is substantially reduced, leading to a dramatic reduction in the volume of liquid cryogen required. SIRTF is presently designed to carry 360 liters of liquid helium, affording an estimated lifetime of 5 years. [For comparison’s sake, IRAS used 520 liters over 10 months, and ISO’s latest lifetime estimate of 2.3 years will result from 2140 liters.] In the Earth-trailing solar orbit, the observatory will initially take perhaps a week to radiatively cool to an outer shell temperature of ~ 50 K. At that point, the thermal coupling of the telescope to the outer shield will be broken, and the boil-off of cryogenic vapor will cool the telescope assembly to an operational temperature of 5.5 K within a few weeks. During these cool-down periods, and throughout the entire prime mission, SIRTF’s LHe bath will always be maintained at < 1.5 K.

Once the 60-day in-orbit checkout period is completed, SIRTF will begin science operations. New observing schedules will typically be uplinked on a weekly basis, although the telemetry design offers the opportunity for more frequent contact. SIRTF’s payload will utilize lossless data compression and store science data onboard the spacecraft for downlinking, permitting an average data acquisition rate of 85 Kbps. The onboard storage capability of 8 Gbits will permit ground operations to downlink a full day of science in the event of a missed telemetry pass. Taken together, the simplicity of SIRTF’s payload and the choice of orbit will result in a flight operations budget that is far less than any comparable space astronomy mission flown previously.

Unlike most flight development programs where the design and requirements are first completed, and then the contractors brought in to bid on development, the SIRTF Project embarked on an experimental approach. The Project Team members, including the industrial contractors, were solicited early enough to enable full participation in the preliminary design process. While JPL remains responsible for Project management, systems/mission engineering, science management, and flight operations, the other Team members have been actively working together during SIRTF’s design phase. Lockheed-Martin (Sunnyvale CA) is responsible for the spacecraft and for the system integration and testing. Ball Aerospace (Boulder CO) is responsible for the cryogenic telescope assembly.

In early 1997, NASA Headquarters designated the upgraded Delta 7920-H as the launch vehicle for SIRTF. The increased ~200 kg lift-capability of this rocket permits the Project to increase the onboard cryogen (from the original 250 liters), while also providing increased mass margin and decreased risk. While SIRTF’s mission lifetime requirement remains at 2.5 years, the Project is increasingly confident that it can extend the prime scientific mission duration to about 5 years, and has scoped the operations activities accordingly.

Interested observers are urged to periodically visit the SIRTF Internet/WWW site (*http://sirtf.jpl.nasa.gov/sirtf/*) for ongoing developments.

2. SIRTF’s PRIMARY SCIENCE THEMES

SIRTF’s scientific agenda was re-evaluated and re-defined following the second budget-driven Project rescope in 1994. The SIRTF Science Working Group (SWG) conducted a careful “bottoms up” re-examination of SIRTF’s science objectives at that time. One goal of the study was to identify areas deemed to be of high scientific priority and for which a cooled meter-class telescope with background-limited detectors and multiple instruments could offer substantial improvement over existing capabilities. Another goal, no less important, was to substantially reduce costs associated with every element of SIRTF -- the telescope, instruments, spacecraft, ground system, mission operations, and Project management.

With an eye towards cost, and in recognition of the unprecedented sensitivity afforded by the latest infrared detector arrays, the SIRTF SWG identified a handful of the most compelling problems in modern astrophysics for which SIRTF could make unique and important contributions. These primary science themes, which received the (re)endorsement of the National Research Council's Committee on Astronomy and Astrophysics in 1994, satisfy most of the major scientific questions outlined for the original SIRTF mission in the NRC’s Bahcall Report. They are:

(1) the search for brown dwarfs and super-planets,
(2) the discovery and study of protoplanetary and planetary debris disks,
(3) the study of ultraluminous galaxies and active galactic nuclei, and
(4) the study of the early and distant Universe.

Apart from being scientifically interesting in their own right, these themes are directly relevant to NASA’s *Origins* Program, which seeks to understand the origins of the Universe, galaxies, stars, and planets.

SIRTF’s capabilities in elucidating the mysteries inherent in these themes have recently been explored by various authors. A summary of SIRTF’s likely contributions in the areas of dust around solar-type stars, brown dwarfs, and in various topics of Solar System science are summarized by Cruikshank and Werner[2]. Backman *et al.*[3] have explored the distribution of interplanetary dust within our Solar System, including the inner zodiacal material and the tenuous dust associated with the Kuiper Belt, and concluded that it bears morphological similarity to the prominent extrasolar disks detected by IRAS. They posit that SIRTF’s photometric, spectroscopic, and imaging capabilities will help to establish links between these systems and our Solar System, and between the dust disks and larger planetary bodies.

Burrows *et al.*[4] have developed a new “non-gray” theory of evolution, spectra, and colors of extrasolar giant planets and brown dwarfs. They conclude that such bodies may be more easily detected with telescopes like SIRTF than previously imagined. They predict, for example, that SIRTF will detect at 5 μm an isolated 10^9 yr old, Jupiter-mass object at a distance of 100 pc, and should detect a $5x10^9$ yr old, 25 M_J object out to a distance of ~ 500 pc.

SIRTF will study ultraluminous IR galaxies to redshifts $z > 5$ at mid- and far-infrared wavelengths, with the goal of characterizing these systems and testing evolutionary scenarios by constructing luminosity functions. Moreover, SIRTF will spectroscopically probe dust-enshrouded AGN to study their excitation, ionizing source(s) and heavy element abundances as functions of redshift (see Voit[5]). At shorter wavelengths, the inevitable redshift of the diagnostic 1.6 μm emission and 2.3 μm absorption features into SIRTF’s wavelength regime permits a photometric determination of galaxy redshifts (see Werner and Eisenhardt[6]) out to $z > 3$. A scientifically-driven requirement to measure L* galaxies at these redshifts translates into a 10-σ measurement of 6 μJy at a wavelength of 8 μm. One intriguing celestial field that SIRTF will likely survey to these limits is the Hubble Deep Field (HDF). Wright[7] has recently simulated what SIRTF is likely to see in the HDF at these infrared wavelengths.

While the four primary themes drove the mission redesign, it should be emphasized that SIRTF's powerful capabilities have the potential to address a wide range of other astronomical investigations, including studies of the outer Solar System, the early stages of star formation, and the origin of chemical elements. Given that one can never underestimate the ingenuity of the community-at-large, potential investigators will be encouraged to propose programs in any scientific area where SIRTF is likely to make significant contributions. SIRTF’s top-level Observatory characteristics are summarized in Table 1.

Table 1
Summary of SIRTF Characteristics

Aperture (diameter)	85 cm
Orbit	Solar (Earth-trailing)
Cryogenic Lifetime	2.5 yrs (requirement) 5 yrs (goal)
Wavelength Coverage	3.5 - 180 μm (imaging) 5 - 40 μm (spectroscopy) 50 - 100 μm (spectral energy distribution)
Diffraction Limit	6.5 μm
Image Size	~ 1.5 arcsec
Pointing Stability (1 σ, 200 s)	0.3 arcsec
Field Of View	~ 5’ x 5’ (each band)
Telescope Temperature	< 5.5 K
SolSys Tracking Rate	~ 0.1 arcsec / s

Potential SIRTF users will find a recent JPL Project Office document[8] to be invaluable. The *Science Requirements Document* (available via the SIRTF Web site at *http://sirtf.jpl.nasa.gov/sirtf/*) reviews the state-of-the-art knowledge in the “Big Four” science themes in greater detail, introduces sample observational programs needed to address the scientifically compelling issues in these areas, and traces how the necessary observations lead to a set of derived mission requirements. The document offers an insightful overview of SIRTF’s utility and its capabilities.

3. SCIENCE PAYLOAD

SIRTF’s science payload consists of three cryogenically-cooled instruments, which together offer observational capabilities stretching from the near- to the far-infrared. Each of the instruments incorporates detector arrays whose capabilities evolved from a technological foundation established by defense-based investments. With NASA sponsorship, industrial fabricators and university-based research groups have collaboratively adapted the detectors to reach background-limited performance in astronomical environments. This leap in sensitivity has been matched by a dramatic increase in the size of detector arrays. For example, SIRTF will fly nearly four orders of magnitude as many detector elements as IRAS, the mission that opened up the infrared sky. Ultimately, it is this revolution in infrared detector technology that will be at the core of any and all scientific discoveries made by SIRTF.

Brief summaries of each of the science instruments appear in the following sub-sections. For additional detail, the reader is urged to visit the SIRTF Instrument Team Web sites listed below.

3.1 InfraRed Array Camera (IRAC)

Giovanni G. Fazio (Smithsonian Astrophysical Observatory, Cambridge MA), Principal Investigator
http://cfa-www.harvard.edu/cfa/oir/Research/irac/firstpage.html

The IRAC camera provides simultaneous images at 3.5, 4.5, 6.3, and 8.0 µm, with 25% bandwidth, over 5.12 x 5.12 arcmin fields of view. The pixel size is 1.2 arcsec. Images from the same field are provided at 3.5 and 6.3 µm using a dichroic beamsplitter, and a second nearly adjacent field and dichroic provides images at 4.5 and 8.0 µm. The 3.5 and 4.5 µm bands use photovoltaic indium antimonide (InSb) detectors, while the 6.3 and 8.0 µm bands use arsenic-doped silicon (Si:As) impurity band conduction detectors. All four detector arrays have a 256 x 256 pixel format and each pixel has a physical size of 30 µm. A cold shutter is provided for dark calibrations, and also allows the detectors to be illuminated by light from a transmission calibrator.

3.2 InfraRed Spectrograph (IRS)

James R. Houck (Cornell University, Ithaca NY), Principal Investigator
http://astrosun.tn.cornell.edu/SIRTF/irshome.htm

The IRS is designed to perform diagnostic observations on previously known sources as well as on sources discovered by SIRTF itself. Low resolution spectra ($\lambda/\Delta\lambda = 50$) can be obtained from 5 to 40 µm. High resolution spectra ($\lambda/\Delta\lambda = 600$) can be obtained from 10 to 38 µm. High efficiency grating and echelle spectrographs are used in conjunction with 128 x 128 Si:As and antimony-doped silicon (Si:Sb) blocked impurity band (BIB) arrays. An internal "peak-up" array can be used in locating and positioning sources with poorly known (± 5 arcsec) coordinates. In addition, this array can be used for imaging at 15 µm.

The IRS comprises four separate cold assemblies or modules, denoted by their relative wavelength coverage and spectral resolution. The Short Hi and the Long Hi modules are echelle spectrographs that cover 10 - 19.5 µm and 19.5 - 38 µm, respectively, with spectral resolution of 600. Their entrance slits are 2 x 5 pixels in size, corresponding to 4.8" x 12.1" for the Short Hi slit and 9.7" x 24.2" for the Long Hi slit. The Short Lo module covers 5 - 15 µm in two sub-bands (5 - 7.5 µm and 7.5 - 15 µm) with spectral resolution R of ~ 50. The entrance slits for the Short Lo sub-bands are each 2 x 30 pixels (3.6" x 54.5") in size. The Long Lo module covers 14 - 40 µm in two sub-bands (14 - 21 µm and 21 - 40 µm, also with R ~ 50. The entrance slits for the Long Lo sub-bands are 2 x 30 pixels (9.7" x 145.4").

The modules are designed for ease of fabrication, integration, and testing. There are no moving parts. No adjustments are required except an initial focus during assembly. The modules are independent of each other optically and mechanically.

3.3 Multiband Imaging Photometer for SIRTF (MIPS)

George H. Rieke (University of Arizona, Tucson AZ), Principal Investigator
http://thneed.as.arizona.edu/~mips/

MIPS is designed to provide SIRTF with diffraction limited imaging capability with noise performance limited by natural sources over the wavelength range from 20 to 180 µm. In addition, a low resolution spectrometer provides spectral energy distribution measurements from 50 to 100 µm. The instrument utilizes three detector arrays: a Si:As BIB array of identical type to that in the IRS instrument; a 32 x 32 array of gallium-doped germanium (Ge:Ga) photoconductors; and an additional 2 x 20 array of Ge:Ga photoconductors stressed to extend their photoconductive response to 180 microns. These arrays provide photometric bands respectively at 24, 70, and 160 µm and a spectroscopy mode with spectral resolution R = 10-20 covering the wavelengths 50 to 100 µm. The instrument will operate at the sensitivity limit set by the photons emitted by the zodiacal dust cloud, except at 160 µm where its performance will be limited by confusion noise due to distant galaxies.

MIPS has been designed to carry out five primary functions: (a) efficient deep mapping and large field imaging in the three photometric bands, (b) photometry of point sources and compact sources in the three bands, (c) super resolution imaging in the three bands, (d) measurement of the spectral energy distributions at low spectral resolution over the 50 to 100 μm range, and (e) measurement of total power by chopping against a cold reference.

The SIRTF instrument technical parameters are summarized in Table 2.

Table 2
SIRTF Instrumentation Summary

λ(μm)	**Array Type**	λ/Δλ	**Field of View**	**Pixel Size** (arcsec)	**Sensitivity** (μJy) (5σ in 500 sec, incl. confusion)
Infrared Array Camera: G. Fazio, SAO, P.I.					
3.5	InSb	4	5' x 5'	1.2	4
4.5	InSb	4	5' x 5'	1.2	5
6.3	Si:As(IBC)	4	5' x 5'	1.2	20
8.0	Si:As(IBC)	4	5' x 5'	1.2	30
Multiband Imaging Photometer for SIRTF: G. Rieke, U. Arizona, P.I.					
24	Si:As(IBC)	4	4.5' x 5'	2.4	240
70	Ge:Ga	4	2.7' x 2.7'/ 5' x 5'	5 / 9.4	1000
50-100	Ge:Ga	20	18.75" x 5'	9.4	6500
160	Ge:Ga (stressed)	4	0.5' x 5'	15	7500
Infrared Spectrograph: J. Houck, Cornell U., P.I.					
< 5 -15	Si:As(IBC)	50	3.6" x 55"	1.8	550μJy
15	Si:As(IBC) peakup imaging	2	55" x 58"	1.8	100μ Jy
10-20	Si:As(IBC)	600	4.8" x 12.1"	2.4	3 x 10^{-18} W/m^{2}
15-40	Si:Sb(IBC)	50	9.7" x 145"	4.8	1.5mJy
20-38	Si:Sb(IBC)	600	9.7" x 24.2"	4.8	3 x 10^{-18} W/m^{2}

The IRAC instrument is being built by NASA's Goddard Space Flight Center (Greenbelt MD), while Ball Aerospace (Boulder CO) is building the IRS and MIPS instruments. The three instruments combined will have only two moving parts: the IRAC shutter and the MIPS scan mirror. Due to mission constraints, only one of SIRTF's three instruments will operate at a given time. To increase the scientific efficiency and productivity over the long run, it is anticipated that a single instrument will operate for days (perhaps a week) at a time.

Successful prototype technology demonstrations of crucial instrument modules and components have recently been completed. Much of the SIRTF development funding has been devoted to the detector materials and cryogenic readouts and multiplexers that are critical to the success of SIRTF. The detector materials include InSb, both Si:As and Si:Sb implemented in the IBC configuration, Ge:Ga, and stressed Ge:Ga, which provides the longest wavelength response. The cryogenic readouts and multiplexers include switched-MOSFET arrays in formats as large as 256 x 256 -- used with the InSb and Si:xx detectors -- and a newly-developed 1 x 32 cryogenic integrator which is used with the Ge detectors. These developments have been uniformly successful across the board. SIRTF will reach its sensitivity goal of natural background limited performance for imaging/photometric and low resolution spectroscopic observations. In addition, SIRTF's arrays will have excellent operational characteristics -- few pixel outages and a high degree of uniformity -- which should facilitate the efficient processing and analysis of SIRTF data.

4. OBSERVING MODES

The three instruments will offer a total of seven observing modes. SIRTF users will specify and plan their observations by selecting available parameters and options contained in electronically distributed Astronomical Observing Templates (AOTs). User-specified parameters will include such inputs as target identification and positioning, observation and scheduling requirements, and relevant time critical information. These AOTs are planned to be available before Calls for Proposals are issued, and will be integrated into the on-line SIRTF Performance and Sensitivity Estimation Tool. The observing modes, and a brief description of each, are summarized below.

4.1 IRAC Mapping and Photometry

The IRAC AOT is used to image point or extended sources at 3.5, 4.5, 6.3 and/or 8.0 μm using 256 x 256 arrays. The shorter wavelengths utilize InSb arrays, whereas the longer use Si:As arrays. Images can be taken in either Field-of-View 1 (3.5 and 6.3 μm arrays) and/or Field-of-View 2 (4.5 and 8.0 μm arrays). Both FOVs do not see the same piece of sky simultaneously, so a primary FOV must be selected when specifying observations.

Standard dither modes can be selected. A subarray mode can also be selected. This mode is intended for very bright sources (~ 1 Jy) and allows very short exposure times on a 32 x 32 pixel subset of the array. Several combinations of observing sequences can be selected: mapping or pointed in full array or subarray modes (pointed only). Each of these can be combined with available dither patterns.

4.2 IRS Staring

This IRS AOT is used for obtaining high resolution ($\lambda/\Delta\lambda = 600$) or low resolution ($\lambda/\Delta\lambda = 50$) two-dimensional echelle spectra over the wavelength ranges 10 to 38 μm and 5 to 40 μm, respectively. Total coverage of these ranges must be done in two segments.

4.3 IRS Spectral Imaging

This IRS AOT is used to for obtaining spectra at all points of an extended source. High resolution ($\lambda/\Delta\lambda = 600$) or low resolution ($\lambda/\Delta\lambda = 50$) spectra are obtained within the wavelength ranges of 10 to 38 μm and 5 to 40 μm, respectively. Total coverage of these ranges must be done in two segments. Because the high resolution slits are only 12 and 24 arcsec in length, large scan spectral imaging will mostly be done at low resolution. A map is made by reading the array while the telescope is executing slow slews back and forth, perpendicular to the slit, offsetting these scans in the cross scan direction. Scan rates are related to the exposure times; during an exposure duration, the scan rate is adjusted so that one half of the slit width is traversed.

4.4 MIPS Photometry and Super Resolution

This AOT is used to make accurate photometric measurements at 24, 70, and/or 160 μm. Each array has its own optimal pattern of pointings that is achieved by a combination of telescope motions and scan mirror offsets. Integration times are accumulated by repeating the pattern. Different dither patterns will result in the ability to properly measure background on the array or by using sky chops. The patterns and pointings are such that super resolution imaging can be achieved through data processing.

4.5 MIPS Scan Mapping

This AOT is used to make large maps at 24, 70, and 160 μm simultaneously. The maps are constructed by using slow telescope tracks, combined with image stabilization using a motion compensating scan mirror. Maps are built up of ~ 5' wide strips and are between 0.5-10 degrees in length. Integration time is accumulated by repetitive scans. All three bands take data simultaneously.

4.6 MIPS Spectral Energy Distribution

This AOT is used to make low resolution ($\lambda/\Delta\lambda$ ~ 10-20) spectra over the wavelength range 50 to 100 µm. The spectral energy distributions are obtained by using the 70 µm MIPS array and the MIPS spectrometer with a 19.8" x 4' slit.

4.7 MIPS Total Power Mode

This AOT is used to establish the true zero level reference for measurements of the absolute brightness of very extended sources. The instrument uses the scan mirror first to expose all three arrays to the sky, chopping the scan mirror to the SED position (such that the 24 and 160 µm arrays do not see sky) and integrating again.

5. COMMUNITY USE OF SIRTF

SIRTF's high observational efficiency will yield at least 7500 hours per year of astronomical data. More than 75 percent of this observing time will be available to the user community, with proposals solicited via periodic Calls for Proposals (CPs). It is currently envisioned that there will be consolidated Guest Observer/Archival Research CPs issued approximately once per year (assuming a 5-year mission).

One of the innovative aspects of SIRTF is the promotion of very large investigations: the *Legacy Science* program. The goal is to establish an opportunity for the community-at-large to propose large investigations that might not normally be approved by time allocation committees. Formally, Legacy Science is defined by these requirements: (i) large coherent science investigations, not normally reproducible via any reasonable number of smaller Guest Observer investigations; (ii) projects whose scientific data, upon archiving, is of general and lasting importance to the broad community; and (iii) projects with non-proprietary data, thereby enabling timely and effective opportunities for archival research and subsequent follow-on observations. A likely attribute of Legacy Science is that the projects may utilize many hundreds, and perhaps more than a thousand, hours of observing time. Legacy Science projects will be solicited sufficiently early to permit the selected teams to be established (and funded) prior to launch. These large projects are expected to comprise perhaps two-thirds of SIRTF's first year of science schedule.

To promote full advantage of this extraordinary opportunity, the SIRTF Project and the SIRTF Science Center are co-hosting a series of three science-motivated conferences in 1998-2000, at geographically dispersed locations throughout the US. The purpose of these conferences, each of which will have a different focus, will be to survey the "state-of the-art" knowledge in topical areas of interest, to consider how the power of the tool called SIRTF can be best used to increase our understanding in that area, and to stimulate the community into thinking how it might put together Legacy Science projects of distinction. Interested attendees are urged to obtain additional information from the SIRTF Web site.

The SIRTF Science Activity Timeline in Table 3 presents a calendar of key events likely to be of interest to the user community. Updates will be made available at the SIRTF Web site.

6. SIRTF SCIENCE CENTER

The SIRTF Science Center (SSC) is located at the Infrared Processing and Analysis Center (IPAC) on the campus of the California Institute of Technology in Pasadena. The SSC is chartered to design, develop, and implement all science aspects of SIRTF operations. Functions of the SSC include: (i) acting as an interface and advocate for the SIRTF science community; (ii) capturing and conducting the SIRTF science program efficiently and in a cost-effective manner; (iii) produce and secure the SIRTF scientific legacy; and (iv) conduct education and public outreach activities pertinent to SIRTF and to infrared astronomy.

The development budget for establishing a functional ground system for SIRTF is rather modest, and has led to a careful investigation into what products and services the SSC can afford to offer. To properly gauge the magnitude of the tasks at hand, we have estimated the size of the user community and the volume of SIRTF observations. The SSC anticipates ~1000 Guest Observer/Archival Research proposals to be submitted in response to each Call for Proposals, with perhaps 300-400 selected for approval. The observing efficiency, coupled with the instrument capabilities, suggest that more than 20,000 observations per year will be scheduled and carried out. The SSC will be responsible for processing and applying calibration – within hours – roughly 1 Gbyte/day of science and engineering data. The SSC will also create a maintain a publicly accessible science archive. The early release of non-proprietary Legacy Science data will permit archival research within one year of SIRTF's launch. The SSC will also be responsible for the validation of science data products before delivery to the science archive and users.

To develop all of these capabilities on a very limited budget requires that the SSC use existing and well-characterized "off the shelf" technology, software and processes wherever possible. The best of previous and current missions will be adopted and adapted to suit SIRTF's needs. One benefit of this approach is that investigators can expect to see the software heritage of HST (for example) in the submission of proposals. The SSC will build upon the inherited expertise, experiences and software developed from other co-located projects at IPAC, including IRAS, 2MASS, ISO, and WIRE. Whenever possible, the SSC will use existing commercial and public-domain software, and will also rely on multi-mission ground data systems support at JPL.

The fiscal constraints have also forced a deliberate examination of data processing tasks, in order to assess the functions that are of broad utility and best suited to centralized "pipeline" processing, versus those that are better left to the individual investigator. The philosophy governing these choices was to "do the basic things very well," rather than attempt to do everything. The SSC will therefore produce, for every independent pointing of the telescope, a two-dimensional image that is flux- and (if appropriate) wavelength-calibrated, cosmetically restored and in FITS format with a world coordinate system that is derived from spacecraft pointing information. This is the minimum requirement that must be met for inertially fixed operating modes. Higher-order processing may be required for operating modes in which the telescope line-of-sight is continually varying or for Solar System observations of rapidly moving targets.

As needed, the SSC will also provide a limited variety of "toolkits" in convenient forms for SIRTF-specific tasks only. That will enable users to take these basic data products and turn them into forms more suitable for scientific data analysis. These tools will not duplicate existing tools readily available in other software packages. Examples of toolkit functions might include the following: (i) making mosaics of individual images from IRAC or MIPS, properly registering them in a world coordinate system and performing source extractions; (ii) combining individual IRS spectra into a datacube of two spatial dimensions and one spectral dimension for analysis of IRS scanning data; and (iii) extraction of a one-dimensional spectrum from any IRS spectral data.

An important design consideration will be a substantial reliance on the electronic dissemination of mission information and communications. The Calls for Proposals, Observatory and Instrument Manuals, and supporting software tools will all be made available via the World-Wide Web. Moreover, proposals are expected to be submitted electronically, too. These electronic exchanges will reduce costs to the SSC and to the user community, while providing the most reliable updated technical information in a timely manner.

As mentioned in §5, there will be multiple opportunities for the community-at-large to propose observational programs on SIRTF. In support of the solicitation process, the SSC will design, build, and maintain Web-based electronic software tools. The focus of these tools will be to enable investigators to begin preparing scientifically valuable programs that maximize the efficiency and utility of the Observatory. These tools will include: (i) comprehensive descriptions of the instrument observing modes (see §4) , (ii) estimates of exposure and wall clock times and expected sensitivity levels; (iii) geometrical and graphical depictions of sky visibility and orientation constraints; (iv) geometrical depictions of mapping patterns used in the relevant observing modes; and (v) estimates of the celestial foregrounds and backgrounds at appropriate wavelengths.

In an analogous manner, the SSC will offer software tools for investigators to compose and submit scientific proposals for new observations and for archival research. The SSC will: (i) provide on-line documentation to guide users through the proposal planning and submission process; (ii) provide expert staff in the use of the SIRTF instruments; (iii) distribute, and update as necessary, on-line Instrument Manuals and SIRTF Facility Manuals that (a) permit the proposer to evaluate the feasibility of their observing programs, (b) provide descriptive and quantitative information on the standard calibrations used in pipeline processing, and (c) provide quantitative data on the actual in-flight instrument characteristics and performance.

Once the data is downlinked from the spacecraft, the SSC will support various data analysis activities, through the development of SIRTF-specific analysis tools that provide the level of processing stated previously in §6. Furthermore, the SSC will offer the search and retrieval tools necessary for accessing archival data, and make them widely available to the community.

7. SUMMARY

The *Space InfraRed Telescope Facility* (SIRTF) has completed its definition phase and is moving into development at the time of this conference (early 1998). A fast-track development schedule will lead to a launch in December, 2001. While the minimum lifetime requirement remains 2.5 years, an enhanced Delta launch vehicle, an increase in on-board cryogen, and clever choices of orbit and system architecture make it increasingly possible that a 5-year mission will be achieved. SIRTF's complement of three instruments will provide imaging between 3.5 and 180 μm, and spectroscopy from 5 to 40 μm. The large-format detector arrays provide high sensitivity, and combined with the predicted observing efficiency and mission lifetime, will likely result in a rich scientific legacy for many years.

More than 75 percent of SIRTF's observing time will be available to the general community, and will be offered through multiple opportunities soliciting Guest Observer investigations. An innovative concept, the SIRTF Legacy Science program, encourages very large-scale projects that are scientifically compelling, but whose data is non-proprietary, and therefore widely available on rapid timescales. It is anticipated that archival research will be supported within the first year of post-checkout operations. The Legacy Science Call for Proposals will be issued by late 2000, and approved investigations will comprise a large portion of SIRTF's first-year schedule. The first Guest Observer proposal solicitation will be issued shortly before launch, with proposals due after on-orbit performance is determined. Subsequent proposal opportunities will be issued on at least an annual basis.

The SIRTF Science Center (SSC) at IPAC will issue the Calls for Proposals and will support all aspects of science operations. The SSC will provide expertise and tools for the planning of SIRTF observations, for the submission of proposals, and also deliver processed and calibrated data. Investigators will interface with the Observatory through Astronomical Observing Templates (AOTs), one for each of the seven observing modes. The user will completely specify observing programs through parameter selection in these AOTs. The SSC will rely heavily on the Internet/WWW for communications and exchange of data with the user community, and for timely informational updates.

SIRTF represents the fourth and final element in NASA's "Great Observatories" program, filling an important niche in our ability to observe and measure the cosmos. In a budget-conscious environment, SIRTF dramatically demonstrates a break from conventional thinking, and relies on new technologies and clever engineering to retain-much of its original scientific potential. It also represents a scientific and technological bridge to NASA's new *Origins* program, and an exciting road to discovering how it all came to be – the planets, stars, galaxies, and the Universe itself.

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