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ARRAYS: THE HEART AND SOUL OF SIRTF

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Abstract. This paper describes the status of NASA's Space Infrared Telescope Facility (SIRTF) program. SIRTF will be a cryogenically cooled observatory for infrared astronomy from space and is planned for launch early in the next decade. It will be the first cryogenic space observatory to make extensive use of the powerful infrared detector array technology discussed at this conference. We summarize a newly developed SIRTF mission concept and show how the availability of detector arrays has shaped the scientific rationale for SIRTF, and how the arrays themselves have become part of the definition of the SIRTF mission.

1. Introduction

SIRTF - the Space Infrared Telescope Facility - has been planned by NASA as a cryogenically cooled observatory for infrared astronomy from space. SIRTF will build on the scientific and technical basis established by the successful IRAS and COBE missions and also on the results of the European Space Agency's forthcoming 1S0 mission. However, SIRTF will go beyond these precursor cryogenic space missions by making extensive use of the infrared detector arrays now coming into use for astronomical applications and discussed extensively elsewhere in this volume, Indeed it is not an exaggeration to refer to detector arrays as the "heart and soul" of the SIRTF mission. They constitute the "heart" because they lie deep within the cryogenic portion of SIRTF, and because the cryogenic power dissipation of the instruments - much of which is attributable to the arrays in one way or another - dominates the helium usage and thus determines the lifetime of SIRTF. The detector arrays form the "soul" of SIRTF because, when' used under the low background conditions provided by a cryogenic telescope in space, these arrays will permit both imaging and spectroscopic observations at unprecedented sensitivity levels across the spectrum from 2,5 to 200um. In addition, as detailed below, SIRTF's scientific programs will make extensive use of many of the other attributes of the detector arrays.

SIRTF is envisioned as a multi-user facility with a broad range of capabilities, The scientific potential of a cryogenic space observatory equipped with state-of-the-art infrared detector arrays is so compelling that SIRTF was designated in 1991 both as the highest priority astronomy mission for the 199os by the National Academy of Sciences, and as NASA's highest priority "flagship" scientific mission by the interdisciplinary Space Science and Applications Advisory Committee.

This paper provides a brief overview of a new SIRTF mission concept, with emphasis on the SIRTF instruments and the various ways in which they will use the detector arrays. Much more detailed descriptions of the

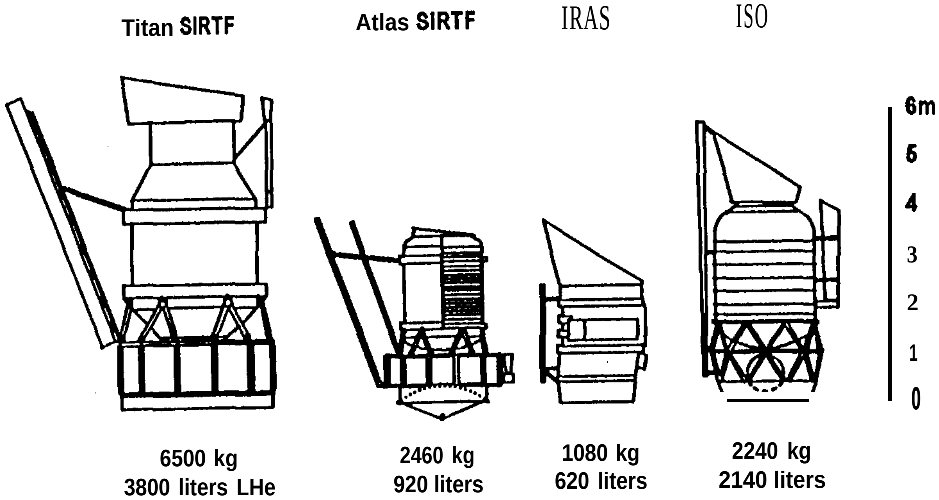

Fig. 1. Comparison of the Atlas SIRTF observatory with the previous Titan SIRTF concept and with ISO and IRAS. The spacecraft are shown to scale, and the mass and cryogenic capacity for each is shown as well.

new mission and the instruments have been published recently (l-3) and details of the SIRTF science program are given elsewhere(4-7).

2. The SIRTF Mission

2.1. The Atlas SIRTF

A key step in the development of the new SIRTF concept came with the realization that an Atlas IIAS rocket could launch a 2500-kg spacecraft into a solar orbit - in which the spacecraft escapes from the Earth's gravity but is capt u red by the Sun. The spacecraft concept for the Atlas mission is compared in Figure 1 both with the previous Titan-launched SIRTF and with IRAS and 1S0. This figure shows dramatically the reduced size and mass of the new SIRTF system. The top-level characteristics of the Atlas mission are summarized in Table 1. The combination of the long lifetime, 85-cm aperture, and large, sensitive detector arrays will give this mission great power for the study of known astrophysical phenomena and for exploring the Universe at infrared wavelengths. This is illustrated in Fig. 2, which compares the sensitivity expected for SIRTF with the levels reached in the IRAS Faint Source Survey and with the predicted brightness of typical targets of the deep surveys described below.

2.2. Instruments and Detectors

The three instruments which are under definition study for SIRTF and their functional capabilities are summarized in Table 2, which shows that the

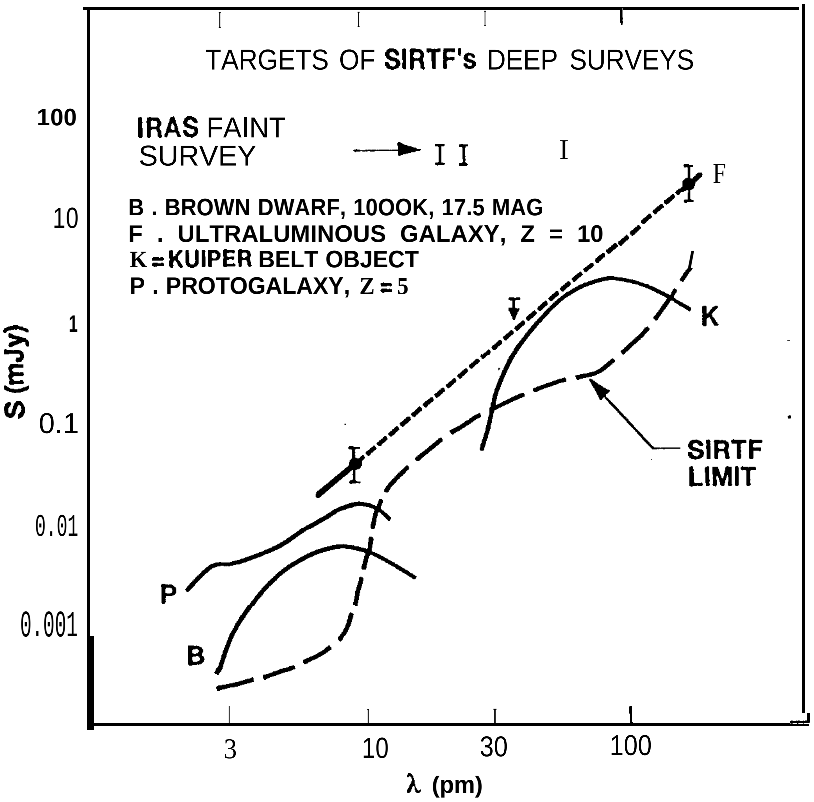

Fig. 2. The photometric sensitivity to be achieved by SIRTF (1σ in 500 seconds) across the infrared band is compared with the predicted brightness of the targets of the SIRTF deep surveys and with the 1σ sensitivity limits of the IRAS Faint Source Survey. The SIRTF sensitivity estimates are based on demonstrated detector performance or current expect at ions and include both natural background and confusion limits. The survey targets are: a Kuiper belt object with 100-km radius, 40 AU from the Sun; a 1000 K brown dwarf with a 10μm magnitude of 17.5; the IRAS protogalaxy candidate FSC10214 as seen at a redshift of 10; and a model protogalaxy assuming $10^{11} M_{\odot}$ of stars are formed at a constant rate for 0.8 Gyr prior to observation at z= 5. The adopted FSC10214 energy distribution is a straight line interpolation between the fluxes detected at 2.2 and 60μm. $\Omega = 1$, $\Lambda_0 = 0$, and $H_0 = 50$ km/sec/Mpc are assumed.

SIRTF instruments will provide both imaging and spectroscopy at all wavelengths from 2.5 to 200μm. Conceptual design studies have shown that the instrument designs are compatible with the constraints of the Atlas mission, but the overwhelming emphasis of our work has been on the detectors. Note from Table 2 that, in a given wavelength band, the same detector material and array architecture is to be used for both imaging and spectroscopy.

The current status of the detector program is that the device-level performance required to meet our goal of natural background-limited sensitivity for broad-band applications has been demonstrated, but that additional development - currently underway - will be needed to meet the more stringent sensitivity requirements for spectroscopy. In addition, the currently available Ge:Ga devices fall considerably short of the format and power dissipation requirements, and these problems are receiving considerable attention at present. Nevertheless, the program overall is evolving from technology development into a technology demonstration phase in which issues such as fabricability and operability in the SIRTF environment will be addressed in a timely way in preparation for project start in 1997.

The various components of the SIRTF detector technology program are described in greater detail in the papers by Pipher, Herter, and Rieke included in these proceedings, covering, respectively, InSb, Si:xx (IBC), and Ge photoconductor arrays. An additional important component of the program is aimed at the development of optimized multiplexer for operation at the low temperatures (< 2K) required by the germanium detectors. The SIRTF detector program is NASA's largest investment in infrared array technology, and it is clear from the presentations at this conference that this investment is already paying considerable dividends in ground-based applications.

2.3. USE OF ARRAYS

Each of the three instruments exploits in a different way the possibilities inherent in the detector arrays: For example, the lRAC will use a dichroic beamsplitter to separate the incident infrared radiation into short wavelength [2.5-5.3pm] and long wavelength [5.3-28pm] bands; the two bands are then separately imaged on the InSb and Si:As detector arrays, respectively. Thus, all IRAC observations will be made simultaneously at near- and mid-infrared wavelengths. A separate filter wheel for each band permits tailoring of the measurement to the problem under study. In addition, the IRAC will incorporate a grism to be used for low resolution spectroscopy from 2.5 to 5pm by dispersing the spectrum along the detector array.

The MIPS will also use a dichroic to permit simultaneous imaging in two of its three bands - the Si:Sb channel from 15-40pm and the Ge:Ga [stressed] band from 120-200pm. In addition, the MIPS incorporates a scanning mirror which can be scanned in opposition to a constant motion of the telescope to freeze an image of the sky on its arrays. Operation of this scan mirror in a sawtooth mode allows adjacent fields on the sky to be imaged without starting and stopping the motion of the entire telescope ($). It provides a very efficient means for SIRTF to survey large areas of the sky at integration times of 10 to 30 seconds per field, which will reach typical sensitivity levels 100 times fainter than the IRAS Faint Source Survey.

For both MIPS and IRAC, the array pixels and instrument optics will permit complete sampling of the Airy disk at all wavelengths longward of

$20\mu m$. This will allow numerical post-processing of high signal-to-noise data which can enhance the spatial resolution of SIRTF's images.

The IRS will illuminate the 128 x 128 Si:As and Si:Sb arrays in a cross-dispersed echelle mode, typically having 10 spectral orders displayed on the array simultaneously. As discussed below, this will allow groups of lines which are close in wavelength to be measured simultaneously, assuring accurate relative spectrophotometry. It will also allow complete 4-$40\mu m$ spectra to be obtained efficiently with only a few settings of the predisperser gratings. in addition, the IRS incorporates a separate array to be used in a "peak-up" mode to facilitate target acquisition at infrared wavelengths.

3. SIRTF Science

Although the details of the SIRTF scientific strategy are only now being defined, we can expect that many of SIRTF's most important scientific advances will be the results of systematic surveys carried out with both spectroscopic and imaging instrumentation. Such an exploration of the Universe at levels set only by the Earth's natural astrophysical environment is fundamental to the scientific rationale for SIRTF, and the large fields of view and high sensitivity of SIRTF's imaging arrays are essential for such surveys. In addition to the particular scientific problems which can be addressed in this fashion, we can anticipate confidently that these surveys, which will probe the cosmos to unprecedented depths at infrared wavelengths [cf. Fig. 2] will lead to the discovery of new and important astrophysical phenomena.

As an example of how SIRTF science will be carried out, we consider studies of the evolution of the infrared galaxy luminosity function. IRAS **showed** that more than half of the luminosity of a typical spiral galaxy emerges at far infrared wavelengths between 40 and $120\mu m$. As detailed by Soifer (9), the far infrared luminosity of galaxies can exceed $10^{12}L_\odot$, well into the luminosity range previously reserved for quasars. IRAS also revealed an association between galaxy-galaxy interactions and enhanced infrared luminosity. The ultra-luminous galaxies - those having $L > 10^{12}L_\odot$ - have optical images suggestive of violent interactions and mergers. Similarly, infrared-luminous galaxies - those having $L_{\rm ir} > L_{\rm vis}$ - are more common among galaxies with close companions or evidence of tidal distortions than among field galaxies. Taken together, and with supporting optical spectroscopy and radio astronomical studies, these data suggest that interactions between galaxies can trigger starbursts, concentrate molecular gas in galactic nuclei, and initiate AGN activity by stimulating the accretion of matter by (perhaps pre-existing) black holes.

An obvious way of testing such ideas is to see how the number and prop erties of infrared-luminous galaxies vary with redshift as we probe back into time. If infrared activity is in fact triggered by galaxy-galaxy interactions, the fraction of galaxies that are infrared-luminous should have been much higher at earlier epochs **when** the co-moving density was higher and interactions more frequent. IRAS' deepest survey, which covered only a small area near the orbital poles, reached back only to redshifts of order 0.1, where various models for the evolution of the infrared galaxy luminosity function are only starting to diverge (10). SIRTF's limiting flux at 60pm is about two orders of magnitude fainter than achieved by IRAS' deepest survey, and a SIRTF deep can improve dramatically upon the results of IRAS.

Although infrared continuum observations are essential to determine the luminosity of these ultra-luminous galaxies, many of which have $L_{\rm ir} >> 10L_{\rm vis}$, spectroscopic diagnostics are the only means of studying the properties of the underlying energy sources. For an object with $L_{\rm ir} >> 10L_{\rm vis}$, there is no guarantee that any of the visible wavelength emission lines originate anywhere near the principal luminosity source, and even near infrared lines may well suffer significant extinction. Therefore, spectroscopic observations at longer infrared wavelengths have a unique role to play in the characterization of the luminosity sources in these galaxies. Voit(11) has recently called attention to a group of neon emission lines, arising from ionization states between NeII and NeV, which cluster together at wavelengths between 7.6 and 36μm. Of particular note are three lines of NeII, NeIII, and NeV, which lie at 12.8, 15.6, and 14.3pm, respectively. These fall in a minimum in the extinction curve - between two silicate absorption bands - and suffer little differential extinction even when viewed through the equivalent of 100 magnitudes of visual extinction. In addition, whereas NeII is common in ordinary HII regions, NeV is produced by photons of energy 100ev, so that the ratios of these lines can distinguish very well between starburst and AGN models. SIRTF's spectrograph, using a large array in cross-dispersed echelle mode, can measure the lines simultaneously to minimize concerns about pointing and aperture size corrections. This type of spectroscopic diagnostic promises to be extremely powerful. A particularly exciting result of such follow-on observations could be the discovery of additional objects similar to the spectacular protogalaxy candidate FSC+10214 found in the IRAS Faint Source Survey (12). As shown in Fig. 2, SIRTF could detect such objects at redshifts greater than 10.

4. Impact of the Shortened Mission

Perhaps the biggest scientific impact of the move from the Titan SIRTF to the Atlas SIRTF is the reduction of the cryogenic lifetime from five to three years. This is potentially a greater loss than the 40 percent reduction in observing time would suggest, because it also reduces the amount of time that will be available for contemplating the initial results from SIRTF and folding them into follow-on observational programs. The potential loss of such opportunities is particularly critical in this case becaue SIRTF is so sensitive that many of its discoveries will not be detectable from other platforms, just as many of IRAS' results will go unexplored at least until the launch of 1S0.

To compensate for this loss of "thinking time", we are planning a scientific strategy for SIRTF which will emphasize surveys during the first six months to one year of the mission. The data from these surveys will be made widely available in a timely fashion so that many scientists can start at once to understand its significance and also to use it as a basis for follow-on investigations from SIRTF. This type of broad participation is consistent with SIRTF's role as an observatory for the entire scientific community; in addition, wc intend to make the community's role a very active one by soliciting widespread participation in defining and executing these early surveys.

5. Conclusions

The capabilities and challenges of SIRTF combine to make it a compelling and challenging mission on both scientific and technical grounds. 'l'he scientific, technological, and engineering groundwork for this exciting step in the exploration of the Universe have been established by many years of work in the academic, government, and aerospace communities. **We** are ready and eager to move forward on a schedule calling for project start in 1997, leading to launch early in the next decade.

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References

1. Kwok, J.H. and Osmolovsky, M. G.: 1993, *Proc. SPIE* 2019, in press.
2. Eisenhardt, P., Fazio, G., Houck, J., and Rieke, G.: 1993, *Proc. SPIE* 2019, in press.
3. Werner, M. W.: 1993, in *Topical Conference* on *Infrared Astrophysics*, in press.
4. Cruikshank, D.P., Werner, M.W., and Backman, D. E.: 1992, *Adv. Space Res.*, 12, (11) 187.
5. Werner, M. W., and Osmolovsky, M.: 1993, *Proc. SPIE* 2019, in press.
6. Werner, M.W.: 1991, *Adv.* Space *Res.*, 11, (2), 279.
7. Werner, M. W.: 1993, in *Sky Surveys: Protostars to Protogalaxies*, B.'I'. Soifer, ed., ASP Conf. Series.
8. Chester, T.J. *et al.*: 1992, *BAAS, 24, 1229.*
9. Soifer, B. T.: 1993, in Sky *Surveys: Protostars to Protogalaxies*, B.T. Soifer, cd.,
10. Tremaine, S.: 1990, in *Baryonic Dark Matter*, D. Lynden-Bell and G. Gilmore, eds.,
11. Voit, M.: 1992, *Ap.J.*, 399, 495. (Kluwer:Dordrecht), p. 37.
12. Rowan-Robinson, M. *et al.*: 1991, *Nature, 351, 719,*

TABLE I

Atlas SIRTF Concept Key Parameters

Orbit	Solar
Lifetime	Three years minimum
Aperture	85 cm
Wavelength Coverage	2.5 – 200μm
Data Rate	45 kbps
Pointing	0.25 arcsec
Image Quality at 3.5μm (50% encircled energy)	2 arcsec
Mass (includes 620 kg contingency)	2460 kg

TABLE 11

SIRTF Instrument Summary

Infrared Array Camera (IRAC) - G. Fazio, P, I., Smithsonian Astrophysical Observatory, Will use InSb and Si: As arrays and dichroic to provide simultaneous imaging, polarimetry in two bands, grism spectroscopy with InSb.

Multiband Imaging Photometer for SIRTF (MIPS) - G. Rieke, P. I., University of Arizona. Will use Si:Sb and Ge:Ga arrays for imaging and polarimetry, and use a scanning mirror to rapid] y survey large areas. IRAC also considering scan mirror.

Infrared Spectrograph (IRS) - J. Houck, P. I., Cornell University. Will use Si:As, Si:Sb, and Ge:Ga arrays to provide spectra from 4- 200μm. Si arrays will use echelle to measure many orders simultaneously.

Wavelength (μm)	Detector Material	Format (Pixels)	Imaging FOV/Pixel	Spectral Resolution
2.5 -5.3	InSb	256 X 256	5'/1.2"	100-200 (grism)
4-28	Si:As (IBC)	128 X 128	5'/2.4"	1000-2000 (cross-dispersed)
12-36	Si:Sb (IBC)	128 x 128	5.3'/2,5"	1000-2000 (cross-dispersed)
40-120	Ge:Ga	32 x 32*	2.65'/5" 5.3'/10"	1000-2000
80-200	Ge:Ga (stressed)	2 x 16	0.66' $\times$5.3'/20"	500-1000

*Ge:Ga Format 4 x 32 in Spectrograph