# (C) INFRARED AND SUBMILLIMETER MISSIONS

# THE SPACE INFRARED TELESCOPE FACILITY (SIRTF)

GIOVANNI G. FAZIO
*Smithsonian Astrophysical Observatory, Cambridge, MA 02138 USA*
and
PETER EISENHARDT
*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA*

**Abstract.** The Space Infrared Telescope Facility (SIRTF) is a one-meter class observatory for infrared astronomy that will be launched into high earth orbit by NASA in the late 1990's. SIRTF's three focal plane instruments will permit imaging and spectroscopy over most of the infrared spectrum with sensitivities of 100 to 10,000 times their predecessors. This paper briefly reviews SIRTF's capabilities, science objectives, and current status.

## 1. Introduction

The Space Infrared Telescope Facility (SIRTF) is a cryogenically-cooled one-meter class observatory for infrared astronomy, which will orbit the earth at an altitude of 100,000 km (Figure 1).

Along with the Hubble Space Telescope, The Advanced X-ray Telescope, and the Gamma-Ray Observatory, SIRTF will be part of NASA's family of Great Observatories. The SIRTF mission will be launched in the late 1990's and will have a lifetime of 5 years or longer. SIRTF will be operated as a facility for the entire scientific community, with over 80the mission available to General Observers. Members of the SIRTF Science Working Group are listed in Table I.

The outstanding success of previous infrared space missions such as the Infrared Astronomy Satellite (IRAS), the first space telescope to survey the entire sky, and the Cosmic Background Explorer (COBE), which is exploring the large-scale cosmic background radiation, has demonstrated that both technically and scientifically, the next step in our exploration of the infrared universe is a facility such as SIRTF. The hoped-for success of ESA's Infrared Space Observatory (ISO) will just increase the need for a facility with the capabilities planned for SIRTF. SIRTF, with its excellent optics, high pointing accuracy, use of the best available detector arrays, wide wavelength coverage, and long, uninterrupted observing periods, will provide the best possible follow-on to these missions.

SIRTF's instruments will permit imaging at all infrared wavelengths from 700 microns and spectroscopy from 2 to 200 microns. Dramatic advances in infrared detector technology will enable SIRTF to gain by factors of 100 to 10,000 in sensitivity over its predecessors; an additional enormous increase in capability results from the availability of these highly sensitive detectors in large-format arrays containing tens of thousands of pixels. The full potential of these devices will be realized through cooling SIRTF below 4K with super-fluid helium and by the use of diffraction-limited optics.

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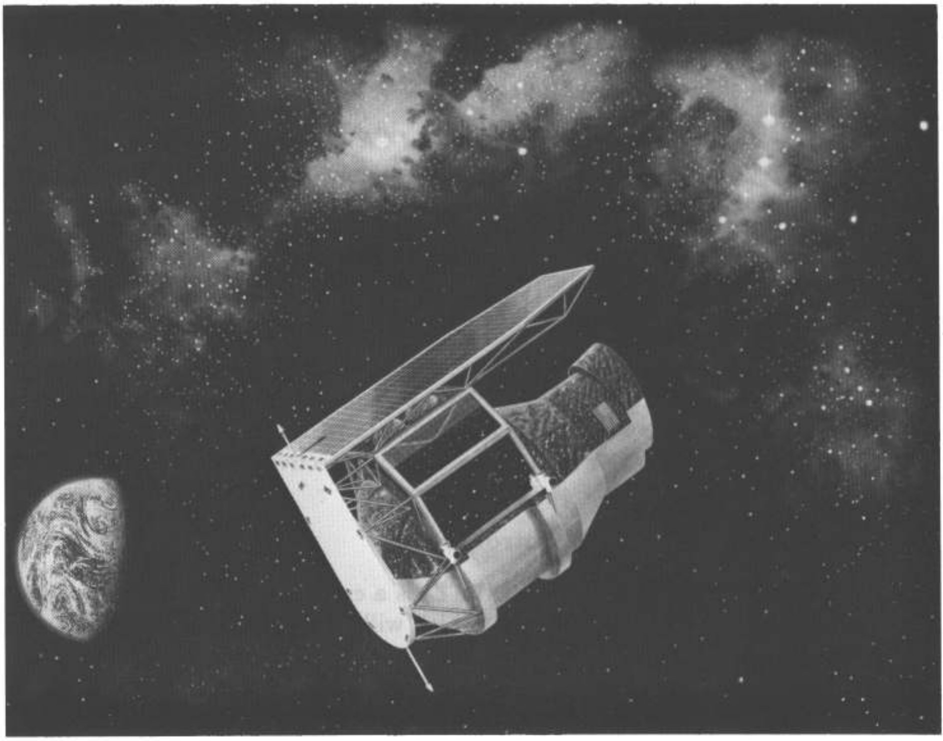


Fig. 1. The Space Infrared Telescope Facility (SIRTF).

TABLE I
Members of the SIRTF Science Working Group

| | |
|---|---|
| DR. MICHAEL W. WERNER<br>JPL | CHAIRMAN OF THE SWG<br>PROJECT SCIENTIST |
| DR. DALE CRUIKSHANK<br>NASA-AMES | INTERDISCIPLINARY SCIENTIST |
| DR. GIOVANNI FAZIO<br>SAO | PI, INFRARED ARRAY CAMERA (IRAC) |
| DR. FRED GILLETT<br>NASA HQ/NOAO | PROGRAM SCIENTIST |
| DR. JAMES R. HOUCK<br>CORNELL UNIVERSITY | PI, INFRARED SPECTROMETER (IRS) |
| DR. MICHAEL JURA<br>UCLA | INTERDISCIPLINARY SCIENTIST |
| DR. FRANK LOW<br>UNIVERSITY OF ARIZONA | FACILITY SCIENTIST |
| DR. GEORGE RIEKE<br>UNIVERSITY OF ARIZONA | PI, MULTIBAND IMAGING PHOTOMETER<br>(MIPS) |
| DR. B. THOMAS SOIFER<br>CALTECH/JPL | DEPUTY PROJECT SCIENTIST |
| DR. EDWARD L. WRIGHT<br>UCLA | INTERDISCIPLINARY SCIENTIST |

TABLE II
The SIRTF system parameters and their comparison with the Infrared Astronomy Satellite (IRAS)

SIRTF
SIRTF/IRAS COMPARISON

| | SIRTF | IRAS |
|---|---|---|
| MIRROR DIAMETER | >90 CM | 60 CM |
| WAVELENGTH COVERAGE | 2–700 μm | 8–120 μm |
| DIFFRACTION-LIMITED WAVELENGTH | 3 μm | ≈15 μm |
| ANGULAR RESOLUTION | (λ/4 μm) ARCSEC | 15 ARCSEC at 12 μm |
| POINTING STABILITY/ACCURACY | 0.15/0.25 (ARCSEC) | 2 ARCSEC |
| MODULATION | ARTICULATED SECONDARY | SCAN |
| FIELD OF VIEW | 15.7 ARCMIN | 1 DEGREE |
| SENSITIVITY | | |
| 10 μm | 6 μJy | 70 mJy |
| 60 μm | 100 μJy | 70 mJy |
| NUMBER OF DETECTORS | >200,000 | ≈60 |
| SPECTRAL RESOLVING POWER | ≳2000 | 20 |
| *MODE* | *OBSERVATORY* | *SURVEY* |
| LIFETIME | 5 YR | 10 MONTHS |
| ORBIT | 100,000 KM<br>CIRCULAR | 900 KM, POLAR<br>SUN-SYNCHRONOUS |

## 2. SIRTF in high earth orbit

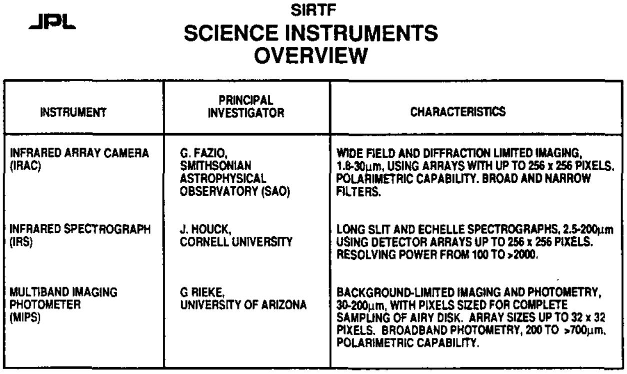
The SIRTF described in this paper is quite different from the 1988 version of SIRTF, which was designed for operation in low earth orbit at 900 km altitude (Werner *et al.* 1988). The high earth orbit (HEO) mission, at an altitude of 100,000 km, will will have greatly improved scientific performance (Werner *et al.* 1989). With an expected lifetime in excess of 5 years and a greater than 80equivalent to 10-15 years of operation in low earth orbit. Improved response at far-infrared and submillimeter wavelengths will result because of reduced telescope background radiation, longer integration times will be possible, and continuous viewing zones at high galactic latitudes will be available which are ideal for deep surveys. A comparison of the relative obscuration by the Earth in the two orbits is demonstrated in Figure 2.

Because SIRTF will orbit beyond the trapped radiation belts, the effects of the South Atlantic Anomaly on SIRTFs detectors will no longer be a problem. However, the cosmic ray flux in HEO will increase and the detectors will now be exposed to occasional solar flare effects.

The high earth orbit SIRTF will also lower the mission risks: there will be no deployable solar panels, safe hold modes of operation will exist, and there will be no atmospheric effects, such as spacecraft glow and atomic and molecular gas contamination.

Spacecraft operations will also be considerably streamlined by the 4-day orbit, excellent sky access, and use of the Deep Space Network for telemetry.

TABLE III
A summary of SIRTF's science instruments



JPL

SIRTF
SCIENCE INSTRUMENTS
OVERVIEW

| INSTRUMENT | PRINCIPAL INVESTIGATOR | CHARACTERISTICS |
|---|---|---|
| INFRARED ARRAY CAMERA (IRAC) | G. FAZIO, SMITHSONIAN ASTROPHYSICAL OBSERVATORY (SAO) | WIDE FIELD AND DIFFRACTION LIMITED IMAGING, 1.8-30μm, USING ARRAYS WITH UP TO 256 x 256 PIXELS. POLARIMETRIC CAPABILITY. BROAD AND NARROW FILTERS. |
| INFRARED SPECTROGRAPH (IRS) | J. HOUCK, CORNELL UNIVERSITY | LONG SLIT AND ECHELLE SPECTROGRAPHS, 2.5-200μm USING DETECTOR ARRAYS UP TO 256 x 256 PIXELS. RESOLVING POWER FROM 100 TO >2000. |
| MULTIBAND IMAGING PHOTOMETER (MIPS) | G RIEKE, UNIVERSITY OF ARIZONA | BACKGROUND-LIMITED IMAGING AND PHOTOMETRY, 30-200μm, WITH PIXELS SIZED FOR COMPLETE SAMPLING OF AIRY DISK. ARRAY SIZES UP TO 32 x 32 PIXELS. BROADBAND PHOTOMETRY, 200 TO >700μm. POLARIMETRIC CAPABILITY. |

## 3. The SIRTF facility

The SIRTF system parameters and their comparison with IRAS are shown in Table II. Although SIRTFs mirror is larger than IRAS, SIRTFs greatly improved sensitivity will be achieved primarily through its higher angular resolution, improved pointing stability, long integration time, and the availability of large-area infrared array detectors with vastly improved sensitivity. SIRTFs sensitivity will be limited only by the natural astrophysical background radiation over most of its operating band.

SIRTF will cover the entire spectral region from 2 microns to 700 microns wavelength and thus uniquely encompasses two important cosmic windows, minima in the natural background radiation located at approximately 3.5 microns and 300 microns, which permit deep views of the early Universe. SIRTFs optical system will provide diffraction-limited images at wavelengths longward of 3 microns over a 15.7 arcmin field of view, and the pointing accuracy and stability are matched to the 0.73 arcsec image diameter at 3 microns.

Figure 3 shows a cross-sectional view of the current concept for the SIRTF telescope.

The optical design is that of a standard Cassegrain telescope with Ritchey-Chretian optics. A 95-cm primary mirror collects the light and reflects it onto a secondary mirror that forms an image plane behind the primary mirror. Also located behind the primary mirror is the Multiple Instrument Chamber (MIC).

Within the MIC a pyramidal-type, multifaceted dichroic mirror (the tertiary mirror) divides the field of view into sectors, directing each sector to one of the instruments. Behind the tertiary mirror will be located the Fine Guidance Sensor, which will used with the spacecraft gyroscopes to provide pointing and stabilization. In a manner similar to IRAS and COBE, the entire telescope system, including the MIC, is suspended in an annular cryogenic tank, containing superfluid helium, which cools the optics and instruments to 1.6 K. The secondary mirror will also be used for conventional chopping at far-infrared and submillimeter wavelengths and for image

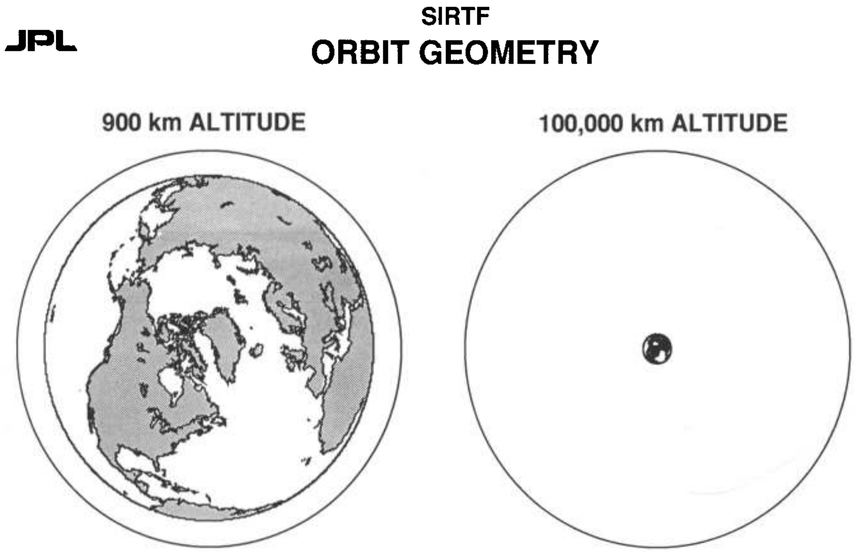


Fig. 2. Orbital geometry of SIRTF in the 100,000 km orbit in comparison to the former 900 km low earth orbit.

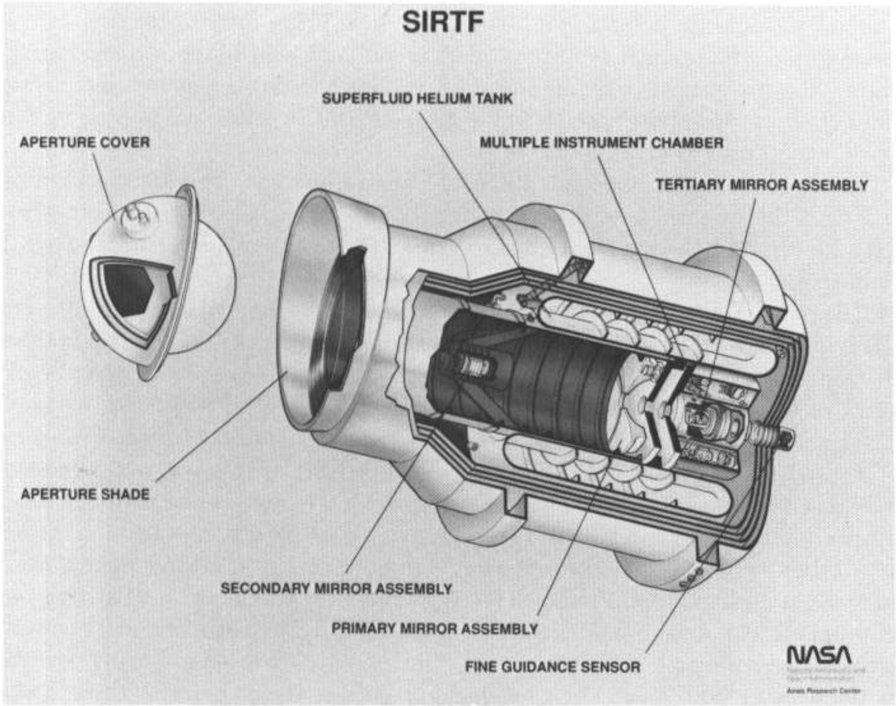


Fig. 3. A cross-sectional view of the current concept for SIRTF.

scanning at the shorter wavelengths. A truncated sun shade shields the telescope interior from stray radiation, allowing the telescope to point within 80 degrees of the Earth and Sun limb without putting an undue load on the cryogenic system. The aperture cover is ejected once the telescope is in orbit and the spacecraft has outgassed.

## 4. Focal plane instruments

The three focal plane instruments were selected in 1985 and are presently under definition study.

The Infrared Array Camera (IRAC) will use large area, two dimensional infrared array detectors to provide wide-field (5 arcmin) and diffraction-limited imaging over the spectral region from 2 to 27 microns. The Multiband Imaging Photometer for SIRTF (MIPS) will provide background-limited imaging and photometry over the wavelength range from 30 to 200 microns, using arrays with pixels sized for complete sampling of the Airy disk; wide-field, high resolution imaging from 50 to 120 microns; and broad band photometry and mapping from 200 to 700 microns, with a possible extension to 1.2 mm wavelength. The very high sensitivity and complete spatial sampling of IRAC and MIPS, combined with the high quality, stable images to be provided by SIRTF, will permit the use of super-resolution techniques to improve the areal angular resolution of the images over that implied by the Rayleigh criterion by factors of five or more. IRAC and MIPS will also have the capability to measure polarization. The third focal plane instrument, the Infrared Spectrograph (IRS), consists of several long slit and echelle-mode spectrographs covering the wavelength interval from 2.5 to 200 microns using two dimensional array detectors. Resolving power will vary from 100 to 2000. An overview of the science instruments is given in Table III.

The expected performance of the SIRTF instruments is compared in Figures 4 and 5 with the brightness of potential targets, the flux levels reached in the IRAS all-sky survey, and the capabilities of existing ground-based and airborne facilities for infrared astronomy.

Figure 4 highlights SIRTF's capability to study objects at large redshift in the distant universe, while Figure 5 features examples from the solar neighborhood. Note from Figure 4 that SIRTF will easily be able to obtain complete high resolution spectra of even the faintest IRAS survey sources – many of which are below the limit of detectability even in broad spectral bands with current infrared facilities.

Of utmost importance is the fact that SIRTFs instruments will make extensive use of the infrared detector array technology which is now becoming available to the astronomical community. SIRTFs sensitivity goal is to be natural-background limited; that is, SIRTFs detectors should be limited only by the fundamental statistical fluctuations in the faint infrared background of the earths natural astrophysical environment. The detectors currently in hand for SIRTF reach this limit at wavelengths between 5 and 200 microns, and further improvements can be expected over the next several years. On a per-pixel or per-resolution element basis, SIRTF thus realizes a full 100 to 10,000-fold increase in sensitivity over the achievements of IRAS and over the best current capabilities at infrared wavelengths (Figures 4 and 5). SIRTFs focal plane instruments will incorporate arrays with tens of thousands of pixels, each operating at this extremely high sensitivity level. In contrast, the IRAS focal plane incorporated 62 discrete detectors, and ISO relies primarily on small arrays (32 × 32 pixels) and on many discrete detectors. SIRTF will thus be the first mission to combine the intrinsic sensitivity of a cryogenically-cooled telescope for infrared astronomy with the tremendous imaging and spectroscopic power of large-format detector arrays. SIRTF represents a truly enormous increase in our capability to explore the Universe at infrared wavelengths.

## 5. SIRTF science objectives

SIRTF's long lifetime will permit scientists from all disciplines to use the facility to carry out a wide variety of astrophysical programs. In the paragraphs below we will discuss key areas of astrophysics where SIRTF's contributions are critical, i.e., where SIRTF's can substantially advance key areas of astrophysics during the coming decade. These principle scientific objectives include understanding how our solar system and the planets formed, the search for other solar systems, the birth and evolution of stars, searching for dark matter in the Universe, probing the earliest stages of the Universe to understand how galaxies formed and evolved, and understanding cosmic energy sources in active galaxies and quasars (Rieke *et al.* 1986).

### 5.1. OUR SOLAR SYSTEM

SIRTF will allow us to measure the chemical composition and the temperature of the most primitive objects in the solar system, such as planetary satellites, asteroids, and the nuclei of distant comets, and thus study what the solar system was like when it formed. SIRTF's measurements of the changing appearance of comets as they approach and recede from the Sun will be particularly useful for determinations of the structure and composition of cometary nuclei. Complete infrared spectra of Pluto, Chiron, and Triton will give definitive information on the atmospheres and icy surfaces of these small and remote bodies.

### 5.2. SEARCH FOR OTHER SOLAR SYSTEMS

IRAS found disks of matter around several nearby stars that suggest the formation of planetary systems. By applying SIRTF's high resolution and sensitivity to the study of circumstellar material around nearby stars, we can learn how commonly such disks occur, as well as their dimensions, structure, and chemical composition. Zodiacal dust clouds like the Sun's can be imaged by SIRTF around the nearest solar type stars, while disks like those found by IRAS can be studied around stars more distant than 1 kpc. For the most prominent systems, such as Vega and Fomalhaut, SIRTF's images will show the orientation, structural features and detail morphology of the disks. The effects of companions, both stars and massive planets, on the dust disks should be discernible using SIRTF's high precision images and super-resolution techniques.

### 5.3. Birth and Evolution of Stars

SIRTF is ideally suited for the study of star formation. Stars are born within dense clouds of interstellar gas and dust. These dust clouds absorb any visible light from stars forming within them, but infrared radiation from these stars in formation can escape from even the densest clouds. SIRTF will produce images and spectra of these regions which will greatly increase of understanding of the chemical, structural, and dynamical evolution of stars in the earliest stages of their evolution. In particular, SIRTF will be a very sensitive facility for the detection of low luminosity protostellar objects. SIRTF's maps of dense, dark clouds will search for the earliest stages of star formation and will be so sensitive that all stars that are formed within these complexes will be detected and characterized through their spectra. These surveys will permit the determination of the entire initial mass and luminosity functions in these clouds.

### 5.4. Brown Dwarfs

Objects more massive than Jupiter and less massive than the 0.08 solar masses required for a star to sustain nuclear burning are expected to be visible in the infrared as they radiate the heat generated by their gravitational contraction. Searches to date have been generally unsuccessful in discovering these objects, called "brown dwarfs", which have been proposed as a form of dark matter. SIRTF will be capable of carrying out substantial searches, both in deep surveys and around nearby stars, over a wide range of luminosities and temperatures for these objects. Their abundance would also provide an important challenge to our understanding of the formation of stars and planets.

### 5.5. Formation and Evolution of Galaxies

The identification of the epoch of first star formation in galaxies is crucial to our understanding of the process of galaxy formation. The quest for this "protogalaxy" epoch has spurred observers for decades. SIRTF can detect a young galaxy of average mass at a redshift of 5, seen when the Universe was less than 10ultra-deep surveys in several broad bands to search for these objects. Observations of nearby galaxies and galaxies at intermediate distances will allow us to describe the time evolution of the physical and chemical properties of galaxies and guide our understanding of how galaxies develop from massive clouds of gas into highly organized systems of stars, gas, and dust.

### 5.6. Ultraluminous Galaxies and Quasars

The IRAS survey has suggested that violent galaxy collisions may trigger activity in the nuclei of galaxies, perhaps providing an explanation for the origin of quasars. Quasars and other active galactic nuclei (AGN), are thought to be powered by massive black holes at their centers, but much of this activity is heavily obscured by gas and dust. SIRTF's imaging surveys will trace the evolution of quasars and ultraluminous infrared objects to redshifts well in excess of 3 (Figure 4) and SIRTF's

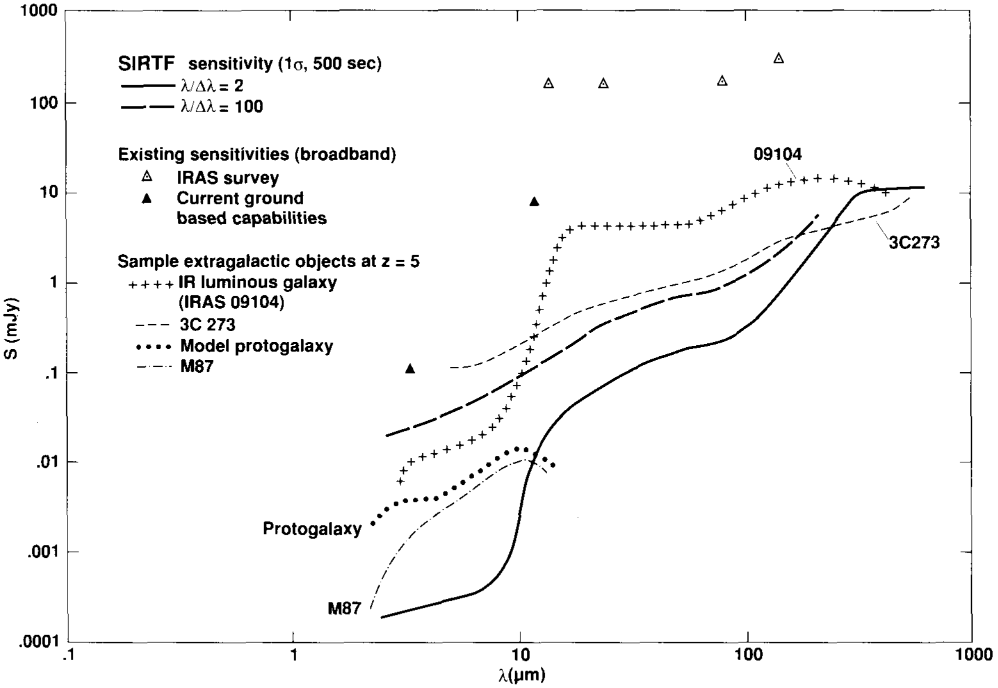


Fig. 4. SIRTF's sensitivity for objects in the distant Universe. SIRTF's sensitivity (1 sigma in 500 seconds) in photometric and low resolution spectroscopic modes is compared with that of IRAS (survey mode) and of large ground-based telescopes. The limiting sensitivity in the far infrared of current airborne telescopes is about that shown for IRAS. The SIRTF predictions are based on demonstrated detector performance or current expectations and also include both natural background and confusion limits. Superimposed on these sensitivity limits are the fluxes of known extragalactic objects of the types to be studied by SIRTF, but moved to cosmological redshifts assuming a Hubble constant of 50 km/sec/Mpc and $q_0 = 0.5$: the giant elliptical galaxy M87, the luminous IRAS galaxy 09104+4109, and the quasar 3C273. The protogalaxy model assumes $10^{11}$ solar masses of stars are formed at at constant rate for 0.8 Gyr prior to observation at the redshift of 5 (90universe at that epoch), and that no dust is present.

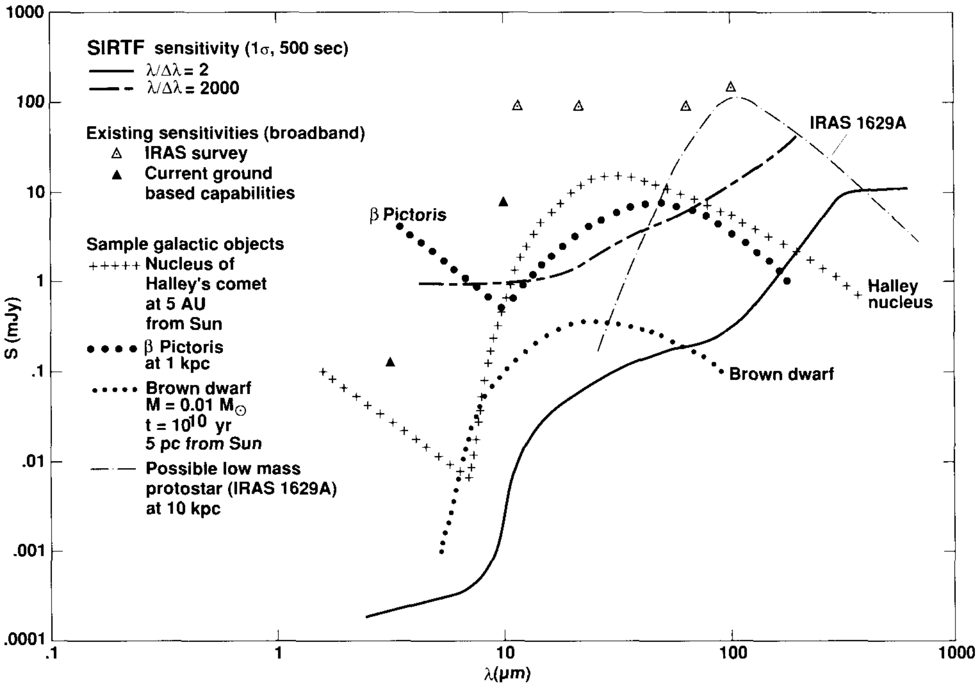


Fig. 5. SIRTF's sensitivity for objects in the solar neighborhood. SIRTF's sensitivity (1 sigma in 500 seconds) in photometric and high resolution spectroscopic modes is compared with that of IRAS (survey mode) and of large ground-based telescopes. The limiting sensitivity in the far infrared of current airborne telescopes is about that shown for IRAS. The SIRTF predictions are based on demonstrated detector performance or current expectations and also include both natural background and confusion limits. Also shown are the fluxes of known and predicted galactic and solar system objects of the types to be studied by SIRTF: Halley's comet, the star beta Pictoris with its associated planetary debris disk, a faint brown dwarf model, and a possible protostar.

spectrogaraphs will identify spectral features which will determine the redshift, and hence the luminosity, of these infrared-bright objects, as well as determine the ionization and excitation conditions in the vicinity of the luminosity sources. Complete flux-limited surveys will test the cosmic evolution of ultraluminous infrared galaxies and infrared-selected quasars by determining their number density evolution with redshift. SIRTF has the unique capabilities to make major breakthroughs in our understanding of these objects.

## 6. SIRTF'S future

In January, 1990, NASA Headquarters transferred the responsibility for the management of SIRTF to the Jet Propulsion Laboratory (JPL). Since that time the Request for Proposals for Phase B for the facility have been released and SIRTF's Phase B program will begin in October, 1990. The new start date (Phase C/D) is anticipated for FY1993, with a launch date in 1999.

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