3.6 FIRST

Introduction

The ‘Far InfraRed and Submillimetre Telescope’ (FIRST) is a multi-user observatory mission that targets approximately the 80-670 μm range in the far-infrared and submillimetre part of the electromagnetic spectrum. FIRST is one of the original four Cornerstone missions in ESA’s Horizon 2000 plan; it was selected as Cornerstone 4 (CS4) in November 1993.

Science objectives

Background

Blackbodies at temperatures of 5-50 K peak in FIRST’s wavelength range, and gases between 10 K and a few hundred K emit their brightest molecular and atomic emission lines here. Broadband thermal radiation from small dust grains is the most common continuum emission process in this band. These conditions are widespread, from our own solar system to the most distant reaches of the Universe.

Predicted sensitivities

The FIRST observing time will be allocated to areas where its capabilities are unique and its scientific impact will be the most profound. A model payload was used to predict FIRST’s sensitivity (Figure 3.6.1) and used to evaluate the scientific capabilities. From the predicted sensitivities it can be seen that:

- Progressing to shorter wavelengths, there is a point in the 100-150 μm range where a smaller cryogenic telescope will be more sensitive, although FIRST will have better angular resolution and lower confusion limits.
- Progressing to longer wavelengths, there is a point in the 800-900 μm range where larger ground-based instruments will be more sensitive and have better angular resolution.
- The sensitivity advantage offered by the relatively cold and very low-emissivity FIRST telescope in the space environment decreases for (very) high-resolution spectroscopy.

The conclusion is that FIRST has unique capabilities in performing photometry and (medium) resolution spectroscopy in approximately the 100-600 μm range. In addition, from space FIRST has access to lines – for very high-resolution spectroscopy – that cannot be reached at all even from aircraft altitude.

Key science goals

The key science objectives of FIRST, as defined by the FIRST Science Advisory Group and further discussed in an ESA symposium in Grenoble (May 1997),

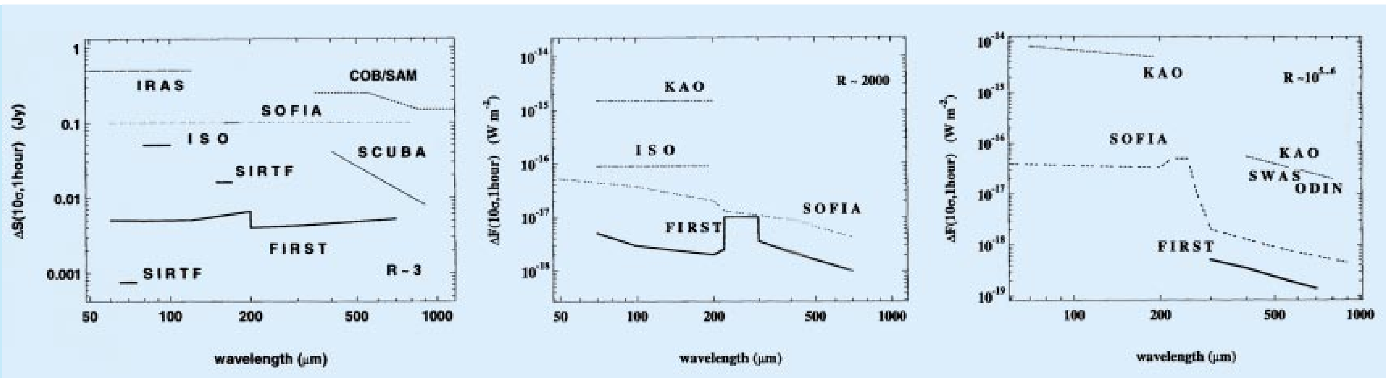
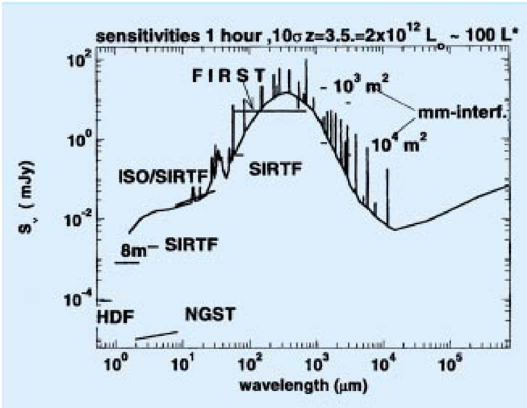


Figure 3.6.1. Calculated FIRST sensitivities (model payload) for (from left to right) photometry (R~3), medium (R~2000) and very high (R~10^{5-6}) resolution spectroscopy. Plotted are also actual or calculated sensitivities for a number of complementary facilities. Note that the curves are 10σ noise levels for 1 h observations. From R. Genzel (private communication).

For further information on FIRST, see http://astro.estec.esa.nl/First



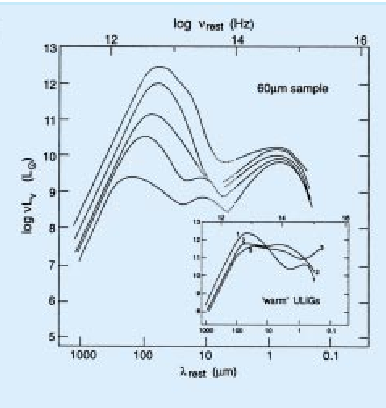


Figure 3.6.2 (left). Calculated 10σ 1 h sensitivities (per detector) for detecting a $100L_*$ starburst galaxy at z~3.5. From R. Genzel (private communication).

Figure 3.6.3 (right). Spectral energy densities for a number of the IRAS 60 μm sample of galaxies. Ultra-luminous IR galaxies emit 90-99% of their bolometric luminosity in the IR. The optical/near-IR luminosity is a very poor indicator of bolometric luminosity. From Sanders & Mirabel, *Ann. Rev. Astron. Astrophys.* 1996, 34,749.

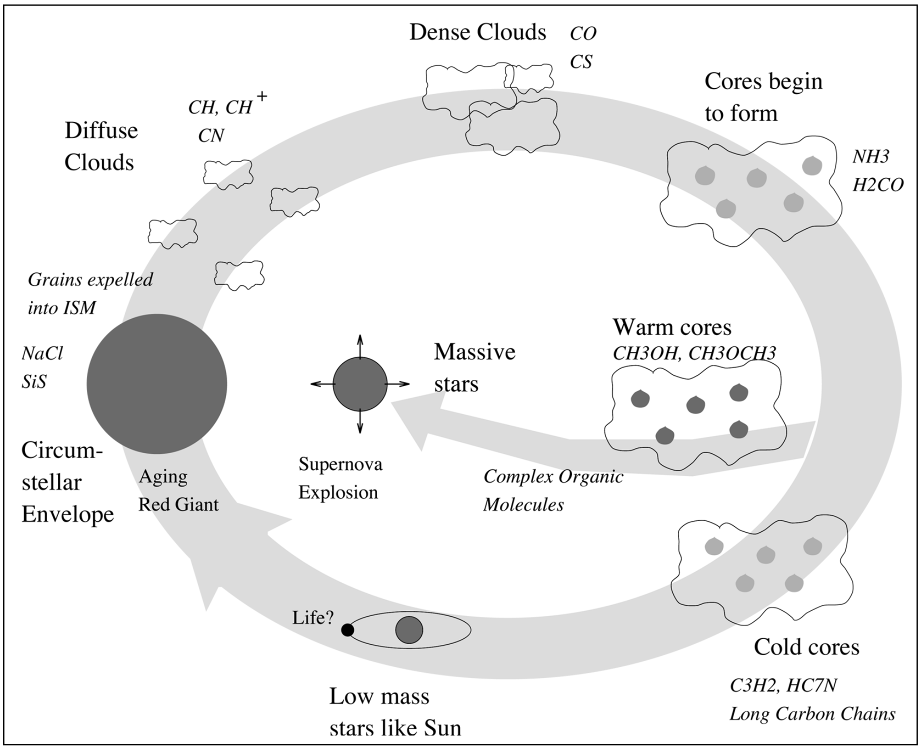


Figure 3.6.4. Illustration of the reprocessing of material in the interstellar medium. From van Dishoeck & Helmich, 1997, ESA SP-388, 3.

emphasise specifically the formation of stars and galaxies, and their interrelation. The list includes (but is not necessarily limited to):

— Deep broadband photometric surveys in the 100-600 μm FIRST 'prime' wavelength band and related research. The main goals will be a detailed investigation of the formation and evolution of galaxy bulges and elliptical galaxies in the first third of the present age of the Universe.

While optical/near-IR observations can detect the stellar light emerging from galaxies undergoing star-formation bursts out to very high redshifts (Figure 3.6.2), they cannot unambiguously determine their total bolometric luminosity (i.e star-formation rate) since the fraction, depending on dust content, of reprocessed (into the IR) star-light is unknown (Figure 3.6.3).

Gravitationally-lensed ultra-luminous IR galaxies such as FSC 10214+4724 already prove the existence of dusty high-redshift starburst galaxies, and the spatially integrated emission of a population of such galaxies may already have been detected. Furthermore, the potential discovery of new classes of objects is an intriguing possibility.

— Follow-up spectroscopy of especially interesting programme objects discovered in the survey. The far-IR/sub-mm band contains the brightest cooling lines of interstellar gas, which give very important information on the physical processes and energy production mechanisms (e.g. AGN *vs* star formation) in galaxies.
— Detailed studies of the physics and chemistry of the interstellar medium in galaxies, both locally in our own Galaxy, as well as in external galaxies, including objects at high redshift. This implicitly includes the important question of how stars form out of molecular clouds in various environments.
— Observational astrochemistry (of gas and dust) as a quantitative tool for understanding the stellar/interstellar lifecycle and investigating the physical and chemical processes involved in star formation and early stellar evolution in our Galaxy. Virtually all major components of this lifecycle (e.g. cloud collapse, freeze-out, disc formation, dust coagulation and planetesimal formation), see Figure 3.6.4, can be probed with FIRST.

  An important advantage of a space mission such as FIRST over ground-based or even airborne observatories is its complete spectral coverage over a wide wavelength range, totally unhindered by the atmosphere. A thorough knowledge of these processes in our Galaxy is a prerequisite for understanding galaxy and star formation at high redshifts.
— Detailed high-resolution spectroscopy of a number of comets, high-resolution molecular spectroscopy of the cool outer planets, and searches for Kuiper-belt objects.

From experience, it is also clear that the ‘discovery potential’ is significant when a new capability is being exploited for the first time. Observations have never been performed in space in FIRST’s ‘prime band’. As a space facility is essential in this wavelength range, FIRST will be breaking new ground.

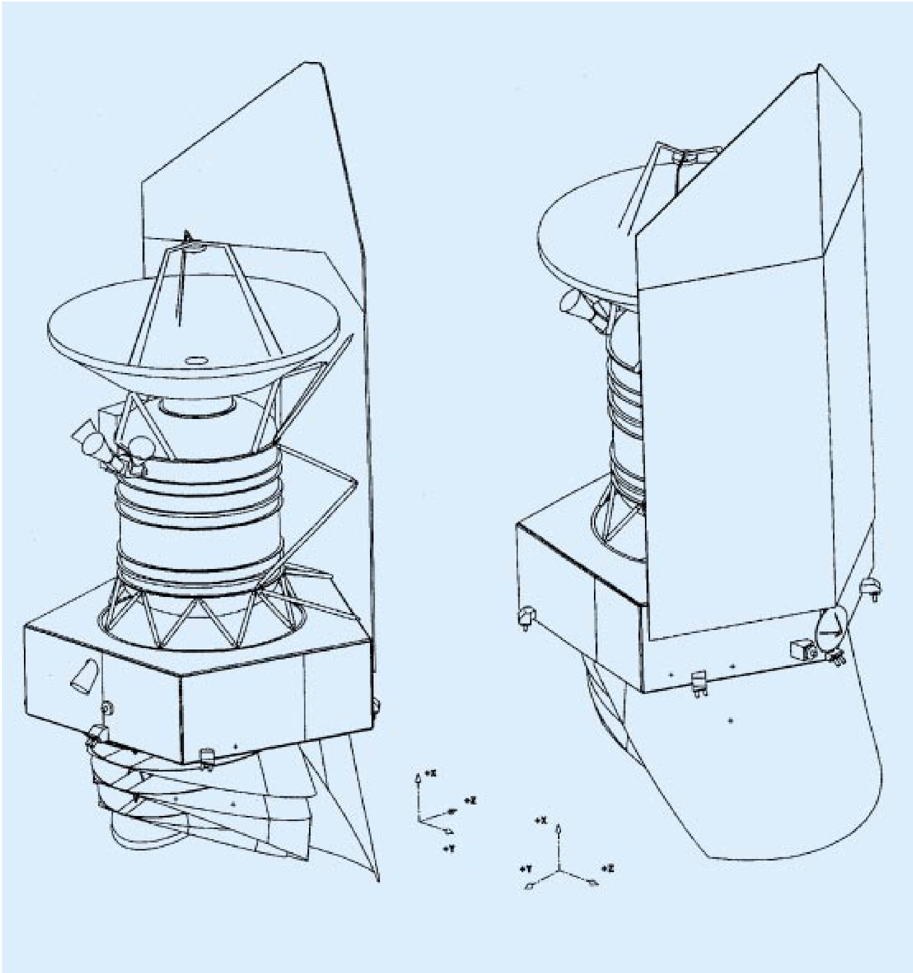
FIRST mission implementation options

Background
Studies subsequent to the 1993 CS4 selection have shown that the now well-proven ISO cryostat technology can also be used to advantage for FIRST. All presently-studied FIRST configurations envisage a payload module based on ISO cryostat technology, and operation at the Lagrangian point L2 of the Earth/Moon-Sun system, approximately 1.5 million km from the Earth.

Spacecraft concept
In 1997, a number of similarities between the Planck (M3, see the 3.5 Planck entry in this volume) cosmic microwave background mapping mission and FIRST prompted ESA to study the possibility of combining the two projects in order to save money without compromising the scientific capability of either.

Three different possibilities for implementing FIRST (and Planck) are being considered. The ‘merged’ option conducts the FIRST and Planck scientific missions conducted consecutively and independently of each other using the same ‘facility’, consisting of the FIRST and Planck payload modules (PLMs) sharing a common service module (SVM). The ‘carrier’ option carries FIRST on top of Planck during the

Figure 3.6.5. **Two views of the 'merged' FIRST/Planck satellite. It measures about 11 m high and 4.5 m wide, and has a launch mass of 4700 kg. The 3.5 m diameter FIRST telescope is protected by the sunshade, and will cool passively to below 80 K. The FIRST payload is housed inside the cryostat, which contains 2560 l of superfluid helium at 1.65 K, giving a predicted cryostat lifetime of 4.5 years in the L2 orbit. The fixed solar panels, three startrackers in a skewed configuration and the local oscillator unit for the heterodyne instrument are visible on the outside of the cryostat vacuum vessel. The Planck payload module is at bottom. The Sun is in the +z direction.**



launch phase. Finally, there are two 'stand-alone' completely separate missions.

The recent industrial studies have focused on the 'merged' concept, which is technically the most challenging. Two studies have been performed competetively and in parallel by industry; one configuration (the main diffferences are in the Planck PLM; see the 3.5 Planck entry in this volume) is shown in Figure 3.6.5.

The focal plane units of the science payload instruments are mounted on a honeycomb optical bench with carbon-fibre-compound (CFC) facesheets, within the cryostat vacuum vessel (CVV), as shown in Figure 3.6.6, and have a common instrument protection shield. The predicted temperatures for various cryostat levels are given in Table 3.6.1. The 1.7 K level is achieved via a silver strap from each instrument in direct contact with the cryogen. The 4 K level is reached by copper straps from each instrument connected to the wheel-shaped heat exchanger, while the 15 K level is gas-cooled. The predicted stationary helium mass flow rate during routine FIRST science operations is 2 mg/s, equivalent to 63 kg (or 435 l) per year.

Table 3.6.1. Predicted temperatures for various FIRST cryostat levels.

	T (K) *(average mode)*
Instrument cold stage	1.7
'4.3 K-level'	4.0
'15 K-level'	9.0
Optical Bench	11.7
Common Instrument Shield	12
Heatshield 1	30
Heatshield 2	43
Heatshield 3	62
CVV average	77
Telescope	78

Telescope development

The FIRST telescope will be provided by NASA as part of its involvement in the FIRST mission. The baseline is an all-carbon fibre reinforced plastic (CFRP)

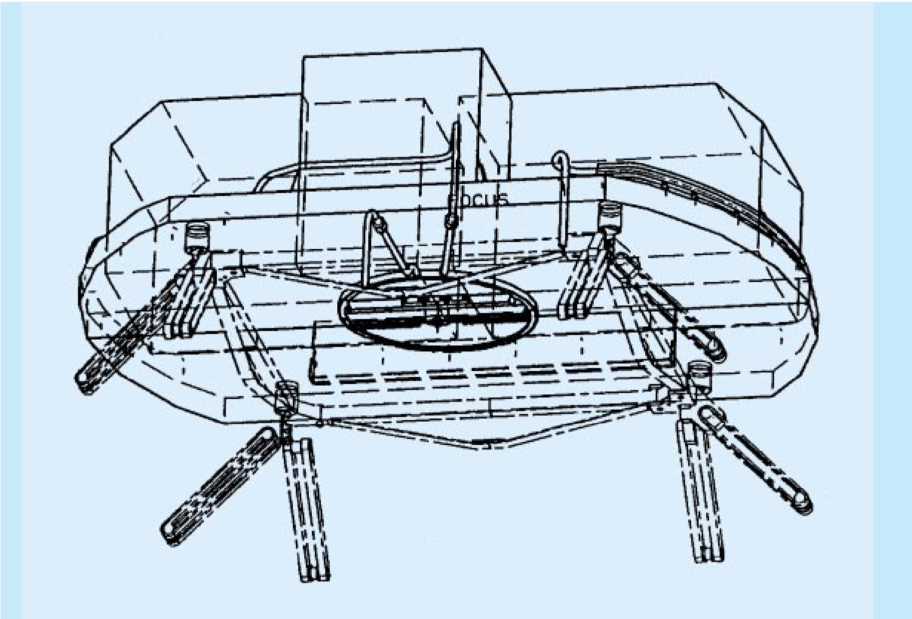


Figure 3.6.6. At left, the focal plane optical bench with the wheel-shaped heat exchanger. The eight supports to the Cryostat Vacuum Vessel (CVV) are also shown, while the common instrument shield is not. Table 3.6.1 lists predicted temperatures appropriate for FIRST routine science operations far away from the Earth.

telescope. It will have a Cassegrain (or Ritchey-Chretien) design with a 3.5 m diameter primary and an ‘undersized’ secondary. It will have a total wavefront error (WFE) of less than 10 μm (with a goal of 6 μm) – corresponding to diffraction-limited operation at 150 μm (goal 90 μm) – in orbit, and a very low emissivity (a few %). Being protected by a fixed sunshade, it will radiatively cool to an operational temperature of below 80 K in the L2 orbit.

Launch and operations

FIRST/Planck would be launched directly into an L2 orbit transfer trajectory by a dedicated Ariane-5. About half the year has reasonable daily launch windows with acceptable L2 orbit injection requirements. An eclipse-free orbit for the entire mission duration can be selected, or obtained by the use of an eclipse-avoidance manoeuver.

Allowing for initial cool-down and subsequent operations far away from the Earth, the superfluid liquid helium cryostat has a calculated lifetime in excess of 4.5 years, using the instrument parameters of the ‘model payload’ used in the course of the industrial work. For the ‘merged’ FIRST/Planck mission, the operation of FIRST and Planck science payloads will take place independently and consecutively according to a scheme that ensures early results from some FIRST ‘key projects’ as well as completion of the full Planck mission in the course of approximately the first 2 years of science operations.

FIRST scientific operations are planned to be conducted 20-22 h per day, while (the remaining) 2-4 h per day are allocated for data downlink by repointing the spacecraft to the Earth and using the 32 m antenna of ESA’s ground station in Perth, Australia.

Science payload

Model payload

In the course of the spacecraft definition activities, the industrial contractors have used a ‘model payload’ as defined by the FIRST Payload Working Group (PWG). It has been used to assess FIRST’s scientific capabilites and payload accomodation, to identify the areas where the payload is critically driving the spacecraft design, and to define interfaces and requirements for payload and spacecraft.

Announcement of Opportunity
The actual FIRST science payload will be provided by Principal Investigator (PI) consortia, selected through an Announcement of Opportunity (AO) process. The AO process is ongoing; the deadline for submission of proposals was 16 February 1998. ESA has received three proposals in response to the AO:

— The Heterodyne Instrument for FIRST (HIFI) instrument is proposed by a consortium led by Th. de Graauw, SRON, Groningen, The Netherlands. HIFI is a heterodyne receiver instrument that combines the high spectral-resolving power capability (0.3-300 km/s) of the radio heterodyne technique with the low noise detection offered by Superconductor-Insulator-Superconductor (SIS) and Hot Electron Bolometer (HEB) mixers. It is designed to provide continuous frequency coverage of the 480-1250, 1410-1910 and 2400-2700 GHz bands.
— The Photoconductor Array Camera and Spectrometer (PACS) instrument is proposed by a consortium led by A. Poglitsch, MPE, Garching, Germany. PACS is a photoconductor detector array instrument that employs two 25· 16 Ge:Ga detector arrays covering 80-130 and 130-210 μm. PACS will perform photometry simultaneously in the two bands, providing full beam sampling at 90 and 180 μm, respectively. As a spectrometer, PACS provides a velocity resolution in 150-200 km/s, with an instaneous coverage of ~1500 km/s.
— The Spectral and Photometric Imaging REceiver (SPIRE) instrument is proposed by a consortium led by M. Griffin, QMW, London, UK. SPIRE is a bolometer detector array instrument comprising an imaging photometer and an imaging Fourier Transform Spectrometer (FTS). The photometer provides broadband photometry simultaneously in bands centred on 250, 350 and 500 μm. The operating temperature of all detectors is 0.3 K, provided by a closed-cycle He-3 sorption cooler.

The instrument proposals are being assessed by an external committee supported by ESA working groups, with the objective of pre-selecting instrument configurations and PIs for FIRST by the SPC at the end of May 1998.

Observation programmes

The FIRST observation time will be shared between guaranteed and open time. The guaranteed time will be defined by the guaranteed time holders. The open time will be allocated to the general community on the basis of calls for observing proposals. The split between guaranteed and open time is listed below.

Satellite commissioning	no observations
Performance verification	no open time
Initial 9 months routine operations	36% open time
Following 12 months	64% open time
Remaining time	76% open time

All proposals will be evaluated and graded by the FIRST Observing Time Allocation Committee (FOTAC) on the basis of scientific merit and technical feasibility. The guaranteed time will be shared between the three PI consortia (30% each), the Mission Scientists (3% combined), with the remaining 7% belonging to the FIRST

Science Centre staff. A small fraction (no more than 4%) of the open time will be allocated to discretionary time and targets of opportunity.

Given the science objectives of the FIRST mission, it is clear that key projects in the form of large spatial and spectral surveys will constitute very important elements of the observing programme, requiring a substantial fraction of the available time of the overall mission. It is envisaged that, early in the mission, a significant time will be spent on several key programmes.

Science operation

The scientific operations of FIRST will be conducted in a novel 'decentralised' manner. The proposed ground segment concept comprises five elements:

— a FIRST Science Centre (FSC), provided by ESA;
— three dedicated Instrument Control Centres (ICCs), one for each instrument, provided by their PIs;
— a Mission Operations Centre (MOC), provided by ESA.

The ground segment elements will be united by dedicated computer links into a coherent science ground segment. These computer links are part of the FIRST Integrated Network and Data Archive System (FINDAS) for which the FSC is responsible. The FSC acts as the single-point interface to the science community and outside world in general. All scientific data will be archived and made available through FINDAS, together with software tools to produce 'standard' data products and to further process the data interactively.

Status and schedule

FIRST is presently in a pre-phase B development phase. The technical studies that provide the foundation for technical, financial and programmatical trade-offs were completed in February 1998. Financial and programmatical information is being added. The selection of how to implement FIRST and Planck ('merger', 'carrier' or 'stand-alone' concept), as well as a pre-selection of the PIs and the science instruments, is scheduled to be taken by the SPC in their meeting at the end of May 1998.