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Extract of Herschel section

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4.1 Herschel

Introduction

The Herschel Space Observatory, the fourth of the original Cornerstone missions in the ESA Horizon 2000 science plan, is a multi-user observatory-type mission that will provide unrivalled observing opportunities for the general astronomical community in the relatively poorly explored 57-670 μm part of the far-IR and sub-mm range. It will bridge the wavelength gap between earlier IR missions such as IRAS, ISO, Astro-F and Spitzer, and ground-based observatories.

Scientific objectives

Herschel (Fig. 4.1.1) is the only space facility dedicated to the far-IR and sub-mm part of the spectrum. It has the potential for discovering the earliest epoch proto-galaxies, revealing the cosmologically evolving AGN/starburst symbiosis, and unravelling the mechanisms involved in the formation of stars and planetary system bodies.

The major strengths of Herschel are its photometric mapping capability for performing unbiased surveys related to galaxy and star formation and its spectral coverage for follow-up observations. Redshifted ultraluminous IR-dominated galaxies, with spectral energy density functions (SEDs) that 'peak' in the 50-100 μm range in their rest frames, as well as class 0 proto-stars and pre-stellar objects in our own and nearby galaxies, have SEDs that peak in the Herschel 'prime' band. Herschel is also well-equipped to perform spectroscopic follow-up observations to characterise further particularly interesting individual objects.

The key science objectives emphasise the formation of stars and galaxies, and their interrelation. Example observing programmes with Herschel will include:

— deep extragalactic broadband photometric surveys in six colours spanning the Herschel wavelength coverage and related research. The main goals include further resolving the IR background into discrete sources, performing 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, and determining how the star-formation rate and galaxy luminosity functions evolve with cosmic time;
— follow-up spectroscopy of especially interesting objects discovered in the survey. The far-IR/sub-mm band contains the brightest cooling lines of interstellar gas, which give important information on the physical processes and energy-production mechanisms (for example, 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, by means of photometric and spectroscopic surveys and detailed observations. This includes implicitly the important question of how stars form out of molecular clouds in various environments using galaxies as 'laboratories' providing, for example, different levels of metallicity;
— 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 in both early and late stages stellar evolution in our own Galaxy. Herschel will provide unique information on most phases of this lifecycle, including the study of the evolution of circumstellar disks during the planet-forming era;
— detailed high-resolution spectroscopy of a number of comets and the atmospheres of the cool outer planets and their satellites;
— studies of Kuiper belt objects, and comparisons with the global properties of those observed around nearby stars.

From experience, it is also clear that the discovery potential is significant when a

For further information, see http://www.rssd.esa.int/herschel/

Figure 4.1.1. Herschel during the mechanical qualification campaign in the ESTEC Test Centre. The cryostat (with the black radiator in the centre), six of the eight side panels plus the top and bottom panels of the service module, the thermal shield and the upper half of the sunshade are flight hardware. The photograph was taken on 1 February 2006 during a Herschel Science Team meeting.

Figure 4.1.2. The Herschel telescope, shown during warm alignment activities at Astrium in Toulouse (F) in summer 2005. (EADS Astrium)

Table 4.1.1. Herschel scientific payload.

Acronym	*Instrument*	*Principal Investigator*
PACS	imaging camera & grating spectrometer, spectral coverage ~57-205 μm	A. Poglitsch, MPE, Garching (D)
SPIRE	imaging camera & FTS spectrometer, spectral coverage ~200-670 μm	M. Griffin, U. Cardiff (UK)
HIFI	high-res heterodyne spectrometer; spectral coverage 157-212 & 240-625 μm	Th. de Graauw, SRON, Groningen (NL)

Table 4.1.2. Principal characteristics of the Herschel mission.

Type of mission: far-IR and sub-mm observatory; ~2/3 open time available to the general user community; 4th ESA Cornerstone mission

Science goals: star and galaxy formation, interstellar medium physics and chemistry, solar system body studies

Telescope: 3.5 m-diameter Cassegrain telescope of silicon carbide

Spacecraft: 3-axis spacecraft with superfluid helium cryostat for instrument focal plane unit cooling

Size: height 7.5 m x width 4 m, launch mass 3 t

Science data rate: 130 kbit/s average production rate

Lifetime: 3 years of routine science operations

Operational orbit: Lissajous orbit around L2

Launch: dual launch (with Planck) on Ariane-5 ECA in 2008

new capability is being implemented for the first time. Observations have never been performed in space in the prime band of Herschel. The total absence of (even residual) atmospheric effects – enabling both a much lower background for photometry and full wavelength coverage for spectroscopy – and a cool low-emissivity telescope open up a new part of the phase-space of observations. Thus, a space facility is essential in this wavelength range and Herschel will be breaking new ground.

Telescope and science payload

In order to exploit fully the favourable conditions offered by being in space, Herschel has a precise, stable, low-background telescope, and a complement of capable scientific instruments. The telescope (Fig. 4.1.2) is passively cooled (placing it outside the cryostat maximises its size), while the instrument focal plane units are mounted on a common optical bench housed inside a cryostat containing superfluid helium below 1.7K. The bolometer arrays in PACS and SPIRE are cooled to ~300mK using dedicated instrument-provided sorption coolers.

During operations, the telescope must have a total wavefront error (WFE) of no more than 6 μm, corresponding to diffraction-limited operation at about 85 μm. It also has a very low emissivity to minimise the background signal, and the whole optical chain is optimised for high straylight rejection. Protected by a fixed sunshade, the telescope will radiatively cool to an operational temperature of around 80K. The design is a classical Cassegrain with a 3.5 m-diameter primary and an ‘undersized’ secondary. The telescope, manufactured by EADS Astrium (Toulouse, F), is made almost entirely of silicon carbide (SiC). The primary mirror blank was made out of 12 segments brazed together to form a monolithic mirror. This was then ground, lapped and polished to the required accuracy, and finally metallised to provide the required high reflectivity and low emissivity. The secondary was machined out of a single piece of SiC, including an integrated scattercone in its centre for standing-wave suppression, and metallised in the same way as the primary. The secondary support structure, consisting of a hexapod and a barrel-like structure, is also made of SiC, carries the launch loads and is optimised for adequate straylight and standing-wave performance.

The scientific payload consists of three instruments (Table 4.1.1), provided by consortia led by Principal Investigators (PIs) in return for guaranteed observing time.

PACS (Photodetector Array Camera and Spectrometer) is a short-wavelength camera and low- to medium-resolution spectrometer covering wavelengths up to about 205 μm. It employs four detector arrays: two bolometer arrays for photometry, and two photoconductor arrays for spectroscopy. PACS can be operated either as a photometer, fully sampling an FOV of 1.75x3.5 arcmin on the sky simultaneously in two broadband colours (either of the 60–85 or 85–130 μm bands plus the 130–210 μm band), or as an integral field line spectrometer covering just under 1 arcmin square on the sky with a resolution in the range 1000–4000 depending on wavelength.

SPIRE (Spectral and Photometric Imaging REceiver) is a long-wavelength camera and low- to medium-resolution spectrometer covering wavelengths longer than 200 μm. It comprises an imaging photometer and a Fourier Transform Spectrometer (FTS), both of which use bolometer detector arrays with individual feedhorns for each detector. There are five arrays in total: three dedicated to photometry, and two for spectroscopy and spectrophotometry. As a photometer, SPIRE covers a large 4x8 arcmin field on the sky that is imaged in three colours (centred on 250, 360, 520 μm simultaneously), and in spectroscopy a field approximately 2.6 arcmin across with a resolution of order 100.

HIFI (Heterodyne Instrument for the Far Infrared) is a heterodyne spectrometer. It offers very high velocity-resolution spectroscopy using auto-correlator and acousto-optical spectrometers, combined with low noise detection using superconductor-insulator-superconductor (SIS) and hot electron bolometer (HEB) mixers. Five dual polarisation SIS mixer bands cover the frequency range 490–1250 GHz, and two HEB bands cover 1410–1910 GHz. HIFI covers a single pixel on the sky, and builds up images either by raster scanning or by on-the-fly mapping.

Spacecraft and in-orbit operations

Herschel is based on the well-proven ISO cryostat technology. It is modular, consisting of the 'extended payload module' (EPLM) comprising the superfluid helium cryostat (housing the optical bench with the instrument focal plane units) that supports the telescope, the sunshield/shade, and payload associated equipment; and the service module (SVM), which provides the infrastructure and houses the warm payload electronics. Herschel is about 7.5 m high and 4 m wide, and has a launch mass of around 3000 kg.

An industrial consortium led by Alcatel Space Industries (Cannes, F) as prime, with EADS Astrium (Friedrichshafen, D), responsible for the EPLM, and Alenia Spazio (Torino, I) for the SVM, and a host of subcontractors from all over Europe, are building the spacecraft. Arianespace will provide the launch services in Kourou. For a summary of principal mission characteristics see Table 4.1.2.

An Ariane-5 ECA launcher, shared with Planck, will inject both satellites into a transfer trajectory towards the second Lagrangian point (L2) in the Sun- Earth system. They will then separate from the launcher, and subsequently operate independently, from orbits of different amplitudes around L2. It offers a stable thermal environment with good sky visibility. Since Herschel will be in a large orbit around L2, which has the advantage of not costing any orbit injection delta-V, its distance to Earth will vary by 1.2–1.8 million km. Herschel will take about 4 months to reach the operational orbit. For the first 2 weeks after launch, while cooldown and outgassing take place, the telescope will be kept warm by heaters to prevent it acting as a cold trap for the outgassing products. It will then cool, for the opening of the cryostat door (thus providing 'first light') about 5-6 weeks after launch. Commissioning and performance verification will take place enroute to L2, followed by a science demonstration phase. Once these crucial mission phases have been accomplished, Herschel will begin routine science operations.

Science operations

Herschel will be a multi-user observatory open to the general astronomical community. It will perform routine science operations for a minimum of 3 years, until depletion of the helium. The available observation time will be shared between guaranteed time (one third) owned by contributors to the Herschel mission (mainly by the PI instrument consortia), and open time allocated to the general community (including the guaranteed time holders) on the basis of calls for observing time. The initial call for observing proposals is planned to be issued in the second half 2006.

The scientific operations of Herschel will be conducted in a decentralised manner. The operational ground segment comprises six elements:

— the Herschel Science Centre (HSC), provided by ESA;
— three dedicated Instrument Control Centres (ICCs), one for each instrument, provided by the respective PIs;
— the Mission Operations Centre (MOC), provided by ESA;
— the NASA Herschel Science Center (NHSC), provided by NASA.

The HSC acts as the interface to the science community and outside world in general, supported by the NHSC (primarily) for the US science community. The HSC provides information and user support related to the entire life-cycle of an observation, from calls for observing time, the proposing procedure, proposal tracking, data access and data processing, as well as general and specific information about using Herschel and its instruments.

All scientific data will be archived and made available to the data owners. After the proprietary time has expired for a given dataset, these data will be available to the entire astronomical community in the same manner they were previously available only to the original owner. The accumulated experience from earlier observatory missions (particularly ISO and XMM-Newton) is being used in the implementation of the infrastructure by ESA and the PIs together. An important conclusion is to build one single system that evolves over time, rather than having separate systems for different mission phases. The first functional version of this system is already being used in connection with instrument-level tests.

Status and schedule

The PIs and science payload were provisionally selected in 1998 and confirmed a year later. The focal plane unit cryogenic qualification models were delivered in late 2004 for integration and testing in the engineering qualification model (EQM), and avionics models for testing together with the SVM. The instrument flight models will be tested, characterised, and calibrated before delivery in the second half of 2006.

The telescope activity began in mid-2001, and the Mid-Term Review was held in November 2001, paving the way for the telescope Critical Design Review (CDR) in April 2002. The telescope was aligned and characterised in warm conditions in summer 2005, immediately followed by successful mechanical qualification. An extensive cryogenic test campaign was underway in early 2006 in Centre Spatial de Liège (B).

The industrial contract for the Herschel spacecraft for Phases-B, C/D and E1 was awarded in April 2001, marking the start of Phase-B. The System Requirements Review took place in autumn 2001, after which the industrial consortium was formed by the selection of subcontractors, involving in excess of 100 procurement activities. The next major step, the Preliminary Design Review took place a year later. The mission-level CDR was held in early 2005.

The first spacecraft hardware to arrive for testing in the ESTEC Test Centre was the SVM structural thermal model (STM), in spring 2005. It was followed by the proto-flight model cryostat, which was tested the Large Space Simulator in late autumn. The entire spacececraft in STM configuration underwent mechanical qualification in early 2006.

Current planning foresees milestones that include instrument and telescope flight model deliveries to ESA and the issue of the first call for observing proposals in 2006. This will be followed by spacecraft integration and extensive system-level spacecraft testing, science ground segment testing (including proposal evaluation and the awarding of observing time), and end-to-end ground testing and simulations, leading to the launch in 2008. Routine science operations are planned to begins about 6 months after launch.