

The Herschel Space Observatory: Mission Overview and Observing Opportunities

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Abstract Herschel is the next observatory mission in the European Space Agency (ESA) science programme. It will perform imaging photometry and spectroscopy in the far infrared and submillimetre part of the spectrum, covering approximately the 55–672 micron range. The spacecraft is now in its final stage of assembly and verification, and is scheduled for launch in April 2009. This paper summarises some of the key aspects of the mission.

1 Herschel at a Glance

The Herschel Space Observatory (Pilbratt et al., 2001; Pilbratt, 2008, hereafter referred as Herschel) is the fourth “cornerstone” mission in the ESA science programme. It is the first large aperture space far-infrared (FIR)/sub-mm observatory, performing photometry and spectroscopy in the 55–672 μm wavelength range. It consists of a large (3.5 m) monolithic low emissivity passively cooled telescope and three focal plane science instruments enclosed in a large (2367 litre) HeII cryostat, providing more than three years of routine operational lifetime. Herschel will be launched in April 2009 from the European spaceport at Kourou along with the Planck spacecraft by means of an Ariane 5-ECA rocket and will be placed in large orbit around the second Lagrangian point (L2) of the Earth–Sun system. From this vantage point, with favourable thermal and radiation environment, Herschel will be able to carry out long observations of a large variety of galactic and extra-galactic targets. Herschel will provide unique and complementary capabilities, bridging the

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gap between existing IR missions like IRAS, ISO, Spitzer or Akari, whose spectral coverage does not extend longwards $200\ \mu\text{m}$, and sub-mm facilities like SWAS or ODIN.

2 Science Objectives

Herschel is aimed to study the “Cold Universe”; about half of the radiated energy in the Universe, and most of its photons, fall within the IR range. In spite of its enormous importance, the FIR region is relatively poorly studied; the Herschel spectral range will cover the peak of the emission from black-bodies with temperatures in the range 5–50 K, as well as the brightest atomic/molecular lines from gases with temperatures between some 10 K and a few hundred K. Broadband thermal radiation from small dust grains (generally “reprocessed” UV/optical/NIR emission) is a common continuum emission process within this spectral range, as occurs in star-forming molecular clouds, star-forming galaxies and active galactic nuclei (AGN).

The main science objectives of the Herschel mission can be summarised as follows:

- Wide-area photometric surveys of the extragalactic and galactic sky, to measure dust-enshrouded star formation activity throughout cosmic time, revealing the cosmologically evolving AGN-starburst symbiosis, and in our own and nearby galaxies today.
- Detailed studies of the physics and chemistry of the interstellar medium, both locally in our own Galaxy as well as in external galaxies by means of photometric and spectroscopic surveys.
- Observational astrochemistry of gas and dust as a quantitative tool for understanding the stellar/interstellar lifecycle, investigating the physical and chemical processes involved in star formation, early and late stages in stellar evolution, including gas and dust disks around young and mature stars.
- Spectroscopic and photometric study of solar system objects and their atmospheres, also crucial as calibration sources.

3 The Spacecraft and its Orbit

The Herschel spacecraft has a modular design, comprising the Extended Payload Module (EPLM) and the Service Module (SVM). The EPLM consists of the payload module (described in Section 4), the sunshade and solar array and payload associated equipment. The SVM houses “warm” payload electronics and provides the services such as power, attitude and orbit control, the onboard data handling and command execution, communications, and safety. Figure 1 shows the main components of the Herschel spacecraft, while Table 1 presents its key characteristics.

Table 1 Herschel spacecraft key characteristics

Spacecraft Type:	Three-axis stabilised
Operation:	Autonomous (3 hours daily ground contact period)
Dimensions:	7.5 m high \times 4.0 m diameter
Telescope diameter:	3.5 m
Total mass:	3170 kg
Solar array power:	1500 Watt
Average data rate to instruments:	130 kbps
Pointing modes supported:	stare pointing, raster (regular grids of stare pointings), line scan maps, custom maps
Absolute pointing Error (APE):	2.24 arcsec (pointing) / 2.36 arcsec (scanning)
Relative Pointing Error (RPE aka pointing stability):	0.24 arcsec (pointing) / 0.88 arcsec (scanning)
Spatial Relative Pointing Error (SRPE):	2.21 arcsec
Cryogenic lifetime from launch:	min. 3.5 years (3 year routine science operations)

The Herschel spacecraft will be placed in a large “halo” Lissajous orbit around L2, with an amplitude of about 700,000 km and a period of approximately 178 days. The distance from the Earth ranges from 1.2 to 1.8 million km. The orbit chosen for Herschel presents a number of advantages: *(a)* Simplifies long observations, since the Earth essentially remains within the Sun constraint, *(b)* provides a very stable thermal and benign radiation environment, *(c)* there is no trace of atmosphere, and *(d)* a large halo Lissajous orbit can be achieved without any injection Δv .

4 The Science Payload

The Herschel payload consists of the telescope, a large HeII cryostat and three scientific instruments. The telescope will be passively cooled; thus its diameter is only limited by the size of the fairing on the Ariane 5-ECA rocket. Its total wavefront error (WFE) is less than $6 \mu\text{m}$ during operations. It has been designed to have a very

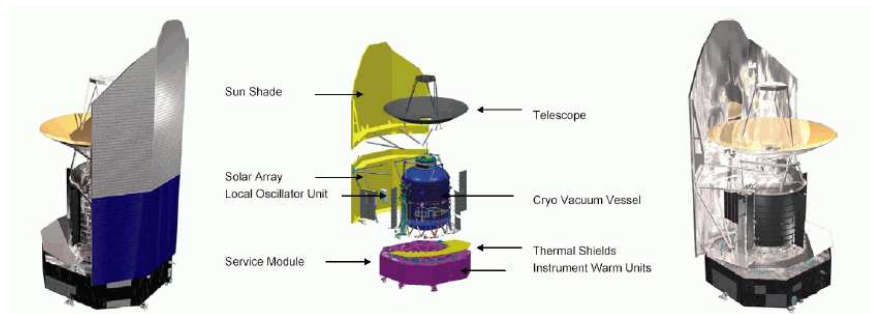


Fig. 1 Herschel has a modular design. On the left, facing the “warm” side and on the right, facing the “cold” side of the spacecraft, the middle image names the major components.

low emissivity to minimise the background signal, and a high degree of straylight rejection. In space the telescope will cool radiatively, protected by a fixed sunshade, to an operational temperature around 80 K, with a uniform and very slowly changing temperature distribution. The chosen optical design is a classical Cassegrain with a 3.5 m diameter primary and an “undersized” secondary. The effective aperture is 3.3 m with a focal ratio of 8.68. The unvignetted field of view (FoV) has a diameter of 0.5° .

The three Herschel instruments (Figure 2) have been provided by international consortia led by Principal Investigators. These are the Photodetector Array Camera and Spectrometer (PACS), the Spectral and Photometric Imaging REceiver (SPIRE) and the Heterodyne Instrument for the Far Infrared (HIFI).

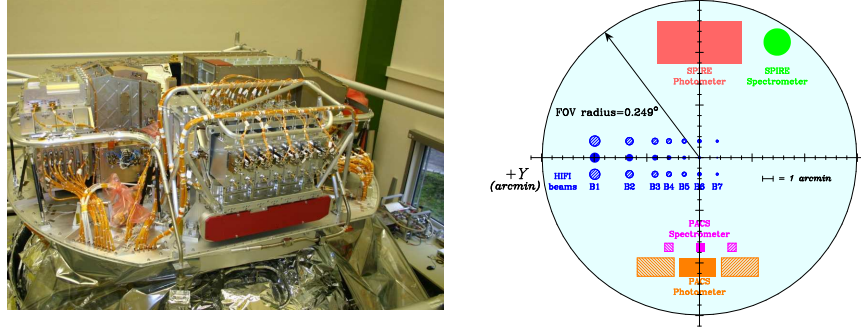


Fig. 2 Left: Herschel flight instruments being integrated in the optical plane. PACS FPU is on the left, HIFI on the right, and SPIRE in the background. Image courtesy Astrum. Right: Herschel field of view (FoV) as seen in the sky (+X axis). The chopped positions are hatched.

The PACS instrument (Poglitsch et al., 2008) consists of: (a) a dual-band photometer, comprising a “blue photometer” with two filters mounted in a wheel, allowing to select either the range $60\text{--}85\ \mu\text{m}$ or $85\text{--}130\ \mu\text{m}$ and a “red photometer” covering the $130\text{--}210\ \mu\text{m}$ range, and (b) an integral field spectrometer in the range $57\text{--}210\ \mu\text{m}$. The photometric bands cover the same FoV, while the FoV of the spectrometer is offset from the photometer (Figure 2). Photometry and spectroscopy are mutually exclusive, so this has no effect in the observational efficiency. The PACS photometer uses 2 bolometer arrays cooled to 0.3 K by means of a ^3He sorption cooler. The “blue” bolometer consists of an array of 64×32 pixels ($3.2'' \times 3.2''$ per pixel) while the “red” bolometer array size is 32×16 pixels ($6.4'' \times 6.4''$ per pixel). Both bands are simultaneously imaged with the same FoV size ($3.5' \times 1.75'$) in both arrays. Imaging PSF has $6''$ FWHM in the $60\text{--}85\ \mu\text{m}$ range, $8''$ in the $85\text{--}130\ \mu\text{m}$ one and $12''$ in the $130\text{--}210\ \mu\text{m}$ range. The PACS integral field spectrometer covers the wavelength range from $57\ \mu\text{m}$ to $210\ \mu\text{m}$, with a resolving power in the range $1000\text{--}5000$ depending on the wavelength for a fixed grating position, with an instantaneous coverage of $\sim 1500\ \text{km s}^{-1}$ and a FoV of $47'' \times 47''$, resolved into 25×25 pixels. An image slicer re-arranges the 2D FoV along a 1×25 pixel entrance slit.

The SPIRE instrument (Griffin et al., 2008) consists of a three-band imaging photometer and an imaging Fourier Transform Spectrometer (FTS). Detectors are feedhorn-coupled “spider-web” NTD germanium bolometers cooled to 0.3 K by a ^3He refrigerator. The photometer and spectrometer do not operate simultaneously. The three bolometer arrays provide broad-band photometry ($R \simeq 3$) in bands centred at 250, 350 and 500 μm , with diffraction-limited beams of 17”, 24” and 35” FWHM, respectively. The field of view is observed simultaneously in all three bands by means of fixed dichroic beam-splitters. The photometer FoV is 4×8 arcmin. The FTS covers a FoV of 2.6 arcmin \emptyset . Two detectors are located at the output ports, covering the spectral ranges 194–324 μm and 316–672 μm .

The HIFI instrument (de Graauw et al., 2008) is a high-resolution heterodyne spectrometer with a continuous coverage from 480 to 1250 GHz in five bands, plus two bands providing a coverage of the 1410–1910 GHz range. Resolving power is in the range 10^3 – 10^7 (300 to 0.03 km s $^{-1}$). Both polarisations of the astronomical signal will be detected for maximum sensitivity. In order to cover a wide frequency range with high sensitivity, HIFI is designed to have 7 mixer bands and 14 Local Oscillator (LO) sub-bands.

5 The Ground Segment

The Herschel ground segment concept comprises several elements geographically distributed:

- The Herschel Science Centre (HSC), provided by ESA and located in the European Space Astronomy Centre (ESAC), close to Madrid, Spain. The HSC is the prime interface between Herschel and the science community and outside world in general. It shall ensure that the scientific productivity and impact is maximised within given constraints, supported by the Herschel Science Team (Herschel ST) and the Herschel Observing Time Allocation Committee (HOTAC).
- Three dedicated Instrument Control Centres (ICCs), one for each instrument, provided by their PIs: PACS at MPE (Garching, Germany), SPIRE at RAL (Didcot, UK) and HIFI at SRON (Groningen, the Netherlands). The ICCs are responsible for the operation of their respective instruments, and for providing software and procedures for data processing.
- The Mission Operations Centre (MOC), provided by ESA and placed at the European Space Operations Centre (ESOC) at Darmstadt, Germany, performs all real time operations of the Herschel spacecraft.
- The NASA Herschel Science Centre (NHSC), provided by NASA and located at the Infrared Processing and Analysis Center (IPAC) of the California Institute of Technology, in Pasadena, USA. It provides support primarily to US-based Herschel users.

6 Observing Opportunities

Herschel will be operated as an observatory facility. Roughly two-thirds of the nominal available observing time (close to 19,800 hrs) will be allocated to open time (OT) programmes; the remainder is guaranteed time (GT), owned by the contributors to the Herschel mission (instrument consortia and mission scientists). Currently, the first Announcement of Opportunity (AO) has concluded, comprising both GT Key Programmes (KP) and OT KP. The KP AO process has allocated $\sim 57\%$ of the nominal observing time. In addition, two additional AO cycles are planned. Both of these will contain a small amount of GT followed by substantial amounts of OT (60% is remaining); each cycle will allocate half of the remaining time. The first of these cycles will be opened early after the observatory routine operations have started (i.e. late 2009), and the second will take place one year later. A third AO cycle could be considered should the Herschel mission significantly exceed the nominal lifetime.

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For more information, please consult the Herschel Space Observatory web page at <http://herchel.esac.esa.int>.

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