# The Herschel Space Observatory

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*Abstract* — **The Herschel Space Observatory is the fourth cornerstone mission in the European Space Agency (ESA) science programme. Herschel will be equipped with a passively cooled 3.5-m diameter Cassegrain telescope and three scientific instruments - HIFI, PACS and SPIRE - which together will carry out sensitive imaging and spectroscopy in the FIR and submillimetre range, covering wavelengths between 57 and 670 μm. This paper summarises the design and scientific capabilities of Herschel and its instruments.**

## I. Herschel and its Scientific Objectives

THE Herschel Space Observatory[1,2] will be the first large-aperture THz space mission, and the first to extend beyond 200 μm wavelength. It is scheduled for launch in early 2009, and will carry a 3.5-m diameter telescope (the largest astronomical telescope yet flown), passively cooled to approx. 80 K, and three scientific instruments: two cameras/medium resolution spectrometers (PACS and SPIRE) and a high resolution heterodyne spectrometer (HIFI).

The main science drivers for the design of Herschel have been: (i) extragalactic and galactic surveys to measure star-formation activity throughout cosmic time and in our own and nearby galaxies today; (ii) detailed studies of the physics and chemistry of the interstellar medium and the stellar/interstellar lifecycle in the Milky Way; (iii) spectroscopic and photometric study of comets, asteroids and the outer planet atmospheres and their satellites. Herschel will be launched into an orbit around the Sun-Earth L2 point (a position 1.5 million km distant from Earth, on the anti-sunward side). Following commissioning and performance evaluation, it will have a minimum operational lifetime of three years.

## II. The telescope

The Herschel telescope[3] is shown in Figure 1. It is a Cassegrain design with a 3.5-m diameter and an undersized secondary mirror to minimise stray light. The mirrors are made from silicon carbide (SiC), with the primary made up of 12 segments brazed together to form a monolithic mirror and then ground and polished to produce the required total wavefront error < 6 μm (corresponding to 'diffraction-limited' operation at < 90 μm). The secondary is made from a single piece, and machined with an integral 'scattercone' to suppress standing waves and the narcissus effect (which can cause unwanted standing waves in heterodyne receivers), and is held in place by a 'barrel' and hexapod structure which is connected to the primary at three points. The telescope is protected by a fixed sunshade and passively cooled to an operating temperature of approx. 80 K with a highly uniform and very stable temperature distribution. The primary and secondary are coated with a reflective aluminium layer, covered by a thin protective 'plasil' (silicon oxide) coating. The overall emissivity of the telescope in the operational wavelength range is < ~2%, giving the lowest possible level of telescope thermal emission (which is the ultimate limit to the sensitivity for photometric observations with PACS and SPIRE). Although the Herschel telescope sets a new standard for large, high accuracy, lightweight space telescopes it is noteworthy that the reflective Al layer, the 'working part' of the telescope, accounts for only 10 g of its total 320-kg mass.

Fig. 1: Herschel spacecraft showing the telescope and sunshade.

## III. The Herschel Instruments

The instruments' cold focal plane units (FPUs) are housed in a superfluid helium cryostat, and their warm electronics units in the spacecraft service module (SVM). Fig. 2 shows the focal plane units during their installation on the Herschel optical bench, and of the fully-assembled spacecraft.

HIFI, the Heterodyne Instrument for the Far Infrared[4], is a seven-band single-pixel heterodyne receiver. It can observe simultaneously in two polarisations, providing redundancy and enhanced sensitivity. The FPU houses seven mixer assemblies: five SIS mixer bands cover 480-1150 GHz and a two Hot Electron Bolometer (HEB) band cover 1410-1910 GHz. The local oscillator (LO) reference signal is generated by a source unit located in the warm spacecraft Service Module (SVM) and fed to the LO unit on the outside of the cryostat vessel, where it is amplified, multiplied and quasioptically fed to the FPU through windows in the cryostat. The SVM also houses the autocorrelation and acousto-optical

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backend spectrometers, which process the intermediate frequency signals and give 4 GHz instantaneous frequency coverage for the SIS channels and 2.4 GHz for the HEB mixers, and provide spectral resolution from 0.14 to 1.1 MHz. HIFI's angular resolution (beam-size on the sky) is diffraction-limited by the telescope primary, and varies between 12" at the shortest wavelengths to 40" at the longest.

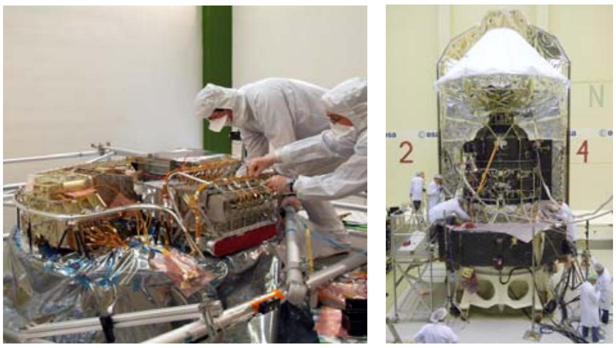

Fig. 2: Herschel instrument focal plane units being installed, and the fully assembled spacecraft.

PACS, the Photodetector Array Camera and Spectrometer[5], will perform photometry and medium-resolution spectroscopy in the 55-210 μm range. The PACS spectrometer is a grating design, optimised for maximum sensitivity when observing line of known wavelength. It has an integral field unit using an image slicer with a grating, and two Ge:Ga 16x25 pixel photoconductor arrays, cooled to < 2 K by a thermal strap to the Herschel helium tank. The 50x50 arcsecond field of view is resolved into 5x5 pixels. The spectral resolution, $\lambda/\Delta\lambda$, varies between 1500 and 4000 across the band, corresponding to a velocity resolutions of 75 − 300 km $s^{-1}$, with an instantaneous coverage of ~ 1500 km $s^{-1}$. The camera has a 1.8x3.5 arcmin. field of view, observed by two arrays of 0.3-K Si bolometers, one with 16x32 pixels and one with 32x64 pixels. The 0.3-K temperature is provided by a recyclable $^{3}$He refrigerator with hold time > 48 hrs. Two bands are imaged simultaneously: 130-210 μm and one of 60-85 or 85-130 μm.

The bolometer arrays are "filled" (i.e., the pixel size corresponds to ~ 0.5λ/D, where D is the telescope diameter), giving instantaneous full spatial sampling of the image. The diffraction limited FWHM beam size is 5.2" in the shortest wavelength band and 12" in the longest wavelength band.

Warm electronics units on the SVM control the instrument mechanisms and detector arrays and interface to the spacecraft for telemetry and commanding.

SPIRE, the Spectral and Photometric Imaging Receiver[6], comprises a three-band submillimetre camera and an imaging Fourier Transform Spectrometer (FTS), both of which use bolometer arrays at 0.3 K. The camera field of view is 4 x 8 arcmin. Three arrays are used for broad-band photometry in spectral bands centred on approximately 250, 350 and 500 μm. The same field of view is observed simultaneously in the three bands through the use of two fixed dichroic beam-splitters. The beams are diffraction limited at 18, 25, and 36 arcseconds at 250, 350, and 500 μm respectively.

By design, an FTS is optimsed for maximum simultaneous wavelength coverage at the expense of some sensitivity since the broad wavelength range means that the background from the telescope is higher than for a spectrometer based on a monochromator, such as a grating. The SPIRE FTS has spatially separated input and output ports. One input views a 2.6-arcmin. field of view on the sky and the other views an on-board reference source. Two bolometer arrays at the output ports are sensitive in overlapping bands covering the whole 194–672 μm band simultaneously. The spectral resolution is set by the total optical path difference, and can be adjusted between 0.04 and 2 $cm^{-1}$ ($\lambda/\Delta\lambda$ = 1000 – 20 at 250 λm).

The SPIRE detectors are feedhorn-coupled with feedhorn apertures ~ 2λ/D, giving high aperture efficiency and the minimum number of detectors for a given field of view. The beams on the sky are separated by more than the FWHM beamwidth, requiring scanning or jiggling of the field of view to provide a fully sampled image. SPIRE's internal $^{3}$He refrigerator cools all five detector arrays to 0.3 K, and is identical in all key respects to the PACS cooler. JFET preamplifiers are used to read out the bolometer signals. Warm electronics units provide the bias and signal conditioning for the arrays and cold electronics, and demodulate and digitise the detector signals and interface with the spacecraft for commanding and telemetry.

## IV. Current Status of Herschel

At the time of writing, the Herschel spacecraft is at the European Space Technology Centre, ESTEC, in the Netherlands. It has been fully assembled, subjected to its mechanical qualification tests, and is now being prepared for instrument performance tests and system tests in a space simulation chamber. It will then be transported to the launch site at Kourou, French Guyana. A set of "Key Projects" – large observational programmes – has been defined and reviewed and is foreseen to occupy the first half of the mission, with the second half available for smaller programmes and follow-up.

More details of Herschel and its scientific capabilities can be found at web site of the Herschel Science Centre[2].

## References


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