Announcement of Opportunity for Key Programmes

Herschel Observers' Manual

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Herschel Observers' Manual

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Preface

The Herschel Space Observatory is an ESA cornerstone mission that will be launched in 2008, alongside the Plank cosmic microwave background mission. Originally known as FIRST (Far InfraRed Submillimetre Telescope) its name was officially changed in the year 2000 in recognition of the 200th anniversary of the discovery of infrared radiation by William Herschel in 1800. Herschel will cover the range from 55 to 670 microns (530-5000GHz) - a region that is effectively totally closed to ground-based astronomy - using a suite of three state-of-the-art instruments called PACS, SPIRE and HIFI.

Herschel is an observatory mission: that is, its time will be distributed among the community instead of being used for a large-scale survey. It is also a consumables-limited mission - its useful life depends on the lifetime of the helium in the dewar that is used to cool the instruments. As an observatory mission its success thus depends on the quality of the science that the community carries out with it and how effectively the helium in its dewar is converted into science. The "helium into science" ratio will be the principal deciding factor in allocating time with the Herschel Space Observatory.

Many aspects of the Herschel Space Observatory are revolutionary. It is, thanks to its innovative design, the largest dedicated infrared telescope ever to be launched into space by a considerable margin. For the astronomer this converts into high sensitivity and a spatial resolution a factor of 6 better than any previous far-infrared telescope launched into space, making Herschel a pathfinder mission in the far-IR. In fact, Herschel will be limited in sensitivity mainly by the confusion from the background of faint, unresolved sources. This will make Herschel a revolution for astronomy in a range of the far-IR that has hardly been exploited so far. Herschel observations will have a huge impact on astronomy and on our understanding of the universe.

This manual describes the observatory aspects of the mission: the spacecraft and its performance; the mission; the space environment in which the Herschel Space Observatory will be operating (very different from previous missions such as IRAS, ISO and the HST); and use of Herschel - from how an observing proposal is received and treated, through to final archiving of the data.

Chapter 1. The Observatory

This section summarises the main characteristics of the Herschel spacecraft, its orbit, pointing performance and observable sky regions.

1.1. Spacecraft overview

The Herschel spacecraft has a modular design, comprising the *Extended Payload Module (EPLM)* and the *Service Module (SVM)*. The EPLM consists of the PLM "proper" with a superfluid helium cryostat - based on the proven ISO technology - housing the Herschel optical bench (HOB) with the instrument focal plane units (FPUs), and supporting the telescope, the sunshield/shade, and payload associated equipment. The SVM houses "warm" payload electronics and provides the necessary "infrastructure" for the satellite such as power, attitude and orbit control, the onboard data handling and command execution, communications, and safety. Figure 1.1 shows the main components of the Herschel S/C. Table 1.1 presents the Herschel Spacecraft key characteristics.

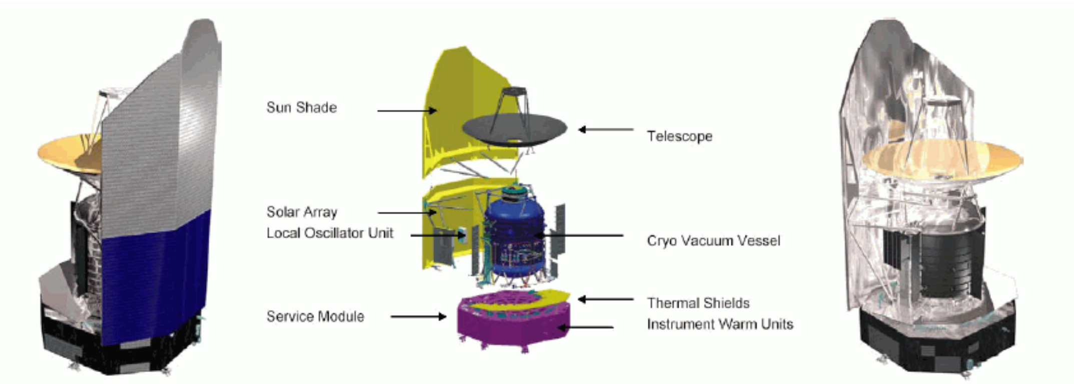

Figure 1.1. The Herschel spacecraft has a modular design. On the left, facing the "warm" side and on the right, facing the "cold" side of the spacecraft, the middle image names the major components.

Table 1.1. Herschel Spacecraft key characteristics

S/C Type:	Three-axis stabilised
Operation:	Autonomous (3 hours daily ground contact period)
Dimensions:	7.5 m high x 4.0 m diameter
Telescope diameter:	3.5 m
Total mass:	3170 kg
Solar array power:	1500 W
Average data rate to instruments:	130 kbps
Absolute pointing Error (APE):	2.45 arcsec (pointing) / 2.54 arcsec (scanning)
Relative Pointing Error (RPE, pointing stability):	0.24 arcsec (pointing) / 0.88 arcsec (scanning)
Spatial Relative Pointing Error (SRPE):	2.44 arcsec
Cryogenic lifetime from launch:	min. 3.5 years

1.1.1. Herschel Extended Payload Module

The EPLM is mounted on top of the satellite bus, the service module (SVM) and consists of the cryostat containing the instruments' focal plane units (FPU) and the Herschel telescope. The following sections describe the main components of the payload.

1.1.1.1. The Telescope

So that the favourable conditions offered by being in space can be exploited to the full, Herschel will carry a precision, stable, low background telescope (Figure 1.2). The Herschel telescope will be passively cooled, allowing the size limitations imposed by active cooling to be overcome. Thus its diametre is only limited by the size of the fairing on the Ariane 5-ECA rocket. The Herschel telescope must have a total wavefront error (WFE) of less than 6 µm (corresponding to "diffraction-limited" operation at < 90 µm) during operations. It must also have a low emissivity to minimise the background signal, and the whole optical chain must be optimised for a high degree of straylight rejection. In space the telescope will cool radiatively, protected by a fixed sunshade, to an operational temperature in the vicinity of 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 telescope has been constructed almost entirely of silicon carbide (SiC). The primary mirror (M1) has been made out of 12 segments that have been brazed together to form a monolithic mirror, which was machined and polished to the required thickness (~3-mm) and accuracy. The secondary mirror (M2), with 308-mm diameter, has been manufactured in a single SiC piece. It is adjusted on the SiC barrel by tilt and focus adjustment shims. In order to avoid the Narcissus effect on the detectors, the central part of the secondary mirror is shaped in such a way that no parasitic reflected beam can enter the focal plane.

The hexapod structure (also made of SiC) supports M2 in a stable position with respect to M1. Finally, three quasi-isostatic bipods, made of titanium, support the primary mirror and interface with the cryostat. The focus is approximately one metre below the vertex of M1, inside the cryostat.

The proper telescope alignment and optical performance have been measured on ground in cold conditions. The measured wavefront performance in cold is in line with the requirements. The measured position has been found reproducible on a number of cooldown cycles and can be accommodated at spacecraft alignment level by adjusting the shimming. However, there is no possibility of in-flight adjustments such as focusing.

The M1 and M2 optical surfaces have been coated with a reflective aluminium layer, covered by a thin protective "plasil" (silicon oxide) coating. The telescope will initially be kept warm after launch into space to prevent it acting as a cold trap while the rest of the spacecraft is cooling down.

Figure 1.2. The Herschel telescope flight model.

Key telescope data are summarised in Table 1.2.

Table 1.2. The Herschel Telescope's predicted characteristics at working temperature (70 K)

Configuration:	Cassegrain telescope
M1 Free diameter:	3500-mm
Focal length:	28500-mm
f-number:	8.68
Field of View radius:	0.25°
M1 curvature radius / conic constant:	3499.02-mm / -1
Aperture stop / distance to M1 apex:	M2 mirror / 1587.555-mm
M2 diameter:	308.11-mm
M2 curvature radius / conic constant:	345.2-mm / -1.279
Image diameter:	246-mm
Image curvature radius / conic constant:	-165-mm / -1
On-axis best focus distance to M1 vertex:	1050-mm

1.1.1.2. The Cryostat

The Herschel cryostat houses the focal plane units of the three scientific instruments depicted in Figure 1.3. The cooling concept for the Herschel instruments is based on the proven principle used for the ISO mission. The temperature required in the instrument focal plane is provided down to 1.7K by a large superfluid helium Dewar (helium at 1.6K), sized for a scientific mission of 3.5 years. This is achieved with a total amount of 2160 litres of helium cryogen. The cryostat provides 1.7K as its lowest service temperature to the instruments. Further cooling down to 0.3K, required for two instruments (the SPIRE and PACS bolometers) is achieved by dedicated ^{3}He sorption coolers that are part of the respective instrument focal plane unit. In orbit the liquid Helium is maintained inside the main tank by means of a phase separator (a sintered steel plug). The heat load on the tank will evaporate the Helium over the mission time at an estimated rate of about 200 grams per day. The enthalpy of the gas is used efficiently to cool parts of the instruments that do not require the low temperature of the tank (two temperature levels, at around 4K and around 10K). After leaving the instruments the evaporated gas is further used to cool the 3 thermal shields of the cryostat.

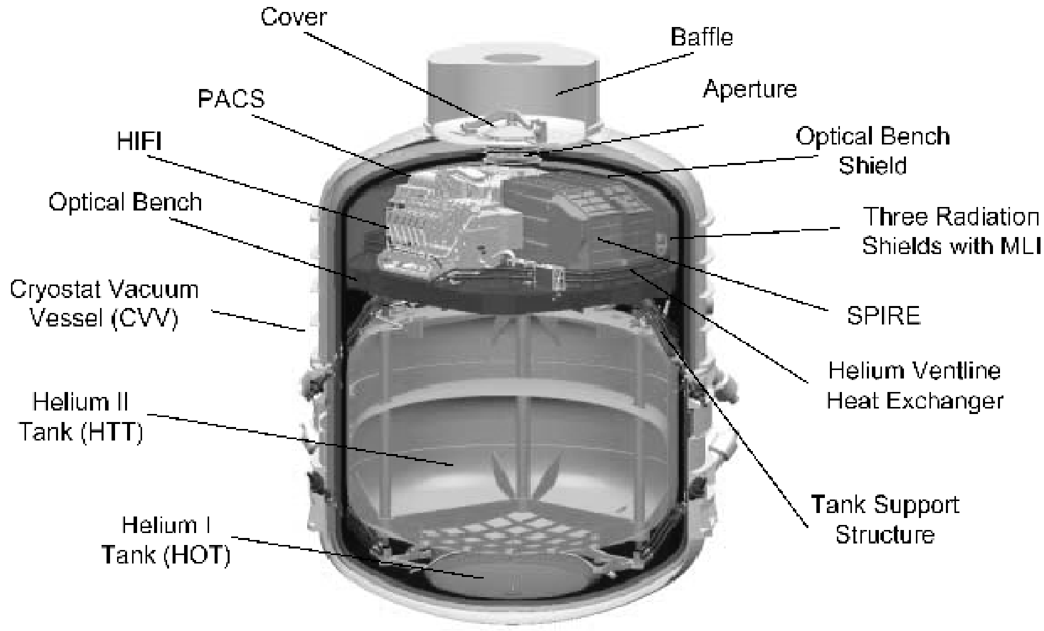

Figure 1.3. The Herschel cryostat.

During ground operations, the vacuum vessel is closed by the means of a cover, located at its top, which is opened once in orbit. To maintain a cold environment inside the cryostat during the last few days before launch in Kourou, an auxiliary liquid Helium tank is used. The space side of the Cryostat Vacuum Vessel (CVV) is used as a radiator area to cool the CVV on orbit to a final equilibrium temperature of about 70K. This radiator area is coated with high emissive coating to achieve low temperatures in the L2 orbit. Multi-Layer-Insulation (MLI) covers the outer CVV-surfaces, in order to insulate it from the warm items (satellite bus and Sunshield). The outer layer of the MLI is optimised for the lowest temperature of the CVV. The outside of the cryostat is the mechanical and thermal mounting base for the Herschel telescope, the local oscillator unit of HIFI, the Bolometer Amplifier Unit of PACS and the large sunshield protecting the CVV from the sun.

1.1.1.3. Instruments

The science payload is accommodated both in the "cold" (CVV) and "warm" (SVM) parts of the satellite. The instrument FPUs are located in the "cold" part, inside the CVV mounted on the optical bench, which is sitting on top of the superfluid helium tank. They are provided with a range of interface temperatures from about 1.7 K by a direct connection to the liquid superfluid helium, and additionally to approximately 4 K and 10 K by connections to the helium gas produced by the boil-off of liquid helium gas, which is used efficiently to provide the thermal environment necessary for their proper functioning. The "warm" - mainly electronics - parts of the instruments are located in the SVM. The following instruments are provided within the Herschel spacecraft:

- The Photodetector Array Camera and Spectrometer (PACS)
- The Spectral and Photometric Imaging REceiver (SPIRE)
- The Heterodyne Instrument for the Far Infrared (HIFI)

The instruments are described in their respective users' manuals

1.1.2. The Service Module (SVM)

The service module (SVM) is the box-type enclosure at the bottom of the satellite, below the EPLM and carries all spacecraft electronics and those instrument units that operate in an ambient temperature environment. It is depicted in Figure 1.4.

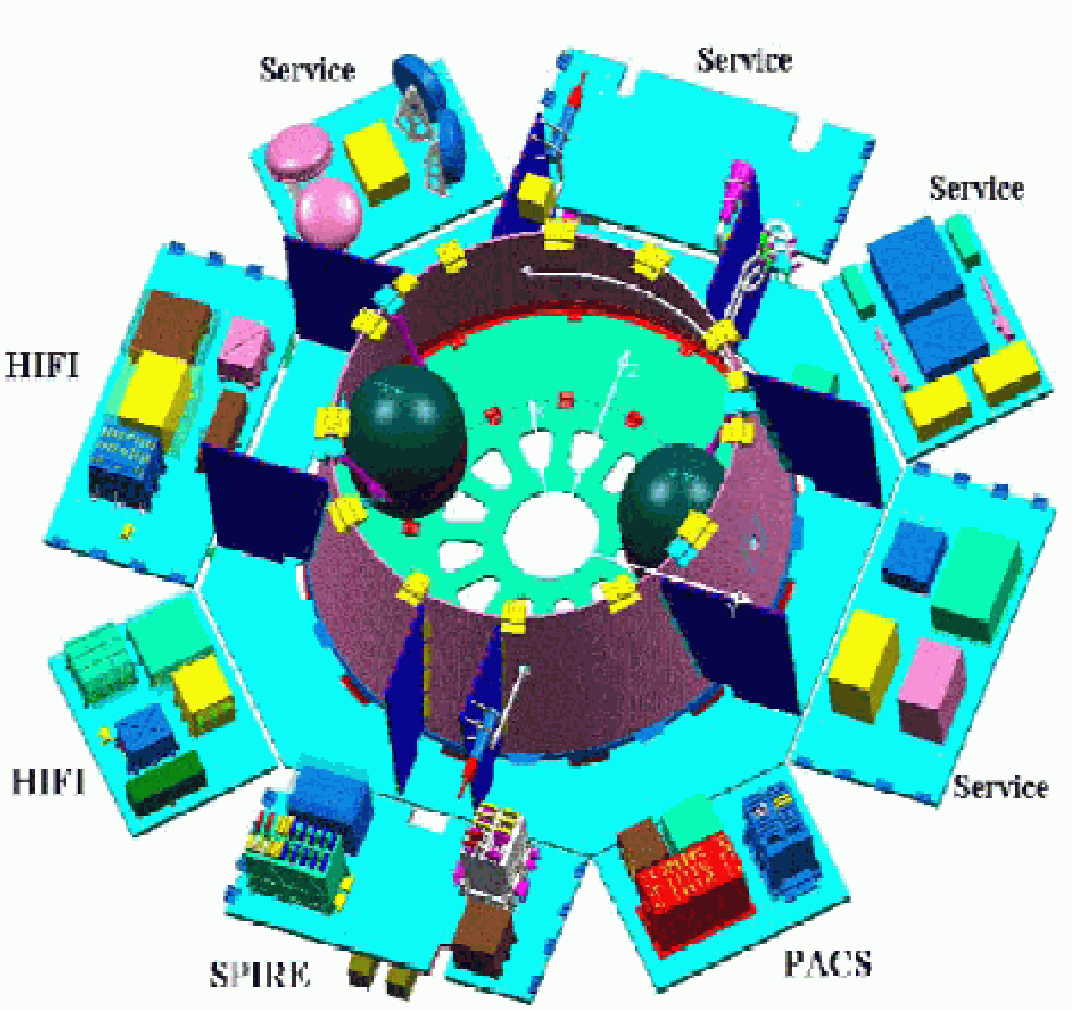

Figure 1.4. The Herschel service module.

SVM modularity is achieved by implementing units of similar function on each of the panels. Panels are either dedicated to one instrument or to a single sub-system (Attitude Control, Power, Data handling-telecommunications). The propellant tanks are symmetrically implemented inside the central cone. The SVM also ensures the mechanical link between the launcher adapter and the EPLM.

1.1.2.1. The Sun shield and solar arrays.

The electrical power of the satellite is produced by the solar array. The solar array is in front of the cryostat to protect it from solar radiation. The rear of the sunshield is covered with multi layer insulation as is the part of the cryostat facing this warm part of the system. The geometrical design has to consider the size of the cryostat and the telescope, the required sun aspect angles of the s/c in orbit and the limited diameter of the fairing of the launcher. For Herschel a relatively simple system with a fixed solar array has been selected. The lower part actually carries the solar cells. The upper part is free of solar cells to allow it to be at a lower temperature, which in turn helps for the telescope to stay at the required temperature. The height of the sunshield is driven by the need to shade the entire telescope when the spacecraft is pointed closest to the sun (60° Sun aspect angle).

1.1.3. Spacecraft Axes definition.

The Herschel s/c coordinate axis system is defined in [RD1] as follows:

- The positive X-axis is perpendicular to the separation plane and nominally coincides with the longitudinal launcher axis. The positive X-axis shall be along the nominal optical axis of the Herschel telescope, towards the target source.
- The Z-axis forms a plane with the X-axis perpendicular to the separation plane such that nominally the Sun lies in the XZ plane (zero roll angle), positive towards the Sun. In other words, the XZ plane is the symmetry plane of the solar array, the Z-axis pointing outwards from the solar array.
- The Y-axis completes the right-handed orthogonal reference frame.

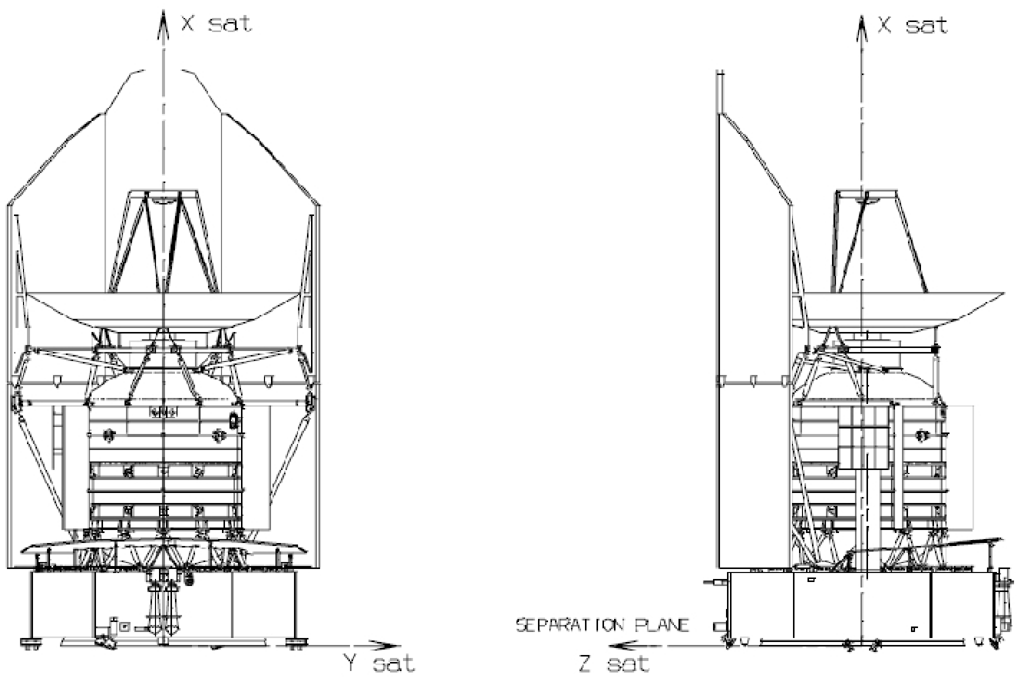

Figure 1.5. Herschel s/c axes (from [RD1])

1.2. Spacecraft orbit and operation

Herschel and Planck will be launched aboard a single Ariane V launch vehicle from European spaceport at Kourou. The launch makes use of the Sylda 5 adapter with Planck being the lower passenger below the Sylda 5 and Herschel mounted as upper passenger. After burnout and separation from the lower Ariane composite, the assembly with the upper stage will orbit the Earth for 107 minutes before the final stage of the launcher is ignited, putting the two spacecraft into the required transfer trajectory towards the second Lagrangian Point L2 (see Figure 1.6). Even though both satellites will finally be in an orbit around L2, their orbits are quite different. Herschel will acquire its final orbital position at around 1.5 million km from the Earth with only a minor correction manoeuvre after a transfer time between of four and six months.

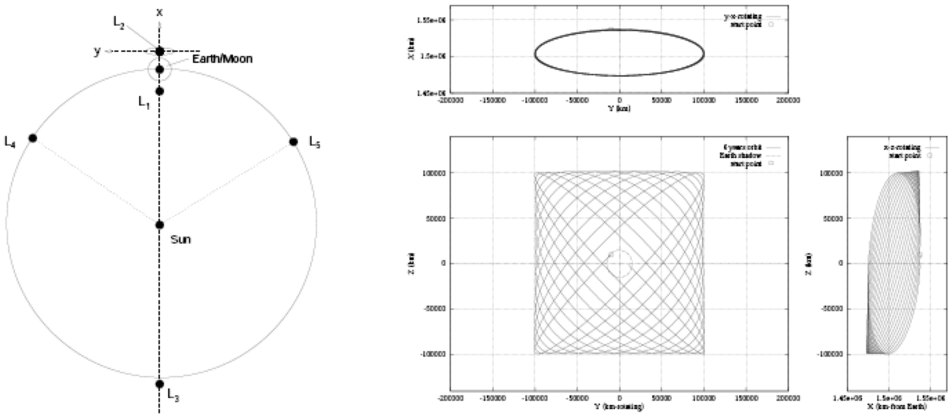

Figure 1.6. ***Left:*** **Position of the Lagrange points for the Sun-Earth/Moon system. L2 lies 1.5 million kilometres from Earth.** ***Right:*** **An example of a Lissajous orbit around L2. The orbit x and y-axis are as shown in the plot on the left, the z-axis is normal to paper.**

The Herschel spacecraft will be eventually placed in a large "halo" orbit around L2 (halo orbits are special cases of Lissajous orbits around Lagrange points where the in-plane and out-of-plane frequencies are the same), 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 summarised below:

- Simplifies long observations, since the Sun and the Earth remain close to each other as seen by the S/C (Sun-S/C-Earth angle always < 40°)
- Very stable thermal and radiation environment
- No trace of atmosphere
- A large halo orbit can be achieved without any injection Δv

Major drawbacks are the long distance for communications and the fact that orbits around the L2 are unstable; without orbit corrections the spacecraft would deviate exponentially from the nominal one. Small correction manoeuvres, applied at monthly intervals, will maintain the orbit close to the nominal one. Figure 1.7 shows an example of large halo orbit around L2 (from [RD2]).

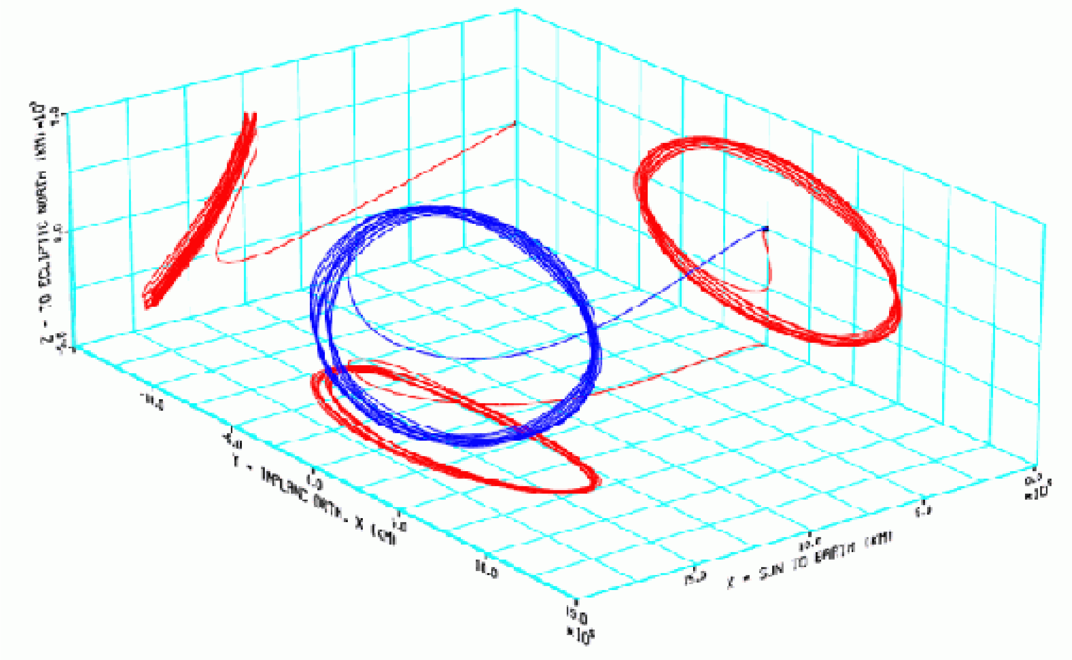

Figure 1.7. A 3D representation of a large halo orbit around L2. The Earth is located at (0,0,0). Red tracks are the projection on the three orthogonal planes of the 3D orbit (blue track).

Herschel operations will be performed by the European Space Operations Centre (ESOC) located in Darmstadt (Germany). The main ground station will be New Norcia (Australia), which is equipped with a a 35-metre antenna using X band up and down links. New Norcia will be backed up by the Cebreros ground station (Spain). In the phase immediately after launch the Kourou (French Guiana) and Villafranca (Spain) ground stations will also be used. During routine operations, the ground station communication link will be restricted to a duration of approximately 3 hours. During this time, the spacecraft antenna will be pointed to the Earth. The data stored in the on-board solid state mass memory will be downlinked, and the mission time line with the new schedule will be uplinked. Real time operations and spacecraft maintenance will also be carried out during this period. The rest of the time the satellite will operate autonomously. The system has been designed to support 48 hours of autonomous operation, with requires a solid state mass memory capability of 25 Gbt. The amount of Herschel data downloaded per day will be in excess of 8 Gbt.

1.3. Sky visibility

The areas of the sky accessible to the Herschel telescope are determined by a number of constraints applicable to Sun, Earth, Moon and other bright solar system objects. In particular, the following constraints are applicable through the mission:

- Sun-S/C-Earth angle of 37°
- Sun-S/C-Moon angle of 47°
- Sun-S/C-LoS angle of 60° to 120° (in the S/C XZ plane)
- Maximum roll angle of ±1°

In order to avoid straylight pollution and also for safety reasons (to prevent large fluxes of light from reaching detectors), the nominal half-cone exclusion angles listed in Table 1.3 apply to observations towards major planets.

Table 1.3. Nominal exclusion angles (half-cones) for observation towards major planets

Instrument	Mode	Mars	Jupiter	Saturn	Instrument Critical
SPIRE	Slew	15 arcmin	15 arcmin	15 arcmin	Yes[a]
	Pointing	1.5 deg	1.5 deg	1.5 deg	Yes[a]
HIFI	Slew	36 arcmin	36 arcmin	36 arcmin	No[c]
	Pointing	36 arcmin	36 arcmin	36 arcmin	No
PACS	Slew[d]	4 arcmin	4 arcmin	4 arcmin	No
	Pointing[e]	1.5 deg	1.5 deg	1.5 deg	No

a. SPIRE has determined that, while Jupiter and possibly Saturn will not damage the instrument, they would render it inoperable for a significant period (possibly even an entire OD)

b. For SPIRE PACS parallel mode both the SPIRE and PACS restrictions apply.

c. HIFI wishes to avoid straylight pollution when observing fainter objects with a SSO close to the instrument LoS. The instrument will not be harmed by the presence of a major SSO in the FoV and will, in fact, even use Mars as its primary calibrator.

d. During slews, the detectors are ON (photometry, spectroscopy or parallel mode).

e. During non-SSO PACS observations. PACS may well wish to observe these SSOs directly.

The time windows when a fixed or moving target or list of targets are visible can be calculated with HSpot. The tool provides an easy way to check in which time intervals a source is visible during the mission. The visibility calculation does not yet take into account the avoidance cones around Jupiter, Saturn and Mars described above, or the reduction in visibility imposed by chopper angle avoidance or map orientation constraints.

The sky visibility for each date depends on the launch date and the orbit of the satellite. Figure 1.8 shows the sky visibility throughout the mission, assuming a launch date on 31 July 2008, and the visibility during the day computed for two particular dates. Considering a nominal duration of the operations, all areas in the sky are visible at least 30% of the time. The sky visible region moves slowly on a daily basis. The two snapshots at the bottom of Figure 1.8 illustrate the sky visibility differences after a 3 month interval.

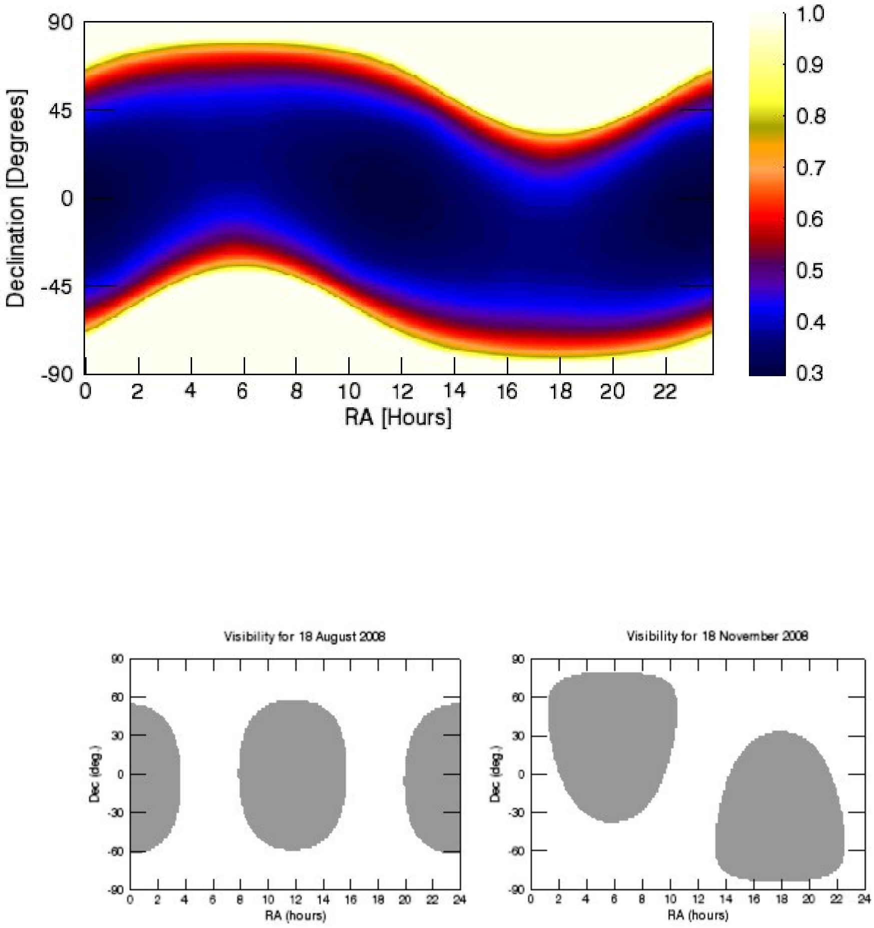

Figure 1.8. Top: The sky visibility across the sky as a fraction of the total hours through the Herschel mission, represented as a colour scale (shown at right) where black represents 30% visibility and white represents permanent sky visibility. Bottom: sky visibility for two sample dates. Shadowed areas represent inaccessible sky areas.

1.4. Herschel pointing performance

This section deals with the pointing performance of the Herschel spacecraft. The spacecraft Attitude Control and Measurement System (ACMS) consists of several components, as depicted in Figure 1.9. The main constituents of the ACMS are the attitude control computer (ACC), gyroscopes (GYR), star trackers (STR), reaction control system (RCS), reaction wheel assembly (RWA), Sun acquisition sensors (SAS), coarse rate sensors (CRS) and attitude anomaly detectors (AAS).

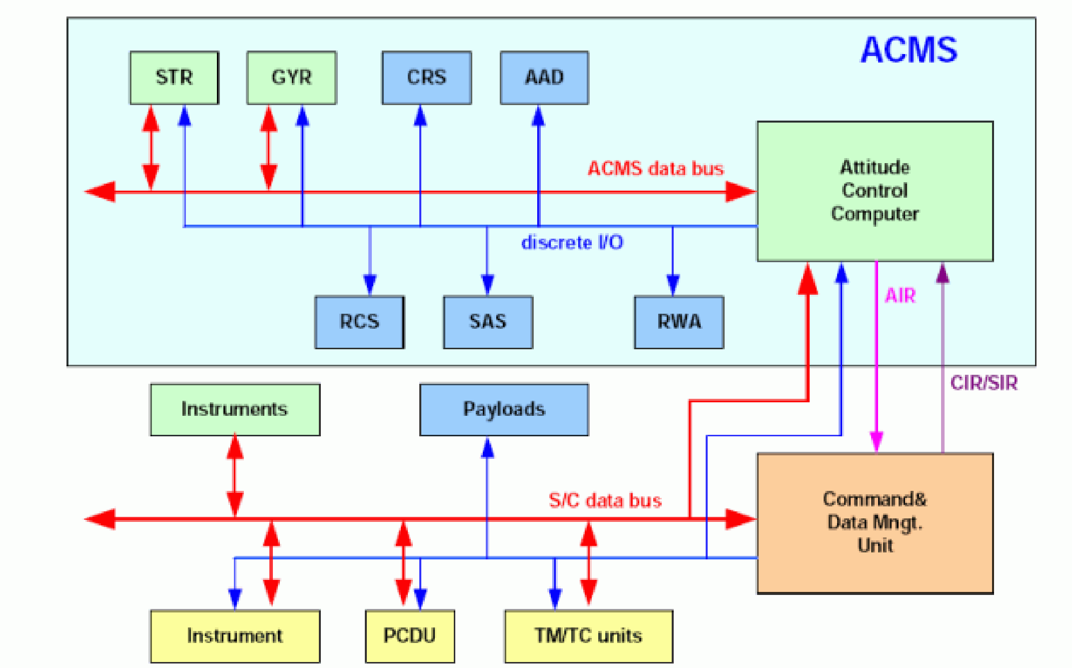

Figure 1.9. Diagram of the Herschel/Planck avionics.

In normal operation, the spacecraft attitude is commanded by means of the reaction wheel system. It comprises four 8.6 kg wheels in a skewed configuration, each with a momentum storage capacity of 30 Nms and a maximum delivered reaction torque of 0.215 Nm in either positive or negative direction.In the baseline configuration, all four whels are powered and used for actuation, providing optimum slew performance and momentum storage. Nevertheless, the ACMS is also capable of operating with only three reaction wheels powered. In the nominal configuration, the maximum slew speed is 0.00204 rad/sec, i.e. ~ 7 deg/sec.

In normal science operation, the spacecraft attitude is controlled by means of two components: the star trackers (STR) and gyroscopes (GYR). The STR comprises two cold-redundant units, nominally aligned with the -X axis. The STR hardware include:

- An objective lens.
- A baffle to protect from undesired straylight from the Sun and other bright sources.
- The focal plane assembly, containing a CCD detector and a thermo-electric cooler for CCD cooling.
- The sensor electronics.

From a functional point of view, the STR can be seen as a video camera plus an image processing unit that, starting from an image of the sky, extracts the attitude information measured with respect to the J2000 inertial reference system and delivers it to the ACC. A CPU (ERC32 microprocessor) controls the CCD sensor and also carries the image processing task.

Key characteristics of the Herschel's STR are:

- The ability to determine the inertial position from "lost in space".
- FoV: 16.4×16.4 deg².
- An onboard catalogue, based on Hipparcos, of some 3000-3500 stars.

- A minimum of 3 stars, 9 is the maximum due to HW limitations.

The STR bias is the largest contributor to absolute pointing error and is pixel-dependent (some 0.8" $\times \sqrt{2}$)

The STR is provided with an enhanced performance mode the so-called "interlaced mode", only applicable if there are ≥ 18 stars in FoV. The STR samples at twice the nominal frequency (4 Hz), 9 stars at a time. A low scan rate (0.2 arcsec/sec) is required. The use of both STRs simultaneously is being considered; this would yield an improved 'a posteriori' absolute attitude knowledge.

Gyroscopes (GYR) are devices that use a rapidly spinning mass to sense and respond to changes in the inertial orientation of it spin axis. *Rate/rate-integrating gyros* provide high-precision measures of the the spacecraft angular rate. The Herschel's ACMS is provided with four gyroscopes mounted in a tetrahedral configuration. The four gyroscopes are hot-redundant, and each of the four can replace any of the others. The fourth gyroscope is not used for control, but serves to detect an inconsistency in the output of the other three.

The STRs provide an absolute reference, but with limited accuracy. On the other hand, GYRs are very accurate, but only on short temporal (bias drift, 0.0016 deg/hour) and spatial (variation in the scale factor should be taken into account for distances larger than 4 deg) scales. Therefore, the GYR attitude must be recalibrated using the STR information. Therefore, in normal operation the spacecraft attitude is computed by combining the STR and GYR measurements in the ACC using a linear Kalman filter. The so-called "filtered attitude" is sampled and downloaded with a frequency of 4Hz.

Herschel pointing modes are based either on stare pointings (fine pointing mode) or moving pointings at constant rate (line scan mode). Raster maps are 'grids' of stare pointings at regular spacings; in the position switching and nodding modes, the boresight switches repeatedly between two positions in the sky. Scan maps are sequences of line scans at regular spacing. Allowed angular speed ranges from 0.1 arcsec/sec to 1 arcmin/sec. In addition, the Herschel spacecraft can track moving Solar System targets at rates up to 10 arcsec/min.

1.4.1. Pointing accuracy definitions

In this section, formal definitions of the spacecraft pointing accuracy parameters are provided. The term 'pointing', when applied to a single axis (e.g. the telescope boresight), refers to the unambiguous definition of the orientation of this axis in a given reference frame. When characterising the pointing performance of the telescope, it is possible to provide a figure of the absolute attitude accuracy provided by the ACMS (absolute pointing error), or how accurate the 'a posteriori' knowledge of the absolute attitude (the absolute measurement error) can be, or how stable the pointing is (the relative pointing error). Furthermore, the pointing performance can be also characterised in terms of the relative accuracy of a set of attitude measurements (the spatial relative pointing error). The latter measurement is important to characterise the accuracy of the relative astrometry in a map comprising several pointings (e.g. from a raster pointing).

Herschel pointing accuracy definitions, presented below, are based on the prescriptions given in the *ESA Pointing Error Handbook* (ESA-NCR-502):

- **Absolute Pointing Error (APE)**: the angular separation between the desired direction and the actual instantaneous direction.
- **Absolute Measurement Error (AME)**: the angular separation between the actual and the estimated pointing direction (*a posteriori* knowledge).
- **Pointing Drift Error (PDE)**: the angular separation between the average pointing direction over some interval and a similar average at a later time.
- **Relative Pointing error (RPE) or pointing stability**: the angular separation between the instantaneous pointing direction and the short-time average pointing direction at a given time period (in this case 60 sec).
- **Spatial Relative Pointing Error (SRPE)**: angular separation between the average orientation of

the satellite fixed axis and a pointing reference axis, which is defined to an initial reference direction.

1.4.2. Pointing performance

The main pointing error contributors within the Herschel spacecraft are:

- To AME and APE:
  - Position-dependent bias within STR. *It is also the main contributor to SRPE.*
  - Residuals from calibration
  - Thermo-elastic stability of the structural path between STR and FPU
  - Instrument LoS calibration accuracy w.r.t. ACA frame (best for PACS)
- To PDE: Thermo-elastic stability
- To RPE: The main contributor is the noise in the control loop comprising STR+Gyro noise attenuated by a linear Kalman filtering.

Table 1.4 summarises the pointing performance of the Herschel spacecraft. The most outstanding non-compliance is related to the SRPE (required 1 arscec vs. predicted performance 2.44 arcsec).

Table 1.4. Herschel pointing requirements (from SRS v3.2)

	Baseline (arcsec)		**Goals (arcsec)**	
Name	Requirement	Performance	Requirement	Performance
APE point	3.7	2.45	1.5	1.45
APE scan	3.7	2.54	1.5	1.63
PDE (24 hours)	1.2	0.71	n.a.	n.a.
RPE point (60 sec)	0.3	0.24	n.a	n.a
RPE Scan (60 sec)	1.2	0.88	0.8	0.81
AME Point	3.10	2.40	1.20	1.42
AME Scan	3.10	2.52	1.20	1.62
AME Slew	10.00	2.59	5.00	1.80
SRPE	1.00	2.44	1.00	1.52

1.4.3. Gyro propagation mode

As commented above, the STRs provide an absolute reference, but are not accurate enough on their own to satisfy the performance requirements. In particular, they are responsible for the SRPE non-compliance. GYRs only produce accurate attitude measurements in short temporal and spatial scales and their measurements should be recalibrated using the STR information. A mechanism has been devised to perform SRPE-compliant raster pointings by using exclusively the accurate gyro information. This is called the "gyro propagation mode" (a.k.a. Calibration Pointing or CP). The procedure consists of the following steps:

- Initial fixed pointing of 30 min to calibrate the GYR bias
- Within the next TBD hours:

- Initial 15 sec calibration in the OFF position
- 600 sec between the recalibrations of the GYR
- 15 sec recalibration in the OFF position.

This mode has been implemented only for raster pointings.

Warning
The gyro propagation mode will not be implemented at AO in February 2007. Please contact Helpdesk http://herschel.esac.esa.int/ for specific enquiries about this topic.

Chapter 2. Space Environment

This section will deal with "space environment" aspects of the mission that affect the noise level and therefore the observatory sensitivity. These include:

- Background, including the telescope, instruments and the celestial background
- Radiation environment (high-energy particles)
- Source confusion (CFIRB and cirrus spatial structure, resolved or partially resolved galaxies)
- Straylight due to sources inside or outside the FoV and to instrumental self-emission

2.1. Background radiation

2.1.1. Telescope background

The Herschel telescope is located outside the cryostat and protected by the sunshade from direct radiation from the Sun. The expected orbital temperature is below 80 K. At this temperature, even given a low emissivity, the source contribution is almost always only a small fraction of the telescope background. For comparison, the telescope background ‘flux’ is of the order of 1000 Jy, while that of Uranus is ~ 250 Jy and Neptune ~ 100 Jy. Therefore, a precise characterisation of its behaviour is of critical importance.

The telescope background depends primarily on:

- The average temperature: The telescope temperature will be in the 60-90 K range, but the actual value will only be known in space. Efforts are being made to lower the value and to narrow the range of uncertainly as much as possible. The telescope temperature depends critically on the temperatures and emissivities of the thermal interfaces, the sunshade/shield and the CVV topside.
- The effective emissivity: beyond 100µm, it has a stronger influence on the telescope background level than the temperature. It has been observed that a 1% reduction in emissivity gives a greater improvement than a 5 K reduction in temperature.
- The straylight (see Section 2.4).

Small spatial and temporal temperature gradients are important to the background stability. The requirements on the primary mirror (M1) are:

- Maximum temperature difference along the S/C Z axis < 10 K (predicted < 0.5 K)
- Maximum temperature difference along the S/C Y axis < 1 K (predicted ~ 0.0 K)
- Along the S/C Z axis: dT/dt < 13.0 mK/min
- Along the S/C Y axis: dT/dt < 1.3 mK/min

2.1.2. Instruments

See "Self-emission" under Section 2.4

2.1.3. Celestial background

Thermal emission from interstellar dust (known as interstellar cirrus) dominates the FIR Sky Background (FIRSB) at lower Galactic latitudes, while the Cosmic Far-Infrared Background (CFIRB) is more significant towards higher Galactic latitudes, also dominating the confusion noise in the PACS and SPIRE photometric bands. Intrinsically diffuse and unresolved components of the FIRSB are (in descending order of their relative contribution, see [RD4] and [RD5]):

1. Diffuse galactic light (interstellar cirrus): quasi-thermal emission of dust in weak gas clouds in the Milky Way. This is the dominant component for wavelengths λ>70µm.
2. Zodiacal light and emission from the asteroid belt: this is the dominant component of the sky background at MIR wavelengths.
3. Cosmic far-infrared background (CFIRB): accumulated and unresolved light of distant galaxies.
4. The cosmic microwave background (CMB): the CMB also has an important contribution in strength, but the fluctuation amplitudes are small, and well below the detection limits of PACS and SPIRE.
5. Intergalactic diffuse emission
6. Integrated starlight: the integrated contribution from faint stars in the Milky Way is an important component for near- to mid-infrared wavelengths, but has a negligible contribution for longer wavelengths, e.g. those of PACS and SPIRE.

A detailed description of the different components of the FIR background is given in the Herschel Confusion Noise Estimator (HCNE) tool Science Implementation Document ([RD4] and [RD5]). The HCNE tool can be accessed as a standalone service to provide background estimates (see the HSC website for more information) or through the HSpot proposal preparation tool.

While the zodiacal light emission is a major contributor to the sky brightness in the MIR range, it is less important for the FIR and sub-mm wavelengths. Moreover, this emission is quite smooth, lacking fluctuations at arcmin scale (angular resolution of the ISOPHOT instrument on board ISO). Smaller scale fluctuations, in principle, are likely to exist, but the presence of such structures have not been yet confirmed by the recent observations of the Spitzer Space Telescope.

Confusion noise due to the integrated FIR-sub-mm emission from faint asteroids individually below the detection limit has been investigated by Kiss et al. (2006) (see [RD5] and references therein). It has been found that the distribution of asteroids concentrates towards the local anti-solar direction, with a corresponding peak of the confusion noise in the anti-solar point, and an extended cloud is present around the maximum. Seasonal variations are also detected. The confusion noise induced by the cloud of asteroids would only be not negligible in the area around the anti-solar direction, but this area of the sky is closed to Herschel anyway due to the satellite's Sun constraint (see Section 1.3), so the asteroid cloud component is not considered in the HCNE.

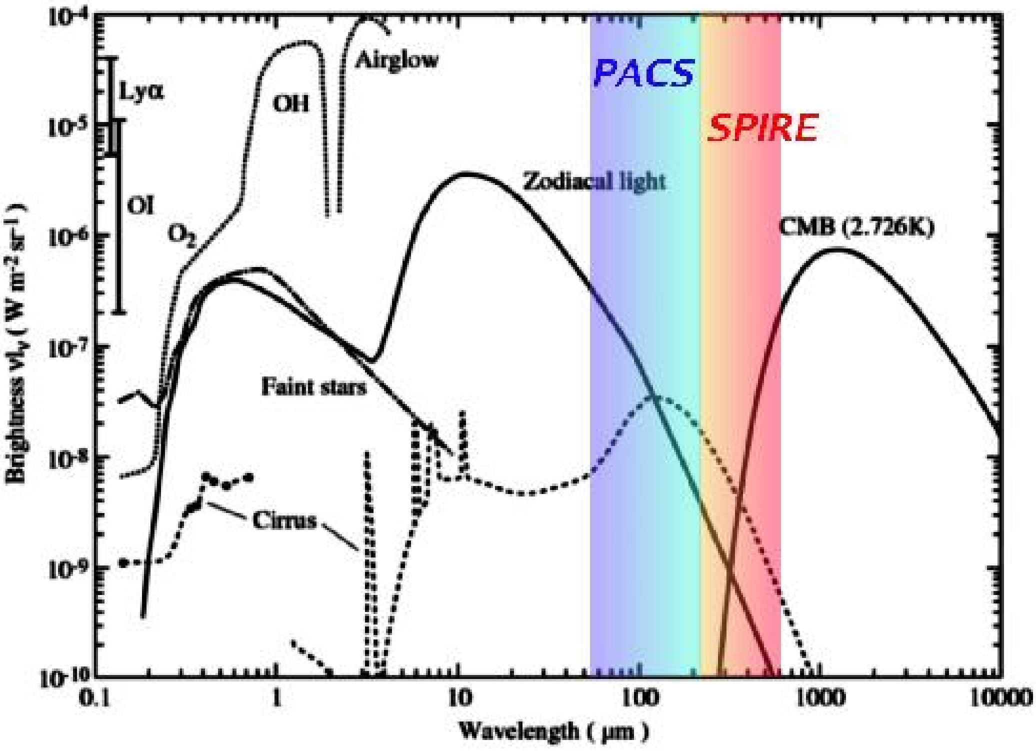

Figure 2.1. Brightness of the night sky, excluding contribution of the extragalactic background (from [RD5], adapted from Leinert et al. 1998, A&A, 127, 1). The spectral range covered by the PACS and SPIRE instruments of the Herschel Space Observatory are indicated. Atmospheric contributors, affecting ground-based observation in the optical and NIR, have been also displayed.

The interstellar medium shows a strong concentration around the Galactic plane; this feature is conspicuous at many wavelengths. However, the cirrus emission is not limited to low Galactic latitudes. It consists of thermal emission of dust in low-density, cool interstellar HI clouds (typically with $T \approx 20K$ and $n \leq 10^2 cm^{-3}$), showing a smooth, modified blackbody SED. It is a strong source of emission, and dominates the sky for wavelengths $\lambda > 70\mu m$, even at high Galactic latitudes. The cirrus emission is highly structured, and shows a typical filamentary structure.

The main characteristic of the cirrus emission is its spatial structure at a specific wavelength. This is usually described by the spectral index, α,of the power spectrum of the image, averaged over annuli ([RD7]). With this parameter the power spectrum is $P=P_o(f / f_o)\alpha$, where P is the power at the spatial frequency f and P_o is the power at the spatial frequency f_o. Due to this parameterisation the structure of cirrus is equivalent to that of a fractal.

According to [RD5], cirrus confusion noise can be generally described by the following equation:

$$\sigma_{cirrus} = c_1 \times (\lambda/D)^{1-\alpha/2} \times B^{\eta}$$

Here σ_{cirrus} is the confusion noise due to the cirrus component, B is the surface brightness of the field α is the spectral index of the logarithmic power spectrum, averaged in annuli (see [RD5] and references therein), λ is the wavelength of the observation and D is the effective diameter of the telescope's primary mirror. The parameters c_1 and η have to be determined from measurements. This is used within the HCNE to compute the noise due to cirrus emission. Details on the computations are given in [RD5].

In many practical cases, Galactic cirrus confusion noise has been found to be easily parameterised as follows (see for instance [RD6] and references therein):

$$\sigma_{cirrus} \sim 0.3(\lambda_{100})^2(D_m)^{-2.5}\langle B_\lambda \rangle^{1.5}$$

where σ_{cirrus} is given in mJy, λ_{100} is the wavelength ratio $\lambda/(100\ \mu m)$, D_m is the telescope diameter in metres and $\langle B_\lambda \rangle$ is the sky brightness in MJy/sr. If we consider fiducial values $\langle B_{70} \rangle = 0.12$ MJy/sr and $\langle B_{160} \rangle = 1.5$ MJy/sr (corresponding to $N_{HI} = 10^{20}\ cm^{-2}$) and $D_m = 3.5$, we get that $\sigma_{cirrus}(70\ \mu m) = 0.22\ \mu Jy$ and $\sigma_{cirrus}(160\ \mu m) = 0.08$ mJy.

2.2. Radiation environment

The L2 environment (and orbits around it) is relatively benign compared to those in geostationary (GO), or low Earth (LEO) orbits. In particular, a series of common threats for satellites in GO or LEO, including the neutral thermosphere, space debris, geomagnetically trapped particles and large temperature gradients, are not a concern for L2 orbits. Environmental aspects to be considered at L2 include:

- Solar wind plasma. Essentially a neutral or cold plasma: 95% protons, 5% He++ and equivalent electrons; 1-10 particles/cm^3. The main risk associated is a low surface charging potential. This plasma may be relatively benign at L2 compared to that found at GO and LEO.

- Ionising radiation: solar flares (energetic electrons, protons and alpha particles), Galactic cosmic rays and Jovian electrons.

- Magnetic fields: Earth's magnetotail extends up to 1000 Earth's radii, so it must be considered (2-10 nT) along with interplanetary magnetic field (~ 5 nT). The effects on the spacecraft and PLM include possible orbit disturbance and electrostatic discharge (ESD).

Therefore, the main radiation components at L2 consist of: Galactic cosmic rays, solar particle events and solar and Jovian electrons. Solar activity follows an 11-year cycle. The last minimum occurred around March, 2006, and therefore the Herschel launch in 2008 will be carried out during a low to moderate activity state, hence only a small number of major solar particle events is expected during the earliest mission stages. The activity will increase towards the end of the nominal mission, 3.5 years later. The number of damaging solar particle events increase dramatically due to the new solar maximum in 2011, which is predicted to be an unusually strong one (certainly one of the 5 strongest ever observed and possibly one of the three strongest). Solar particle events will be particularly problematic during a possible extended mission.

In the early stages of the mission, the dominant radiation source will be Jovian electrons, characterised by a energetic population and a 13-month synodic year modulation. Solar electrons will be an important source at lower energies with abrupt peak emissions, and a 27-day period.

The Herschel spacecraft is equipped with standard radiation environment monitors (SREM); the SREM is a particle detector developed for satellite applications. It measures high-energy electrons (from 0.5 MeV to infinity) and protons (from 20 MeV to infinity) of the space environment with an angular resolution of some 20 degrees, providing particle species and spectral information. The SREM data will be received on-ground and processed by the Space Weather Group at ESTEC, providing valuable information on the radiation environment at L2.

2.3. Source confusion

Source confusion is an additional noise factor closely related to the astronomical background, described in Section 2.1. The sensitivity limit due to confusion is determined by the telescope aperture, observation wavelength and the position on the sky. The sensitivity cannot be improved by increasing the integration time after reaching the confusion limit. The most important contributions to source confusion are:

- Structure of the CFIRB, as well as resolved and partially resolved extragalactic sources dominate at high galactic latitudes.

- Small-scale structure in cirrus clouds may dominate at intermediate Galactic latitudes. The contribution depends heavily on the level of cirrus emission at the position on the sky.

The confusion noise is usually defined as the (stochastic) fluctuations of the background sky brightness below which sources cannot be detected individually. In addition to the diffuse galactic foreground cirrus component, these fluctuations are caused by intrinsically discrete extragalactic sources in the beam. Due to the limited telescope diameter compared to the wavelength, these fluctuations play an important, if not dominant, role in the total noise budget in extragalactic surveys carried out in the MIR, FIR and sub-mm range. Moreover, the noise due to extragalactic sources depends strongly on the shape of the source counts at a given wavelength.

There are two different criteria to derive the confusion noise, and thus the detectability of a point-like or compact source:

- First, the target source flux should be well above the average background fluctuation amplitude. This is the basis of the "photometric criterion", derived from the fluctuations of the signal due to sources below the detection threshold S_{lim} in the beam.
- On the other hand, the observed source should be far enough from its neighbours to be properly separated; this is the basis of the "source density criterion", which is derived from a completeness criterion and evaluates the density of the sources above the detection threshold S_{lim}, such that only a small fraction of the sources are missed because they cannot be separated from the nearest neighbour.

Generally, we should compare the confusion noise derived from both criteria, in order not to underestimate it artificially. The confusion noise, σ_c, and confusion limit, S_{lim} are defined as follows:

$$\sigma_c^2 = \int f^2(\theta,\phi)d\theta d\phi \int_0^{S\_lim} S^2(dN/dS)dS$$

where $f(\theta,\phi)$ is the instrumental 2D beam profile, that can be approximated by a Gaussian profile with the same FWHM as the expected PSF, or by an Airy function, S is the source flux density (in Jy) and dN/dS is the differential source number counts (in $Jy^{-1}sr^{-1}$).

Then, the total noise is computed by square-adding the different noise contributions, in this case the photon (and instrumental) noise and the confusion noise, i.e. $\sigma_{total} = (\sigma_p^2 + \sigma_c^2)^{½}$

The photometric criterion is defined by choosing the S/N ratio q_{phot} between the faintest source (of flux S_{lim} and the noise σ_c due to fluctuations from beam to beam caused by sources fainter than S_{lim}, as given by the implicit equation:

$$q_{phot} = S_{lim} / \sigma_c(S_{lim})$$

q is usually chosen between 3 and 5, depending on the specific objectives.

The source density criterion is defined by setting the minimum degree of completeness of the detection of sources above the limiting flux S_{lim}, which is driven by the fraction of sources lost in the detection process due to a nearest neighbour source with flux above S_{lim} too close to be separated given an instrumental beam size. For a given Poissonian source density N(>S), the probability P of finding a nearest neighbour with $S \geq S_{lim}$ at a distance closer than the minimum angular separation θ_{min} is given by:

$$P(< \theta_{min}) = 1 - \exp(-\pi N\theta^2_{min})$$

An acceptable probability limit is $P_{max} = 0.1$. The minimum distance is usually parameterised using the FWHM of the beam profile $\theta_{min} = k\theta_{FWHM}$, and $0.8 \leq k \leq 1$. Fixing the probability we obtain the corresponding "source density criterion" limiting density of sources:

$$N_{SDC} = -\ln(1-P(<\theta_{min})) / \pi N k^2\theta^2_{FWHM}$$

The instrumental beam area, is given by $\Omega \sim 1.14\theta^2_{FWHM}$. Therefore, for P = 0.1 and k = 0.8, the density is 1/16.7 sources/beam. The limiting source flux, S_{SDC} is thus determined by using existing number counts results and a suitable model for infrared galaxy evolution extrapolating the data to the appropriate wavelengths and (faint) flux levels. The confusion noise, σ_{SDC} is computed using the same relation as for the photometric criterion, as the S/N ratio $q_{SDC} = S_{SDC} / \sigma_{SDC}$.

The Herschel confusion noise predicted data shown in Table 2.1 have been derived by Lagache et al. 2003 ([RD8]) using number counts derived from a phenomenological model based on template spectra of starburst and normal galaxies, and on the local infrared luminosity function. This model has been found to be in very good overall agreement with ISOCAM at 15 µm, IRAS at 60 and 170 µm and SCUBA at 850 µm (see references within [RD8]). Confusion level predictions for Herschel/PACS have been also computed by Dole et al. 2004 ([RD9]) based on recent Spitzer/MIPS number counts from Papovich et al. 2004 ([RD10]) shown in Figure 2.2. They obtain S_{SDC}(70 µm) = 0.16 mJy and S_{SDC}(160 µm) = 10.0 mJy.

Table 2.1. PACS and SPIRE confusion noise according to photometric and source density criteria. From [RD9]. It can be seen that for PACS and SPIRE's shortest wavelength, source density is the applicable criterion, while for SPIRE at longer wavelengths, the photometric criterion produces more realistic estimates.

		σ (mJy)	**S_{lim} (mJy)**
PACS 75 µm	q_{phot} = 5.0	2.26×10^{-3}	1.12×10^{-2}
	q_{SDC} = 8.9	1.42×10^{-2}	1.26×10^{-1}
PACS 110 µm	q_{phot} = 5.0	1.98×10^{-2}	1.0×10^{-1}
	q_{SDC} = 8.7	1.02×10^{-1}	8.91×10^{-1}
PACS 170 µm	q_{phot} = 5.0	3.97×10^{-1}	2.00
	q_{SDC} = 7.13	9.93×10^{-1}	7.08
SPIRE 250 µm	q_{phot} = 5.0	2.51	12.6
	q_{SDC} = 5.2	2.70	14.1
SPIRE 360 µm	q_{phot} = 5.0	4.4	22.4
	q_{SDC} = 3.6	3.52	12.6
SPIRE 550 µm	q_{phot} = 5.0	3.69	17.8
	q_{SDC} = 2.5	3.18	7.94

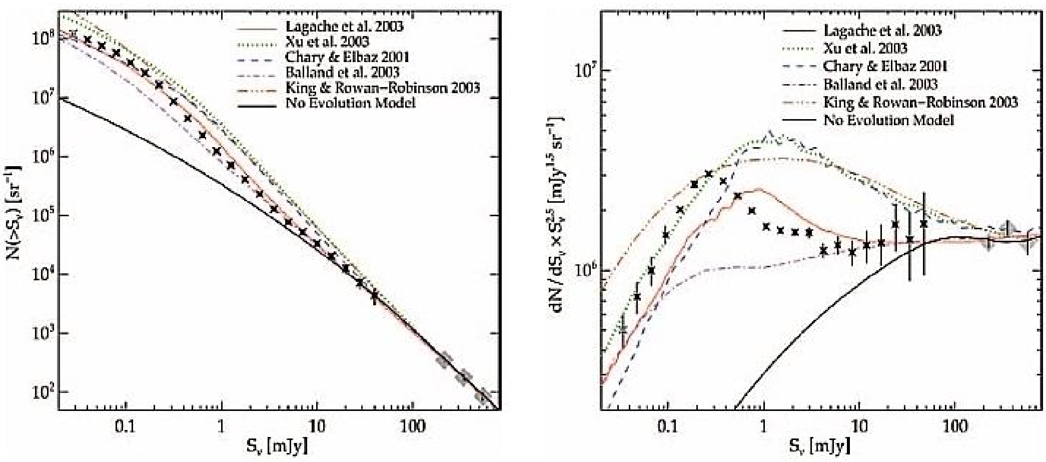

Figure 2.2. Cumulative (left) and differential (right) 24 µm number counts from [RD10]. The differential counts have been normalised to an Euclidean slope, $dN/dS_\nu \sim S_\nu^{-2.5}$. The curves show predictions from different recent models, including that from Lagache et al. 2003.

2.4. Straylight

The Herschel design has been carried out including the instrument optical layout. This approach allows the level of straylight that originates from the various sources at detector level to be provided directly. Therefore, the straylight requirements are given directly as the straylight reaching the detector. The following apply over the full operational wavelength range:

- **Scattered light from sources outside the telescope FoV**: Taking into account the worst possible combination of the positions of the Moon and the Earth w.r.t. the line of sight (LoS) of the telescope, the extreme values are:
  - Sun-S/C-Earth angle of 37°
  - Sun-S/C-Moon angle of 47°
  - Sun-S/C-LoS angle of 60° to 120° (in the S/C XZ plane)
  - Maximum roll angle of ±1°

  The straylight will be < 1% of background radiation induced by the self-emission of the telescope.
- **Sources inside the FoV**: over the entire FoV at angular distances ≥ 3 arcmin from the peak of the point-spread-function (PSF), the straylight shall be $< 1 \times 10^{-4}$ of PSF peak irradiance (in addition to level given by diffraction).
- **Self-emission**: The straylight level, received at the defined detector element location of the PLM/FPU straylight model by self emission (with "cold" stops in front of PACS and SPIRE instrument detectors), excluding the self emission of the telescope reflectors alone (but including any other contributor, notably the M2 hexapod), shall be < 10% of the background induced by self-emission of the telescope reflectors.

According to current straylight analysis for the orbit configuration of Herschel (see [RD3]), for sources outside the FoV, the straylight radiation is within specification, except for small locations on the sky, where radiation reflected from rectangular hexapod structures can enter the instruments directly. These small locations exist primarily for the Moon. Only two minor paths were found which could be applicable also to the Earth. For the worst-case locations of the Moon, the specification is exceeded by a factor 16.4.

For sources inside the FoV, the requirement is met by a wide margin.

Finally, for thermal self-emission, the requirement is not met. Actual values (expressed as a fraction of the background induced by self-emission of the telescope reflectors) are:

- 30% for PACS and 19% for SPIRE (pessimistic case)
- 12% for PACS and 8% for SPIRE (optimistic case)

Chapter 3. Ground Segment

3.1. Ground Segment Overview

The operations of the Herschel Space Observatory are conducted in a decentralised manner. As can be seen in Figure 3.1, the Ground Segment comprises the following elements:

- A Herschel Science Centre (HSC), provided by ESA, located at ESAC, Madrid. The HSC, supported by the NASA Herschel Science Center (NHSC), located at IPAC, acts as the point of interface to the science community and the outside world in general. The HSC is supported by the Herschel Science Team, for the maximisation of the scientific return of the mission, and by the Herschel Observing Time Allocation Committee (HOTAC) for the selection of observing proposals.
- Three dedicated Instrument Control Centres (ICCs), one for each instrument, provided by the respective PI. Each ICC is responsible for enabling the operation and for the calibration of its instrument.
- A Mission Operations Centre (MOC), provided by ESA, located at ESOC, Darmstadt, which is responsible for the execution of all in-orbit operations.

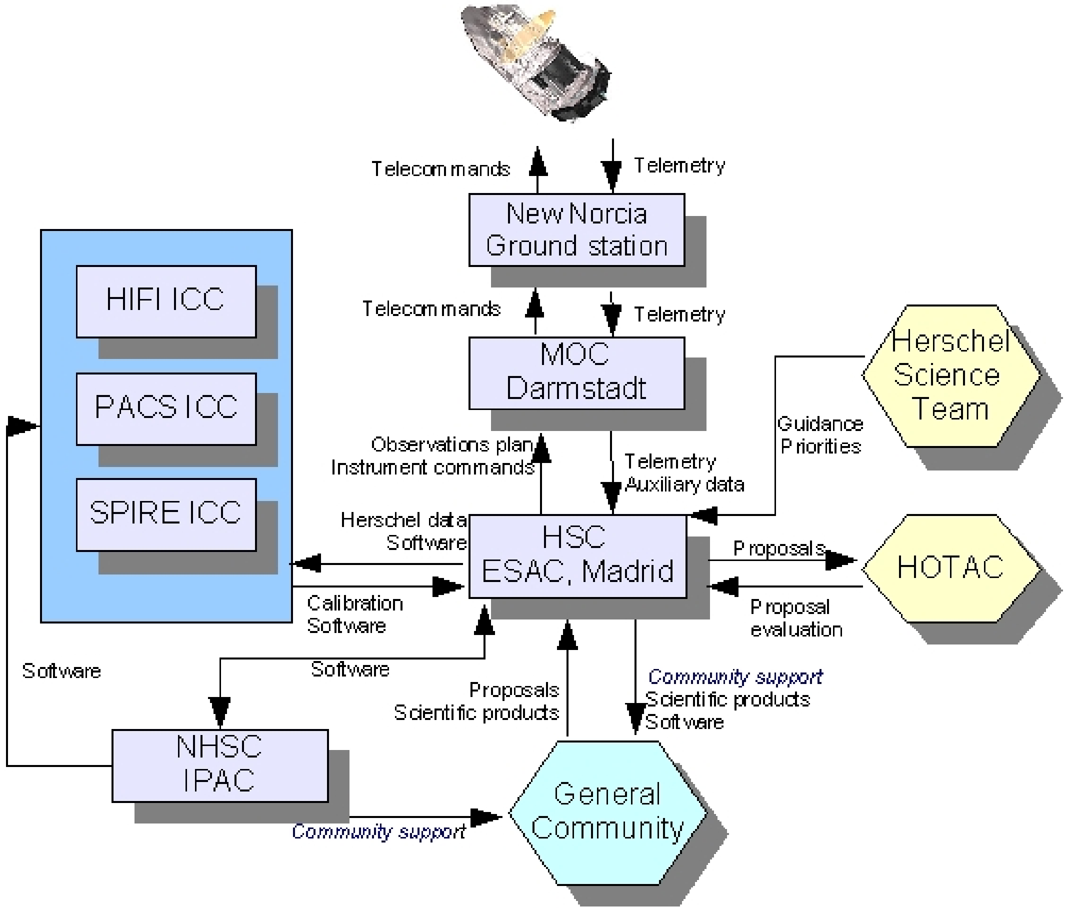

Figure 3.1. Herschel Space Observatory Ground Segment

3.2. From proposal to observations

The Herschel Science Centre provides the information required for the submission of proposals in the Herschel Space Observatory Web site (http://herschel.esac.esa.int), in collaboration with the ICCs. Astronomers are requested to register to access observatory services, which include the capability to submit proposals, access to the Helpdesk and retrieval of observational data from the Herschel Science Archive.

Proposal entering and submission is done through the HSpot tool (see Section 6.1), the Herschel Observation Planning Software. A scientific proposal contains at least one AOR, or Astronomical Observation Request. Each AOR is based on an AOT, or Astronomical Observation Template, which is a pre-defined observing mode, characterised by an instrument configuration and way of operation that have been optimised for the execution of a particular type of observation (see Chapter 6). An AOR is generated when the proposer provides the parameters required for the selected AOT, and is equivalent to the term "observation" used in this document.

A proposal submitted through HSpot is stored in the Herschel Space Observatory database. The proposer, and co-proposers selected by the principal investigator, are allowed to retrieve, modify and upload their proposal(s) until the closing date of the AO. At that time, the database is closed to HSpot, and the HSC distributes the stored proposals to the HOTAC panels. Proposers can check the status of their proposal(s) in relation to the HOTAC review in the Proposal status Web page (http://herschel.esac.esa.int). During the review process, the HSC provides support to the HOTAC and, on request, assesses the technical feasibility of the observations. In addition, a systematic technical feasibility assessment is carried out on all accepted proposals.

The period of proposal submission before the HOTAC review is called Phase-1. After the HOTAC review results are public, proposal submission Phase-2 starts. In this period, observers are allowed to refine their accepted proposals, modify them following the HOTAC guidelines, and use updated AOTs and the latest available observatory knowledge. Please see the "Herschel Space Observatory Call for Proposals: Policies and Procedures" document for a definition of proposal submission Phase-1 and Phase-2, and for the policies on proposal modifications. The end of proposal submission Phase-2 results in a consolidated database of accepted proposals and its corresponding AORs.

3.3. Mission planning and execution of the observations

The observatory schedule will be defined by the database of accepted observations. The HSC will carry out a careful study of the observation database to define a long-term mission plan that will accommodate all constraints and will maximise the scientific return. Following the agreed long term mission plan, short term observing schedules, together with the corresponding instrument commands, will be produced with the Mission Planning System at the HSC, and transferred to the Mission Operations Centre (MOC), at ESOC. The MOC will add the satellite commands and produce the final detailed mission timeline that will be uplinked to the spacecraft.

The basic time unit for the mission planning is the Operational Day, or OD. It is defined as the interval of time between the start of two consecutive DTCPs. The DTCP, or Daily TeleCommunication Period, is the time interval when the spacecraft antenna will be pointed to the Earth to receive telecommands and send the recorded telemetry. The duration of an OD will normally be about 24 hours, but it will depend on the availability and detailed schedule of the New Norcia Ground Station, which is shared with other ESA missions. The operational constraints of the Herschel instruments determine that only observations with a certain instrument sub-system are scheduled in a single OD. For instrument sub-systems that require cooler recycling, only observations of that particular sub-system (e.g. PACS photometer) will be scheduled in two consecutive ODs.

The satellite will execute autonomously the mission timeline that has been uplinked during the DTCP. The observational data will be stored on board, and downlinked to the New Norcia Ground Station (which is backed-up by the Cebreros Ground Station) during the next DTCP. In this period, which lasts approximately 3 hours, the status of the satellite will be monitored and operational or emergency procedures will be applied when necessary. In addition, the mission timeline with the commands to be executed during the next OD will be uplinked. This though is a rolling process. In case a DTCP communications linkage with the ground station is missed the satellite must always have two operational days of observations stored in the onboard computer. This means that the commands to be executed are always added to the end of the onboard file so that, in the case of a communications failure, there will always be sufficient commands on board to last until the end of the DTCP of the following OD.

The downlinked satellite telemetry will be transferred from the ground station to the MOC, where it will be consolidated and be made available to the HSC. The HSC will routinely retrieve the consolidated telemetry and auxiliary data from the MOC, and ingest them in the HSC database.

3.4. Data processing and products

All Herschel telemetry and auxiliary data will be automatically processed at the HSC with the Standard Product Generation software (SPG), to produce the observational data products. The following four levels of Herschel data products are defined:

- Level-0 data product: Raw telemetry data as measured by the instrument, minimally manipulated and ingested as Data Frames into the mission data base/archive.
- Level-1 data product: Detector readouts calibrated and converted to physical units, in principle instrument and observatory independent. It is expected that level-1 data processing can be performed without human intervention.
- Level- 2 data product: Level-1 data further processed to such a level that scientific analysis can be performed. For optimal results many of the processing steps involved to generate level-2 data may require human interaction, based both on instrument understanding as well as understanding of the scientific aims of the observation. These data products are at a publishable quality level and should be suitable for Virtual Observatory access.
- Level-3 data product: These are the publishable science products where level-2 data products are used as input. These products are not only from the specific instrument, but are usually combined with theoretical models, other observations, laboratory data, catalogues, etc. Their formats should be Virtual Observatory compatible and these data products should be suitable for Virtual Observatory access.

While the generation of level-0 and level-1 data products will be automatic, proper quality level-2 and level-3 data products may require interactive processing. It is expected that the degree of human intervention necessary to generate these products will decrease with time as the knowledge of the instruments' behaviour increases during the mission. This is the same as saying that the quality of the automatically generated product will be progressively enhanced. However, in many cases it will not be possible to discard interactive processing, especially in the derivation of level-3 data products.

In addition to these observational products, calibration, auxiliary and quality control products will be provided. For more information on the Herschel products, please see the corresponding Instrument Observer Users' Manual. The Herschel Products Definitions document and the Herschel Data Users' Manual document contain detailed descriptions of all Herschel data.

Herschel data products will be stored in the Herschel Science Archive. By using the Herschel Science Archive Browser, astronomers will be able to search, browse, select and retrieve data products according to the observations proprietary rights. The Herschel Science Archive will also act as a repository of highly processed data products provided by the astronomical community. When requesting observational data from the Herschel Science Archive, the user will be offered as options:

(i) to retrieve directly the stored products,

(ii) to request re-processing with the latest SPG version, and

(iii) to perform On-Demand processing of the selected observations. In the latter, the user customises the standard product generation by choosing values for given parameters that will depend on the type of observation (e.g. low flux observation data processing).

In addition to standard products, a Herschel Observer Interactive Analysis package will be offered to the astronomical community to interactively reduce the Herschel data (starting from level-0, -1 or -2 products), and to perform science analysis. The Herschel Interactive Analysis package does not require commercial licenses and is built to be platform-independent. The distribution will include source of software, calibration data and documentation. In addition, the astronomer will be able to develop and integrate his/her own data processing algorithms within the system.

3.5. Quality control

Observation quality control is an important responsibility of the HSC. Its main purpose is to ensure that the observations have been correctly executed, that their observational data meet the established requirements, and that they can be processed error free. It is important to note that the HSC will not assess systematically the scientific validity of individual observations, but will concentrate on their execution and the data processing aspects.

In combination with the SPG processing, the observational data will be run through the Quality Control Pipeline (QCP). An HSC operator will inspect visually all Herschel observations and will proceed according to agreed observatory procedures. For certain types of problems, the operator will request the assistance of the instrument and satellite specialists at the HSC, ICCs or MOC, who will investigate the reason for the anomaly, assess its impact on the quality of the observational data and determine possible implications for the ground segment. In severe cases, observations may be flagged as "bad" in the database, and made available for re-scheduling. For every observation, quality information will be gathered in a "quality control report summary" product, that will be available in the Herschel Science Archive in addition to the observational data. The report will contain both the automatically generated quality control data and the conclusions of the problem analysis by the experts, when applicable. Items that will be included in the report are: MOC spacecraft and operations information, on-board observation execution anomalies (instrument or satellite related), telemetry gaps, pointing issues, space weather events, instrument specific warnings (e.g., high glitch rate), and data processing problems.

3.6. Calibration observations

The calibration and cross-calibration of the Herschel instruments is the responsibility of the observatory, in particular of the ICCs and the HSC. The pointing calibration is the responsibility of the HSC and the MOC. Therefore, the preparation and scheduling of calibration observations is an exclusive duty of these groups. The calibration data required for the reduction and analysis of the Herschel observations will be provided to the astronomer in the form of products in the Herschel Science Archive, and will be integrated in the Data Processing software (SPG, QCP, IA).

Calibration and engineering observations will be the main components of the schedule during the Commissioning and Performance Verification phases. Their aim will be to achieve the necessary understanding of the instruments and spacecraft, and attain the required calibration and pointing accuracies to ensure a proper execution and data reduction of the science observations during the Science Demonstration and Routine phases. In the routine phase, it is expected that up to 15% of the available observatory time will be used for calibration. Calibration observations may be based on non-AOT observing modes defined by the instrument specialists at the ICCs and HSC, but in general they will be defined using the AOTs available to the community for science observations. Calibration observations are in principle public. However, if a calibration observation is a duplicate of a scientific observation (see the "Herschel Space Observatory Call for Proposals: Policies and Procedures" document for a definition of "duplication"), the corresponding proprietary rights will apply.

Chapter 4. Mission phases

4.1. Launch and Early Orbit Operations

The current baseline and thus orbit file in HSpot anticipates launch on 2008 July 31. After injection into the transfer trajectory towards the second Lagrangian point (L2) of the Sun-Earth system, Herschel and Plank will separate from the launcher and subsequently operate independently from Lissajous orbits of different amplitude around L2. The transfer to the operational orbit will last approximately 4 months; during this time there will probably be 3 navigational manoeuvres, two close to the launch (L+2 days and L+12 days), and the third close to the injection (10 days before). The Low Earth Orbit Phase (LEOP) can be considered to last until the first two trajectory corrections have been made. During these initial 2-3 weeks of spacecraft cooldown, the telescope will be heated to prevent from acting as a cold trap. The LEOP operations will be centred around the checkout of the spacecraft sub-systems and the navigation into the correct trajectory. Following the second navigation manoeuvre, the instruments will be switched on to start payload operations.

4.2. Commissioning Phase

Once Herschel has been successfully launched and injected into the transfer trajectory towards the operational orbit, the spacecraft and instrument commissioning phase will commence for a nominal period of one month. A significant part of the spacecraft commissioning will already be interleaved with LEOP. Prior to the first trajectory manoeuvre, basic properties of the satellite (centre of mass, moments of inertia) and proper functioning of basic spacecraft sub-systems (Radio Frequency (RF), thermal control, power sub-system, data handling, attitude and orbit control, thrusters, Solid State Recorders (SSR), etc.) will already have been established, at least to the extent that these subsystems are required for spacecraft operations.

Spacecraft commissioning will be completed alongside instrument commissioning, which will focus on switch on, functional checkout of the prime instrument sub-systems and their modes, plus observations to confirm the instrument/satellite system characteristics (e.g. instrument aperture pointing) after the cryostat lid is opened, approximately 6-8 weeks into the mission.

4.3. PV Phase

At this point, the calibration and performance verification (PV) phase will commence. The PV phase is intended to obtain in-flight characterisation of all instruments e.g. in terms of stability, sensitivity, resolution, timing and other calibration parameters. It includes the validation of the instrument observing modes and the calibration and data processing of the resulting data. To achieve this, a schedule of astronomical observations and internal calibrations, defined and iterated pre-launch covering a nominal period of 2 months will be executed using normal observatory procedures. This schedule will be based upon an agreed in-orbit calibration plan generated jointly by the ICCs and the HSC. The plan contains a description of all planned calibration activities and associated calibration sources (internal and astronomical) required to characterise fully each instrument.

4.4. Science demonstration

The PV phase will be followed immediately by the "science demonstration phase". Over the course of one month the observing capabilities of Herschel will be pushed to their limits in selected areas of the observation capability phase space, to evaluate and optimise the observation strategies. This will be used to decide how to perform "Key Project" observations in the optimum manner, to demonstrate the capabilities of the Herschel Space Observatory to the astronomical community and also for public relations purposes.

4.5. Routine operations

Once the goals of the PV and science demonstration phases have been met, Herschel will go into the routine science operations phase for a minimum of 3 years. Early on, mainly Guaranteed Time and "Key Project" observing programmes will be performed. Key Projects will be performed early in the mission to permit follow-up and to give the Guaranteed Time holders at the HSC the opportunity to obtain real data to work with, in preparation for supplying community support to the open time observers with the benefit of a thorough knowledge of the entire observing chain from proposal submission to access and reduction of data.

All observers will be able to track the whereabouts of their proposals and will be notified when the resulting data can be accessed.

Table 4.1. Herschel mission key dates.

Mission phase	Start	End
Launch	L=31 July 2008	
Early Orbit Phase	L	L+12 days
Commissioning Phase(1 month)	L	L+1 month
Performance Verification Phase (2 months)	L+1.5	L+3.5 months
Science Demonstration Phase (2.5 months)	L+3.5	L+6 months
Herschel Routine Phase	L+6 months	L+40 months (baseline estimate); Boil-off = B
Run-down phase (3 months)	B	B+3 months
Mission consolidation phase (6 months)	B+3 months	B+9 months
Active archive phase (48 months)	B+9 months	B+57 months
Archive consolidation phase (6 months)	B+57 months	B+63 months (End of Herschel mission)
Historical archive phase (indefinite)	B+63 months	(TBD) End of all Herschel activity

4.6. Post-Operations Phase

The Herschel post-operations phase will consist of the rundown monitoring phase (starting at the moment of helium boil-off), mission consolidation phase, active archive phase, and the archive consolidation phase (at which point the transfer to the subsequent historical archive phase takes place), which is the final formal phase of the mission.

The goal of this phase is, within the constraints of time and available resources, to maximise the scientific return from the Herschel mission by facilitating continuing widespread effective and extensive exploitation of the Herschel data. This will continue after the conclusion of this phase (i.e. in the historical archive phase).

The ultimate legacy of Herschel will be the historical archive, plus the sum of all the knowledge, both scientific and technical, derived from implementing and operating Herschel.

4.7. Archive Phase

The historical archive phase is outside the funded Herschel mission. This phase commences after the end of the post-operations phase.

The historical archive will provide access to all Herschel observations and derived products. The products will all be derived in the archive consolidation phase during the post-operations phase in a consistent manner and to consistent standards using the best knowledge of Herschel instrument calibration and data processing. In addition, the software, documentation - manuals, etc.- and tools will be available from the historical archive.

Chapter 5. Overview of scientific capabilities

Herschel is a versatile observatory with a wide range of capabilities that cover point-source photometry, imaging, large area mapping and spectroscopy at both intermediate and high resolution. Despite the relatively small size of far-IR detectors compared to their visible and near-IR equivalents, it will be able to map large areas of sky efficiently to faint limits. The telescope is designed to give diffraction-limited images - resolution 6 arcseconds - at 90 microns.

5.1. General aspects

The Herschel Space Observatory will cover the wavelength range from 55 - 670 microns. This corresponds to the maximum of emission for black bodies in the range from 5-50K approximately. Hence Herschel will be best suited to observing icy outer solar system objects and cool and cold dust in the universe, both in the rest frame and redshifted. A prime objective will be to study the formation of galaxies in the early universe as cool dust is an excellent tracer of star formation. The Herschel range is also the one at which cool and cold gases emit their strongest lines, meaning that Herschel will also be a superb laboratory for examining the chemistry of planetary atmospheres and of the interstellar medium.

The Herschel Focal Plane is shown in Figure 5.1. The different instrument arrays and apertures are labelled. The full, unvignetted field of view is approximately half a degree.

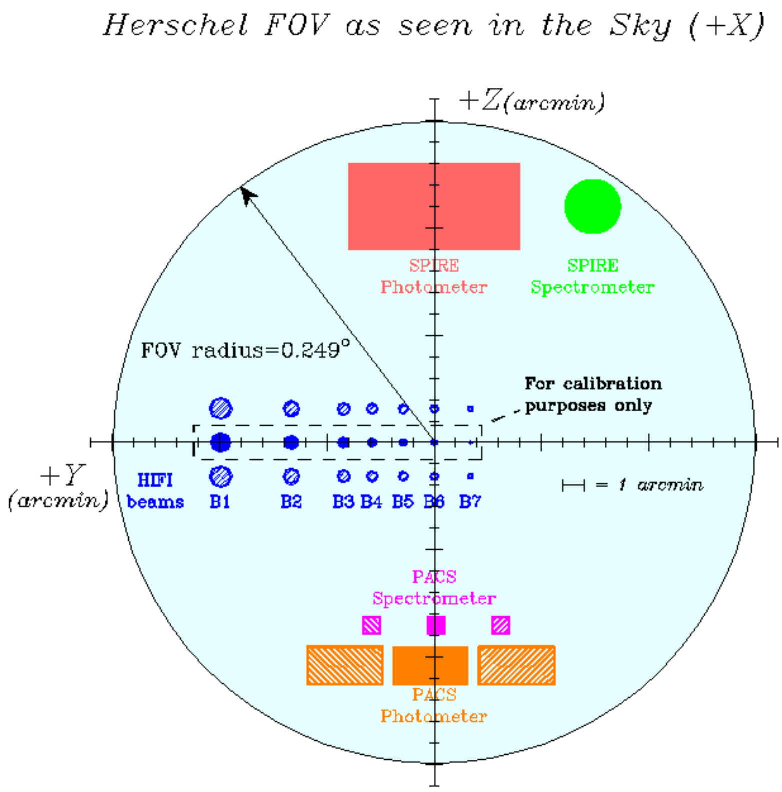

Figure 5.1. The Herschel Focal Plane.

5.2. Photometry with Herschel

5.2.1. Instrument capabilities

The full wavelength range of Herschel will be covered by six broadband ($\Delta\lambda/\lambda$=3) filters. In SPIRE, all three filters (250, 350 and 500 µm) will be imaged simultaneously on three spiderweb bolometer arrays. PACS users will be able to image with a "red" (130-210 µm) and "blue" (either 60-85 or 85-130 µm) filter simultaneously on two bolometer arrays. This makes Herschel a superb instrument for multicolour surveys. It is anticipated that both PACS and SPIRE will be able to image approximately half a square degree per day to the extragalactic confusion limit and, of course, much larger areas of the sky to a lesser sensitivity.

The main imaging capabilities are summarised in Table 5.1. As dust is a strong tracer of star formation, one of Herschel's greatest strengths will be the possibility of studying the history of star formation in the universe. By combining PACS and SPIRE data, users will be able to follow the dust emission signature of starbursts redshifted to increasing wavelengths in ever more distant galaxies. This will make Herschel an enormously powerful facility for studying the formation and evolution of galaxies.

Observations with Herschel will give a new insight into the process of star and planet formation. Observations with Herschel will be able to study both the processes of star formation in molecular clouds and the debris disks that are the tracer of planetary system formation in young stars. To date, few debris disks are known and observations with Herschel, with its wide wavelength coverage, will allow many more to be detected and studied. Similarly, Herschel observations will be valuable in the study of the later phases of stellar evolution, particularly circumstellar shells, mass-loss in general and stellar winds.

Finally, Herschel will be a powerful tool for studying the physics of the more distant and colder objects of the solar system: such as cometary nuclei and cometary atmospheres. Herschel observations will permit the albedos and thus the surface conditions and diameters of these bodies to be measured with great precision.

Table 5.1. The main imaging capabilities of PACS and SPIRE. Please note that the wavelength range of detector sensitivity is approximate and the instrument sensitivities depend on the observing mode, so the values given are only orientative: please consult the relevant observing manual for more detailed values.

	PACS	SPIRE
Wavelength range	60-210 µm	200-670 µm
Field of view	1.75x3.5'	4x8'
Pixel size	3".2 (60-130 µm), 6".4 (130-210 µm)	18" (250 µm), 25" (350 µm), 36" (500 µm)
Typical sensitivity (5σ/1hr, point source)	2.5 mJy (blue and green bands), 3.5 mJy (red band)	3.5 mJy
Confusion limit (approx)	0.1 mJy (70 µm), 1 mJy (100 µm), 5 mJy (160 µm)	10 mJy (200 µm), 20 mJy (670 µm)
Filters	60-85 or 85-130 µm and 130-210 µm (simultaneous)	250, 350 and 500 µm (simultaneous)

5.2.2. Using SPIRE and PACS in parallel

Herschel offers a parallel mode for users who wish to carry out large-scale mapping programmes with a wide range of wavelength coverage.

5.2.2.1. The benefits of using parallel mode

Parallel mode allows observers to use both SPIRE and PACS simultaneously in a fast (60 arcsec/s) and slow-speed (20 arcsec/s)scanning mode to cover very large areas of sky quickly in all three

SPIRE bands and in two of the three PACS bands, to a modest sensitivity. This mode is intended to make ambitious, multi-band, large area mapping programmes more efficient than carrying them out individually with each instrument in turn.

5.2.2.2. The limitations of using parallel mode

SPIRE and PACS point at different places on the sky separated by 21 arcminutes. This means that this mode is extremely inefficient at mapping small areas of sky. Although a minimum area of 30x30 arcminutes is permitted, alternatives should certainly be considered for any area of sky smaller than one square degree and possibly even for larger areas than this. A second potential drawback is that parallel mode data may require a special calibration regime to be used, both to obtain precise absolute spatial coordinates of detected sources and to obtain the highest quality of flux calibration.

5.3. Spectroscopy with Herschel

Herschel offers two types of spectroscopic capability. PACS and SPIRE offer low to intermediate resolution spectroscopy covering the full Herschel wavelength range. HIFI offers high-resolution spectroscopy over the range from 240-625 μm (480-1910GHz) using heterodyne techniques. Users will thus be able to select a wide range of resolutions from $\Delta\lambda/\lambda$=100 to $\Delta\lambda/\lambda$=10 000 000 according to the brightness of their source and the science that is required. The main spectroscopic capabilities are summarised in Table 5.2.

In its highest resolution mode Herschel will offer a velocity resolution as high as 0.3km/s. The wavelength range covered by Herschel has many thousands of lines of water, atomic transitions and organic molecules. This will allow Herschel to study the chemistry of the interstellar medium, tracing water and organic molecules in molecular clouds. Herschel will also be able to study the chemistry of solar system bodies such as atmosphere of Mars and the comas of comets.

All three instruments have a mapping capability in spectroscopic mode, even though HIFI's is somewhat limited, although by no means negated, by the fact that its detector has only a single pixel. The PACS and HIFI can scan the detectors across the sky, accumulating spectroscopic data along the length of the scan (SPIRE does not have this capability as taking a SPIRE spectral scan takes a finite amount of time, so spectroscopy cannot be taken "on the fly"). All three instruments can make a raster map in spectroscopic mode. This allows a spectroscopic survey to be made either of a region that has been mapped in imaging mode, such as a cluster of galaxies, or across a known extended source such as a molecular cloud.

Table 5.2. The main spectroscopic capabilities of PACS, SPIRE and HIFI. For more details please check the relevant instrument manual.

	PACS	SPIRE	HIFI
Wavelength range	55-210 μm	194-672 μm	157-213 and 240-625 μm (with gap)
Field of view	47x47"	2.0' (unvignetted)	Single pixel (see below)
Pixel size	9"	16", 34"	39" (488GHz), 13" (1408GHz)
Sensitivity (5σ/1hr, point source)	$2x10^{-18}$ Wm^{-2} (130 μm, 1st order), $5x10^{-18}$ (70 μm, 3rd order). Continuum: 100 mJy (1st order), 250 mJy (3rd order)	$2.8x10^{-17}$ Wm^{-2} (250 μm, low resolution), $3.3x10^{-17}$ Wm^{-2} (500 μm, low resolution)	TBD (see below)
Resolution	900-2100 (1st order, 102-210 μm), 1800-3000 (2nd order, 72-98 μm), 2600-5400 (3rd order, 55-72 μm)	40-1000	$1000-10^7$

Note

For the latest information on instrument sensitivities please check the Herschel website at http://herschel.esac.esa.int/.

Note also that the PACS sensitivity below 57 microns is very low, although HSpot permits the entry of line observations at shorter wavelengths.

Chapter 6. Observing with Herschel

Herschel is an observatory mission. Thus, as in ground-based telescopes, the astronomer who is requesting the observations must provide all the information necessary to carry them out. These instructions are known as an "Astronomical Observation Request" (AOR), which is made using a standard Astronomical Observing Template (AOT) (see Section 6.3). This information is then converted into spacecraft and instrument commands that are uplinked to the spacecraft to execute the observations. The system is designed to make the process of defining observations as simple as possible for the observer. The following section describes this process.

6.1. Introduction to HSpot

The astronomer's interface with Herschel is an observation planning program called HSpot. HSpot allows the astronomer to define targets and observations, to calculate the time required and likely s/n and to submit a proposal with the requested observations. At any stage of this process the work in progress can be saved and recovered later. HSpot has been adapted from the original Spitzer Space Observatory SPOT program and thus will be familiar to Spitzer users.

HSpot can be downloaded from the Herschel Science Centre web page at the url:

http://herschel.esac.esa.int/

HSpot is eminently user-friendly and simple to use. New users can generally familiarise themselves with the main functions in an hour or so of simply playing with the program.

6.1.1. Will HSpot run on my computer?

HSpot has been developed to run on the three main operating systems currently in use: Unix/Linux, Windows and Mac. The development work has been carried out on Solaris and ported to these operating systems and the system has been extensively tested. We thus believe that HSpot should run reliably on all the principal operating systems available to users. For each operating system certain common platforms are supported. Users are strongly urged to use these standard combinations of operating system and platform, as no guarantee can be offered that HSpot will run correctly on other combinations and no guarantee can be made of support for other platforms. Similarly, users will understand that, for example, the Windows version of HSpot has been extensively tested on Windows XP - it is assumed that HSpot will work correctly on earlier versions of Windows too, but the testing on earlier versions, such as Windows95, has been necessarily less extensive. No testing will be done on Windows Vista until after the initial call for proposals has been announced, but we do not anticipate problems with its use. Detailed information on the operating systems and platforms supported can be found in the HSpot manual. HSpot runs under Java and users are strongly advised to ensure that all updates and patches of their operating system are installed. Updates to HSpot may be released from time to time as new information becomes available on instrument or observatory performance, or upgrades are required; HSpot will download and install these automatically (*strongly advised*) and warn the user when a new version of the program is available, unless the user specifically turns off this capability.

6.1.2. Proposal presentation

Proposal presentation is extremely simple with HSpot. Once the observations to be carried out are defined and saved, the proposal can be submitted quickly and easily from the "Tools" menu. A submitted proposal can still be retrieved before the deadline for submission and revised, if necessary and as many times as necessary. To submit a proposal, apart from the AORs (that is, the source information, instrumental configuration, exposure time, etc. for each object to be observed) the proposer needs a text file with the proposal abstract (maximum 2000 characters including spaces), which can be read in directly, a PDF file of the scientific justification (limited to a maximum of 5Mbt and prepared with the HerschelFORM PDFLatex package that is available on the Herschel Science Center webpage) and to give basic information such as the proposal title, list of co-Is and the observing call that the proposal is responding to. When a proposal has been submitted HSpot will confirm that it has been received correctly.

6.2. Types of target

HSpot deals with two fundamental types of target: fixed targets and solar system objects.

6.2.1. Fixed targets

A fixed target is any object that does not require a differential tracking rate. This can be a star, a galaxy, an AGN, etc. Herschel works with Equatorial J2000 coordinates and only target entry in Equatorial J2000 will be accepted (this is to facilitate checks for duplicate pointings, which are extremely complicated if many coordinate systems are used for target entry). If the source is known to NED or SIMBAD these coordinates are used, if not, the user must enter a J2000 R.A. and Dec. On some occasions the proper motion of the target may become important; this can be entered in HSpot if necessary, once again, the epoch must be in 2000 coordinates. All fields can be edited after name resolution.

6.2.2. Moving targets

A moving target is a solar system object that requires a differential tracking rate to be programmed. On target entry the user should select the "Moving" tab and resolve the NAIF ID of the target name. The Herschel Observations Planning System will use the NAIF ID to calculate coordinates for the time of observation and to calculate the differential tracking rate required, which should be less than 10 arcsec/minute at the date of observation (this limits the capability of Herschel to see objects passing very close to the Earth, although faster rates up to 30 arcsec/min may be permitted if scientifically justified). User entry of target coordinates is not permitted as any solar system object with a reliable enough orbit to be observed by Herschel will have a NAIF ID.

6.2.2.1. What is a NAIF ID?

NAIF is NASA's Navigation and Ancilliary Information Facility. This offers an information system called SPICE for spacecraft navigation. SPICE uses a unique 7 digit identification code for all natural solar system bodies, while spacecraft are identified with a negative integer code. Because of the simplicity for this system of ID codes and given the increasing possibility of confusion of objects (for example, there are both planetary satellites and asteroids named Io, Ganymede and Dione and increasing numbers of asteroids are later found to show cometary activity and may receive multiple designations) it is increasingly used for telescope scheduling. A short summary of NAIF IDs is given in the relevant secion of the HSpot Users' Manual on the Standard Ephemeris for moving target entry.

6.2.2.2. Solar system object ephemeris accuracy

When a Solar System Object has a well-controlled orbit of high accuracy (for a periodic comet this means two returns for which a successful linkage has been made, for a asteroid or minor body it usually means observations at a minimum of 6 or 7 oppositions, apart from Earth-crossing objects for which the criterion is typically 3) it will receive a number from the Minor Planet Center. A numbered comet has a designation such as 190P/Name, while an asteroid receives just a number. An unnumbered asteroid has a NAIF ID starting with a 3. Objects with such a designation have a relatively low accuracy ephemeris that may be considerably in error when extrapolated to the future. As an example, even an object with three oppositions may have a position that has a 3# error of more than 60 arcseconds when extrapolated 5 years into the future. If the spread of observations is unfavourable, or there are few astrometric observations, it may not even be possible to obtain a good ephemeris extrapolation with a 3-opposition orbit. With 4 oppositions the 3# error in the extrapolated position may still be greater than 20 arcseconds over 4 years. This means that faint objects that have not been observed recently may be difficult to locate and identify with Herschel and thus are high risk observations.

6.2.2.3. What accuracy of ephemeris is required?

Three problems are present when there is uncertainty in the ephemeris. In approximate order of importance these are:

In general the tracking errors should be kept below 1 arcsecond during the observation. In general this should not be a problem with distant objects, it may become a serious problem with more nearby ones.

For PACS photometry, the source position must be known with high enough precision that it should fall within a bolometer matrix of 52x52 arcseconds. In practical terms this means that the following two criteria of positional accuracy should be fulfilled:

- For aperture photometry: 15 arcseconds
- For PSF fitting: < 10 arcseconds

For HIFI it should be remembered that the smallest aperture is 13 arcseconds, thus necesitating centring at the arcsecond level to avoid light losses.

For SPIRE the main consideration is that the FWHM of the detectors is 18 arcseconds and the jiggle amplitude 6 arcseconds: if the positional error is greater than the jiggle amplitude there will be light losses.

- Possible errors in the required tracking rate.
- Difficulties with photometry

In the HSpot Users' Manual a list of solar system objects included HSpot is given in which flags objects with deficient ephemerides.

- For numbered asteroids the ephemeris should be of sufficient precision in all cases.
- For unnumbered asteroids and minor bodies it may be essential to take astrometry to refine the orbit before observations can be attempted with Herschel.
- For numbered and ToO comets recent astrometry may be essential, depending on the case. A numbered comet will almost invariably require post-recovery astrometry to refine the orbit before observation can be attempted. Recently discovered comets with a short orbital arc will also almost invariably require pre-Herschel observation astrometry to refine their ephemeris.

6.3. AOT entry

An AOT is an "Astronomical Observation Template". This will be familiar to users of ISO and Spitzer. An AOT is a standard observing mode with an instrument that can be translated into instructions for the spacecraft to carry out the observations autonomously. Herschel will observe autonomously between DTCPs, so each observation must be carried out in a standard way that the spacecraft can understand. Thus, for each of the instruments only pre-defined types of observations can be carried out. The astronomer produces an AOR (Astronomical Observing Request) by taking an AOT and customising it for the required observations.

Following the experience of ISO, the number of AOTs has been deliberately restricted to allow observers as many options as possible, without requiring an unwieldy number of observing modes to be calibrated.

The first stage in AOR entry is to define the target. If it is a known object its name can be resolved with SIMBAD or with NED or, for a solar system target, as a NAIF ID. For unknown names (e.g. start points for scans), J2000 coordinates must be supplied by the observer. After defining the object, the observer should check that it is observable by Herschel by calculating its visibility windows.

Once the target is defined the observer must then select the required instrument and AOT to be used.

Nine basic observing modes are supported: for HIFI, single point (point source photometry), mapping and spectral scans; for PACS, photometry, line spectroscopy and range spectroscopy; for SPIRE, SPIRE photometer and spectrometer; and the SPIRE PACS parallel mode. Each of these modes is further subdivided, HIFI, for example, offers a choice of eight different mixer bands. PACS photometry allows five variants including point-source photometry and chopped raster maps. SPIRE Spectrometer offers point source and raster maps, three choices of image sampling, and four choices of spectral resolution, etc. HSpot will guide you through this process of definition with a series of pull-down menus and pop-up windows.

For each observation there is a basic minimum unit of observing time required; the observer need only specify how many repetitions of this unit time are required -- obviously greater sensitivity is obtained through more repetitions (four integrations will give twice the sensitivity of a single one), but the observation takes longer. At any time the "Observation Est..." (Observation Estimate) button can be pressed and HSpot will give an estimate of the total time that the observation will take, including the overheads involved, with a break-down of information about the observation. If the total length of the observation exceeds the maximum permitted, HSpot will give a warning that the observation duration is out of limits.

The observer can vary the parameters of the observation (more or fewer repetitions, nodding on or off, larger or smaller chopper throw, a wider or narrower range of wavelengths or length of scan, etc.) and see how the time estimate varies. Once an acceptable combination of parameters has been found the observer accepts the parameters that are defined to fix the AOR; this AOR can however be modified later, if necessary.

When a proposal is submitted, HSpot takes the currently defined list of AORs and links them to the proposal. It is thus essential to ensure that the correct AOTs and AORs are defined and that the source visibility and observing time are correct for each target.

6.4. Constraints on observations

HSpot allows the observer to define many different kinds of constraints on observations. This may be to observe an object at a certain time, to carry out observations in a certain sequence, or with a certain detector orientation, or to repeat observations at a certain interval. However, observers should be wary of overconstraining their observations and of defining constraints that are not strictly necessary, as each constraint that is added makes an observation more difficult to schedule.

Warning
Overconstrained observations may be impossible to schedule.

6.4.1. Chopper avoidance angles

In all chopped observations there is a certain danger that a nearby bright source could lie in the chop position, which is at 90 degrees to the position angle reported by HSpot. HSpot allows chopper avoidance angles to be defined. If, even when the chopper throw is changed, it is impossible to avoid a nearby bright object then defining a chopper avoidance angle should be considered. A chopper avoidance angle tells the observation planning system that the observation should be scheduled in such a way that the chopper will not chop at this range of angles. This however should be done with great caution as a star that looks bright in a DSS or 2MASS image is unlikely to be bright, even at the shortest Herschel wavelengths. A chopper avoidance angle is only necessary when there is a strong far-IR source present in the reference position.

Over the year the apparent rotation of the sky makes the position angle of the chopper on the sky change (this is the roll angle of the spacecraft, measured from north through east, using the spacecraft z-axis as reference - the z-axis is perpendicular to the orientation of the long axis of the PACS and SPIRE arrays). In other words, by selecting a chopper angle constraint we are effectively placing a timing constraint on our observations, stating that it may not be made at certain times of year. However, the Position Angle calculated in has a strong ecliptic latitude dependence. For sources in the ecliptic the Position Angle will barely vary with time during a visibility window. For the two observing windows available each year two values differing by exactly 180 degrees will be found (Figure 6.1). In these cases defining a chopper avoidance angle is, at best, irrelevant (as the PA will only vary in a range of a few degrees anyway) and, at worst, catastrophic because it is may make all observations totally impossible, with no part of the visibility window permitted.

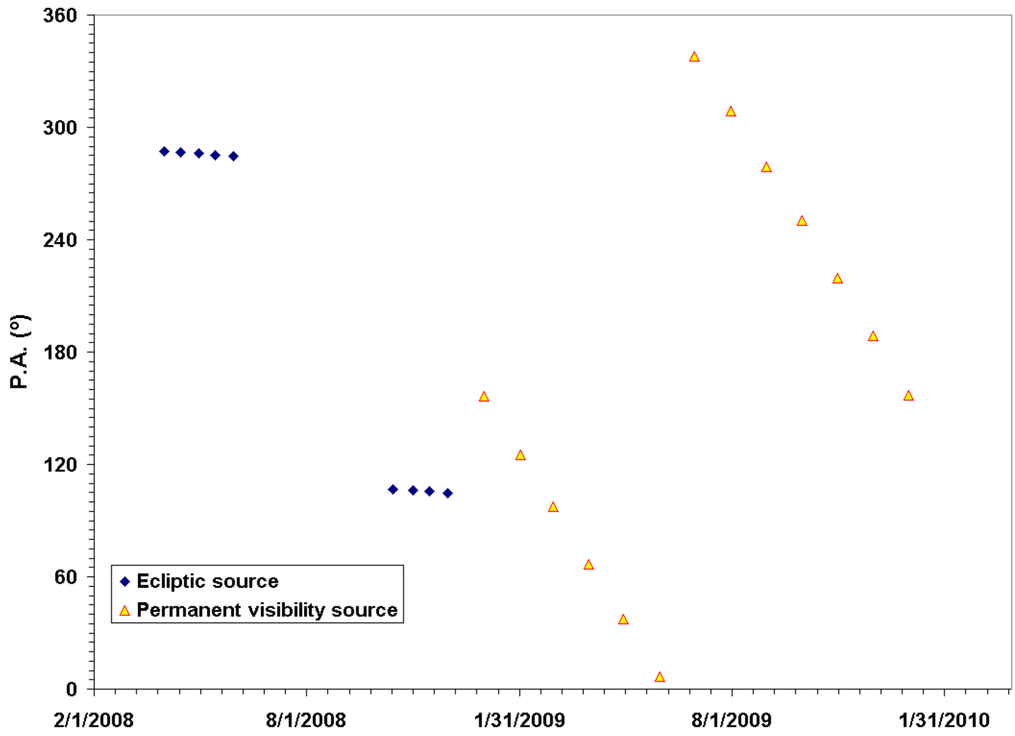

Figure 6.1. Position angle variation for sources on the ecliptic and at the ecliptic pole, in the zone of permanent sky visibility. For sources at intermediate ecliptic latitude the annual range of variation of PA will be between these two extremes.

Note

Understanding chopper avoidance angles

HSpot reports the spacecraft roll angle for any particular date of observation. The chop angle will be perpendicular to this angle. If, when you visualise an AOR, you find a bright source in your reference position, you must ADD 90 degrees to the PA in HSpot to avoid a position in the chopper off position. If you have a source in the nod off position you must SUBTRACT 90 degrees to the PA reported in HSpot.

At high ecliptic latitude we have a zone of permanent sky visibility and the PA of the chopper rotates rapidly with time. Here, even a quite wide chopper avoidance angle range may equate to only a relatively small effective restriction on dates. Figure 6.1 shows how the PA changes for a source almost at the ecliptic pole, which is within the permanent sky visibility zone.

At intermediate ecliptic latitudes there will be a break in the visibility windows, although this may be small. When the instrument +Z-axis crosses celestial north there will be a discontinuity in the PA value. Observers should take care of this when defining chopper avoidance angles for sources that are close to +60 degrees ecliptic latitude. A practical example of this is shown for PACS in Figure 6.2 for an object at an ecliptic latitude of 59.5 degrees, close to the point at which there is continuous visibility, but where there is are still two annual visibility windows with a short gap between them. PA=000 degrees is shown (the horizontal position), along with the plotted positions of the PACS imaging detectors are for a hypothetical case with 2008 March 31st (start of visibility window) PA=127.4 degrees, 2008 June 15th (mid-window) PA=054.6 degrees, 2008 September 10th (end of visibility window) PA=333.7 degrees.

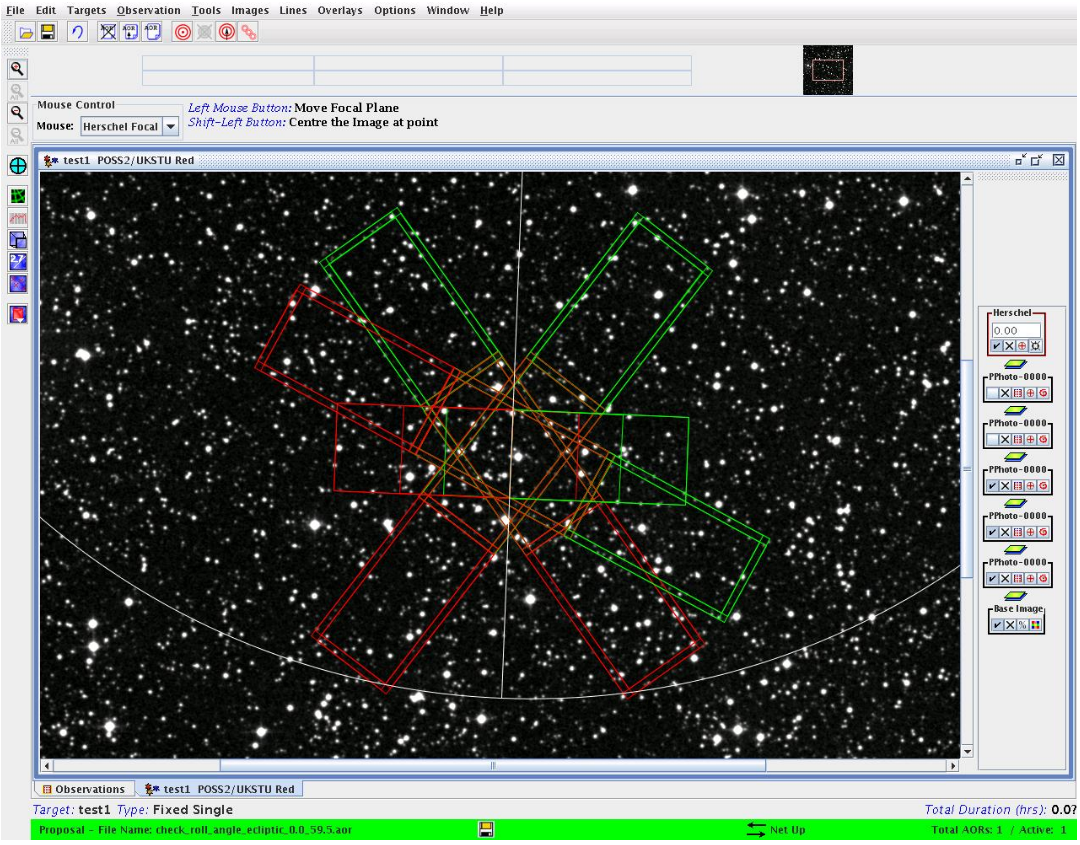

Figure 6.2. An illustrative example. The position angle variation for PACS for an object at an ecliptic latitude of 59.5 degrees, close to the point of permanent visibility. The horizontal position is PA=000 degrees. The plotted positions of the PACS imaging detectors are for a hypothetical case with 2008 March 31st (start of visibility window) PA=127.4 degrees, 2008 June 15th (mid-window) PA=054.6 degrees, 2008 September 10th (end of visibility window) PA=333.7 degrees. The situation is effectively identical for other dates.

> **Warning**
>
> Close to the ecliptic even a small range of chopper avoidance angle may equate to a huge scheduling restriction, potentially making observations impossible to schedule. However, given the very small range of Position Angle change close to the ecliptic, any chopper avoidance angle will either be irrelevant (the PA will never be within the defined avoidance), or catastrophic (the avoidance angle range makes the observation impossible by definition by covering the entire range of PA change).
>
> At high ecliptic latitude it is easier for telescope scheduling to take a chopper avoidance into account.
>
> However, at high ecliptic latitude the chopper PA will often rotate through 360 degrees giving a dephase that must be taken into account when defining a chopper avoidance angle.
>
> In all cases an observer should consider very carefully if defining a chopper avoidance angle is really, genuinely necessary.
>
> All constraints on observations imply an increased observing overhead and thus decreased observing efficiency.

6.4.1.1. Map orientation constraints

PACS and SPIRE offer the possibility to define a map orientation constraint. In other words, the telescope should scan in a certain direction only, or within a certain range of directions. Further details of such orientation constraints and their limitations can be found in the relevant instrument manual.

Warning
An map orientation constraint equates to a telescope scheduling restriction and implies that an observation may only be made at a certain, limited range of dates, thus making their execution more problematic. Over-restricting observations may mean that for operational reasons it becomes impossible to carry them out.

6.4.2. Fixed time observations

In certain cases there may be a strong scientific reason for requesting that an observation be carried out at a fixed time. A flag can be put in the AOR defining that the observation be carried out at a set time defined by the astronomer. This obliges the observation planning system to block the observation at this date and time, usually to within a few seconds, although at the cost of putting severe constraints on telescope scheduling, particularly as instruments have to be blocked by days.

A less constraining way of fixing the time is to define a timing window during which the observation should be carried out. A range of dates may be defined during which the observation must be made. This gives the observation planning system more liberty to work around the constraint.

6.4.3. Concatenation of observations

Concatenation or chaining of observations may be defined to oblige the observation planning system to carry out observations together. This may be important in the case of a variable object where it is essential that two or more observations are carried out as close to each other in time as possible (an example of such a case might be the need to obtain photometry with PACS at 60-85µm, 85-130µm and 130-210µm, requiring two AORs to be defined that might otherwise be carried out on different days).

Five methods of chaining of observations are, in principle, permitted, although not all will be implemented at AO:

- Concatenation of observations

  Two or more AORs for the same target are linked together (concatenated). These must use the same instrument and the same observation type (i.e. you cannot combine PACS and HIFI spectroscopy in a single chain, nor can you combine SPIRE photometry and spectroscopy in a single chain, nor SPIRE PACS parallel mode with any other PACS, SPIRE or HIFI mode). At present HSpot does not permit observations in different HIFI bands to be chained either. You can mix a SPIRE photometry map and point source photometry. The mission planning system will treat these observations as a single pointing. If it is important for observations to be carried out together they should be chained.

  Targets must be separated by no more than 1 degree to be chained. Fixed and moving targets can be chained, although it is the observer's responsability to ensure that they will be less than 1 degree apart at some point during the missiona nd thus that the observation is schedulable.

  As many chains as are required may be defined and as many observations as are required may be put in each chain, but the total observing time requested in each chain must be less than 18 hours.

  The great advantage for the observer, apart from ensuring that observations are carried out together, is to avoid the need for a slew between integrations, thus saving a 180 or 600s slew overhead.

- Follow-up observations

  This mode is for repeat observations, for example of a variable source. A time between repeat observations can be defined. Chained observations can be sequenced so that the entire chain is repeated after a number of hours or days. The chain or sequence can be repeated several times if monitoring is required over a period of time.

> **Warning**
> The observer can request that a sequence be carried out with a very exact interval, or within a band of time (e.g. each observation should be within 8 and 12 days of the previous one). The stricter the constraint, the more difficult it will be to accommodate the observations in the observing schedule, to the point that highly constrained observations may be impossible to carry out.

- Sequencing

  This mode is to carry out observations in a particular order, although not necessarily the same day. This may be necessary when two or more measurements are required and it is essential that one be carried out first to allow the other observations to be reduced when carried out.

- Group within

  In this mode observations must be carried out in a certain time frame, but with no restraint as to *when*. An observer can specify that all the observations in the group should be carried out within a maximum of, for example, one month; in this case the observatory planning system will complete all the AORs within a month of carrying out the first one. The observations may be carried out in any order within this time interval.

- Shadow observations

  This mode is designed for solar system objects. In it, a second, identical observation, is carried out a certain amount of time before or after. The effect of this is to take an observation of a field before or after a solar system object has passed through it to allow the background to be measured exactly.

> **Warning**
> This option will not be implemented at AO in June 2007. The shadow target option will be available at a later date. Please contact Helpdesk (http://herschel.esac.esa.int/) for specific enquiries about this topic.

6.5. Limiting length of observations

6.5.1. Fixed targets

There are a series of fundamental constraints on the length of observations with Herschel. There is an operational constraint that the coolers on PACS and SPIRE must be recycled for 2 hours every 48 hours. However, in practice, the limit will be imposed by the need to have a 3-hour daily telecommunications period (DTCP) with the ground station to download data and upload instructions. It is likely that this will be combined with routine housekeeping operations that cannot be carried out during the DTCP [due to the strict limitations on spacecraft pointing caused by the requirement that the antenna point very exactly towards the Earth], such as astronomical calibration observations.

Thus, it is assumed that, in practice, there will be a limit of 18 hours to individual observations with Herschel. Observers who wish to take longer observations than this must split their AOTs into shorter segments. Special care should be taken when requesting observations close to the 18 hour limit that they will remain possible even if sensitivities are found to be lower or overhead longer than expected when in flight. Note also that long AOTs do impose strong constraints on mission planning and may be difficult to accommodate in the telescope schedule. However, the telescope can only stare at a single point in space for 50000s (13.9 hours) thus, for a photometric deep integration on a fixed target the maximum AOR length is significantly shorter than 18 hours.

6.5.2. Moving targets

Moving targets must be dealt with in mission planning in a different way to fixed targets, as the spacecraft must calculate an instantaneous position and track on it, rather than on the stars. This requires the mission planning software to interpolate the position of the object at any moment from the Chebyshev Polynomials that define the target's ephemeris. At present it is thought that this process may not be valid for integrations longer than 5 hours and that tracking accuracy cannot be guaranteed for longer moving target AORs, thus a limit of 5 hours is placed on the observation of solar system objects.

6.6. Observing overheads

Each observation that is made with Herschel implies certain overheads. These are detailed in the time estimation breakdown and are charged against the observation. The onus is thus on the observer to make observations as efficient as possible so that precious observing time is not wasted on unnecessary overheads.

6.6.1. Telescope slew time

Herschel takes a certain amount of time to slew between targets. The median slew time is expected to be of the order of three minutes (although this will depend critically on the density of targets in the sky), thus all unconstrained observations will be charged 180s as observatory overhead for slewing the telescope (for constrained observations a 600s slew overhead is applied - see Section 6.6.4). It is possible that at a later date the 180s median slew overhead will change as the observing database is filled and knowledge of source distribution on the sky becomes better. For concatenated observations on the same target a zero telescope slew overhead is applied.

6.6.2. Scans and rasters

When making maps there are certain overheads implicit in the process.

6.6.2.1. Raster maps

In a raster map the telescope must make a slew, stop and wait for the pointing to be stabilised. Due to the satellite's large moment of inertia the process of acceleration, deceleration and stabilisation adds a significant dead time (of the order of 15s) to the measurement in each position.

6.6.2.2. Scan maps

Scan maps are generally more efficient and add less overhead to an observation than a raster map. In this case the overhead is the acceleration at the start of a scan and the deceleration at the end of the scan. The telescope then makes a small slew to the start position for the return scan.

6.6.3. Internal calibration

Each observation requires an internal calibration against black body sources maintained at rigidly controlled temperature. These measurements are essential to the health and success of all observations and are thus charged against the observation. The calibration time is typically in the range 30-300s according to the AOT used.

If the calibration time is less than the slew overhead, it is not charged to the user as an overhead as the calibration is carried out in its entireity during the slew; when this calibration time excedes the slew overhead that has been applied, the excess is charged as an overhead to the astronomer.

6.6.4. Constrained observations

Constrained observations (see Section 6.4) limit the telescope scheduling and limit observing efficiency producing hidden overheads, thus a flat rate of 600s will be charged on all constrained observations in addition to other observational overheads.

If a constrained observation is concatenated, the 600s overhead is applied only to the first observation.

For a fuller definition of what constitutes a constrained observation that will be charged a 600s overhead, please see the (Policies and procedures) document.

6.7. Details to take into account in the observation of moving targets

6.7.1. Background and PA variations

For all targets the main components of background are the zodiacal light (at short wavelengths) and the Interstellar Medium (ISM) at longer wavelengths. For a fixed target the ISM will have a fixed value at any wavelength, being highest for targets in the Galactic Plane and the zodiacal light will vary with ecliptic latitude and solar elongation. For a moving target the ISM background will, logically, vary with time, although these variations will be a function of the object's heliocentric and geocentric distance - for distant planets the time variations will be slow.

As an example, the following shows how the PA (Figure 6.3) and the estimated background at 80 microns (Figure 6.4) vary through a visibility window for the satellite Triton of Neptune (NAIF ID 801). At this wavelength the zodiacal light dominates and increases as the solar elongation decreases. Note too how the PA barely changes over the duration of an observing window; this has strong implications for any potentially constrained observations.

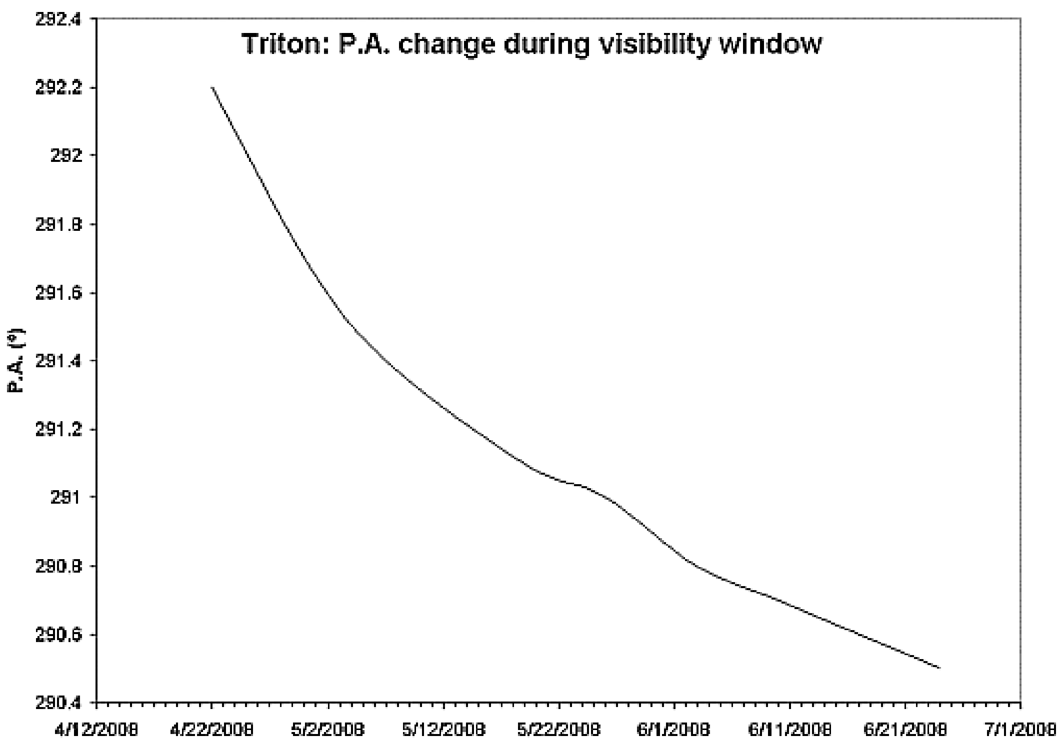

Figure 6.3. PA variation for a typical solar system object: Neptune's satellite Triton. Note how the PA variations over the course of a full observing window amount to less than 2 degrees. This makes it effectively impossible to accomodate map orientation or chopper angle avoidance constraints.

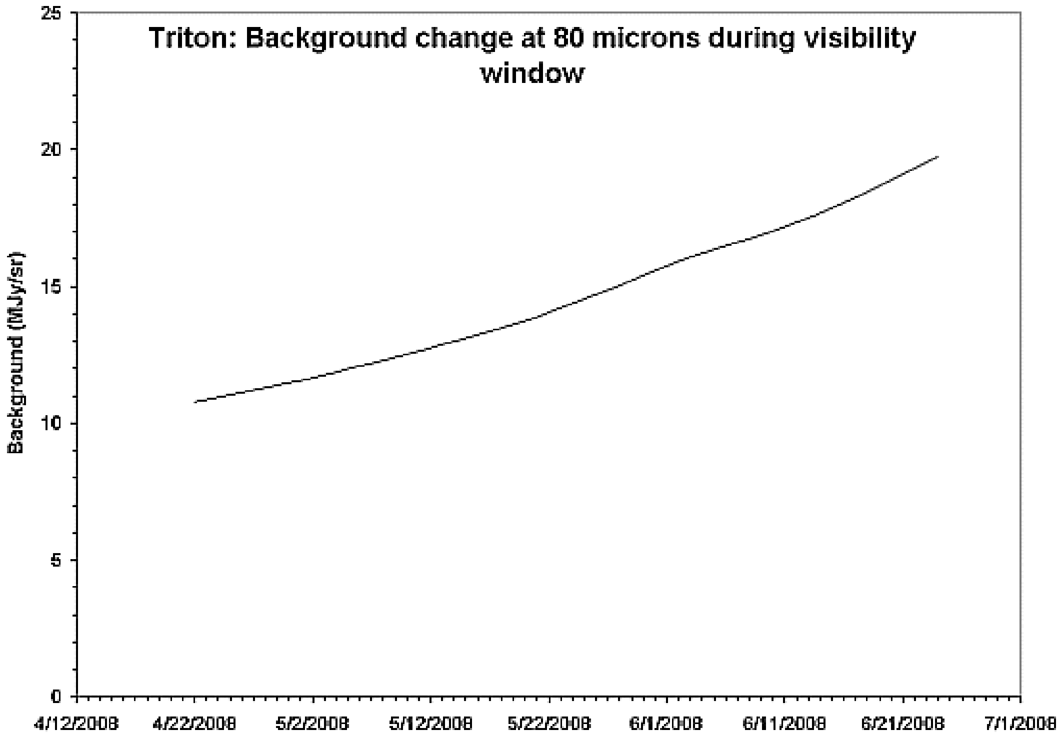

Figure 6.4. The background variation for Triton at 80 microns. The background is dominated at this wavelength by the Zodiacal Light contribution. As the elongation changes over the course of the observing window the background effectively doubles with time. At longer wavelength the ISM component will also change as the target moves across areas of different background. For objects relatively close to the Sun the ISM component may vary enormously in a comparatively short space of time.

6.7.2. Satellite visibility

Note that for satellites of solar system objects HSpot only calculates the visibility window with a solar elongation criterion. It does *not* take into account if the object is genuinely observable by Herschel. It is the astronomer's responsibility to make the necessary checks. Many solar system satellites experience transits and occultations by their parent planet. Similarly, it may not be resolved at the wavelength of observation, or instrument safety constraints may make it impossible to observe a satellite when at less than a certain elongation from the parent planet (please contact Helpdesk (http://herschel.esac.esa.int/) for specific, detailed enquiries about this topic).

As an example, the following plots show how the elongation of Io, Jupiter's innermost Galilean satellite (NAIF ID 501), varies from the centre of the disk of Jupiter. In the first plot (Figure 6.5) we see how the elongation varies with time over part of a visibility window. In the area marked in grey the satellite is either in transit, or occulted and thus, by definition unobservable. The second plot (Figure 6.6) shows the offsets in R.A. and Dec. (in arcseconds) over a full observing window. The ellipse marks the approximate size of the disk of Jupiter which suffers a variation of about 10% with time. Note that the entire area of the plot is smaller than the PACS or SPIRE instrument array (see Table 5.1).

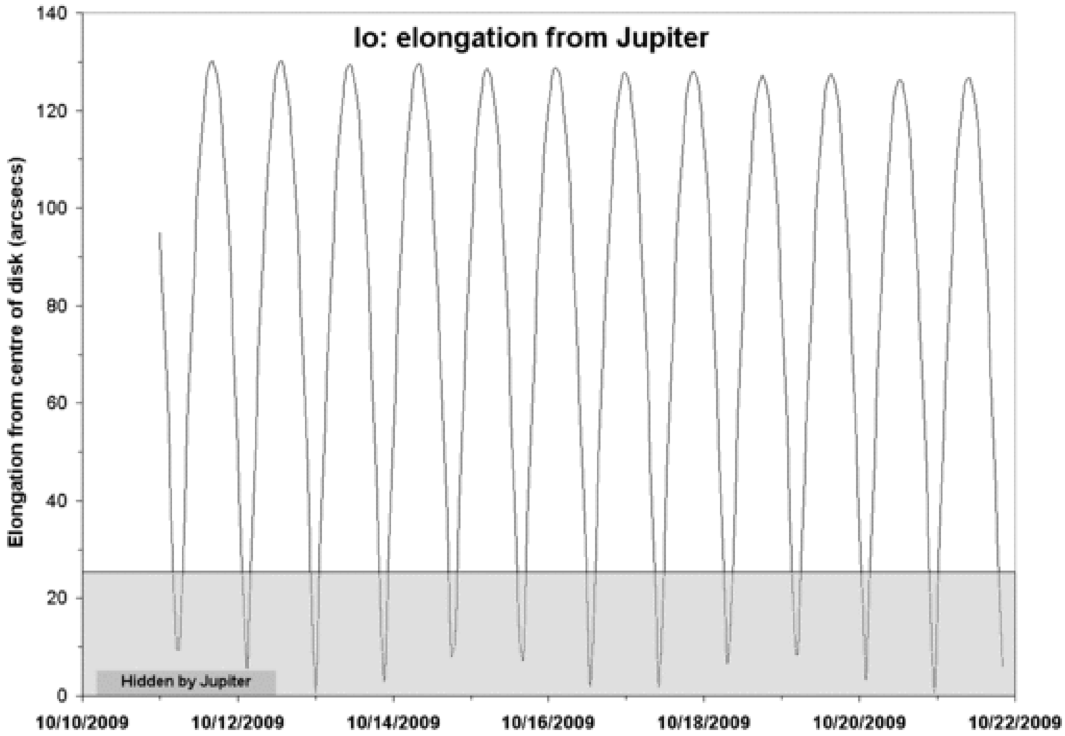

Figure 6.5. The variation of the elongation of Io from the centre of Jupiter with time. The area in grey is the region when Io is either superimposed on the disk of Jupiter (in transit) or behind the disk of Jupiter (occulted). HSpot does not warn the user if visibility of a planetary satellite is limited in this way.

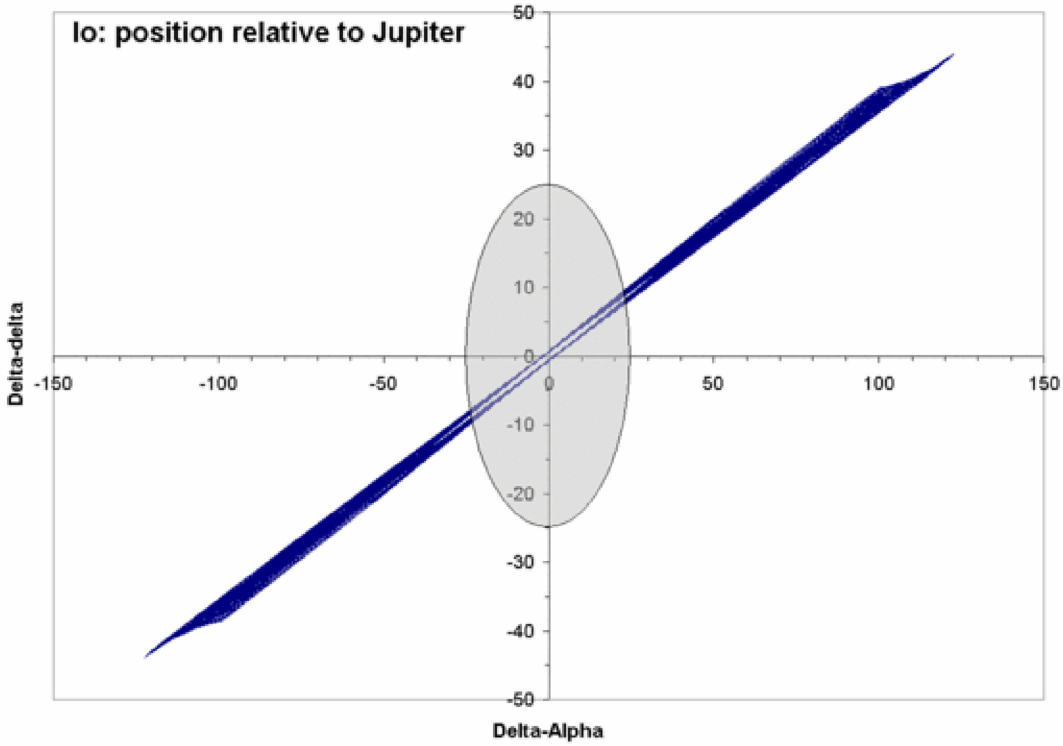

Figure 6.6. The variation in the offset of Io from the centre of Jupiter through an entire visibility window. The grey ellipse represents the approximate mean size of the disk of Jupiter. Note that the entire area of this plot is smaller than the field of view of either PACS or SPIRE. If requesting observations of a planetary satellite the observer should check the visibility of the satellite using the [JPL Horizons pro-

gram at the url: http://ssd.jpl.nasa.gov/horizons.cgi.

Warning

If requesting observations of a planetary satellite the observer should check the visibility of the satellite using the JPL Horizons program at the url: http://ssd.jpl.nasa.gov/horizons.cgi. The observations will almost certainly have to be entered in HSpot with a time constraint.

Chapter 7. Acronyms

2MASS - 2 Micron All-Sky Survey

AAS - Altitude Anomaly Sensors

ACA - Altitude Control Axis

ACC - Attitude Control Computer

ACMS - Attitude Control and Measurement System

AGN - Active Galactic Nucleus

AME - Absolute Measurement Error

AOR - Astronomical Observation Request

AOT - Astronomical Observing Template

APE - Absolute Pointing Error

CP - Calibration Pointing

CFIRB - Cosmic Far Infrared Background

CRS - Coarse Rate Sensors

CUS - Common Uplink System

CVV - Cryostat Vacuum Vessel

DTCP - Daily Telecommunications Period

DSS - Deep Sky Survey

EPLM - Extended Payload Module

ESA - European Space Agency

ESAC - European Space Astronomy Centre

ESD - Electrostatic Discharge

ESOC - European Space Operations Centre

FIRSB - Far Infra Red Sky Background

FIRST - Far Infra Red Space Telescope

FoV - Field of View

FIR - Far Infra Red

FPU - Focal Plane Unit

FWHM - Full Width Half Maximum

GO - Geostationary Orbit

GYR - Gyroscope

HCNE - Herschel Confusion Noise Estimator

HIFI - Heterodyne Instrument for the Far Infrared

HOB - Herschel Optical Bench

HOTAC - Herschel Observing Time Allocation Committee

HSC - Herschel Science Centre

HST - Hubble Space Telescope

IA - Interactive Analysis

ICC - Instrument Control Centre

ID - Identification

IPAC - Infrared Processing and Analysis Center

IRAS - Infrared Astronomical Satellite

ISM - Interstellar Medium

ISO - Infrared Space Observatory

LEO - Low Earth Orbit

LEOP - Low Earth Orbit Phase

MOC - Mission Operations Centre

MIR - Mid InfraRed

MLI - Multi-Layer Insulation

NAIF - Navigation Ancillary Information Facility

NASA - National Aeronautics and Space Administration

NED - NASA Extragalactic Database

NHSC - NASA Herschel Sciencce Centre

OD - Operational Day

PACS - Photodetector Array Camera and Spectrometer

PDE - Pointing Drift Error

PDF - Portable Document Format

PLM - Payload Module

PSF - Point-source Spread Function

PV - Performance Verification

QCP - Quality Control Pipeline

RCS - Reaction Control System

RF - Radio Frequency

RPE - Relative Pointing Error

RWA - Reaction Wheel Assembly

S/C - Spacecraft

SAS - Sun Aquisition Sensors

SCUBA - Sub-millimetre Common-User Bolometer Array

SED - Spectral Energy Distribution

SPG - Software Product Generation

SPIRE - Spectral and Photometric Imaging REceiver

SREM - Standard Radiation Environment Monitor

SRPE - Spatial Relative Pointing Error

SSO - Solar System Object

SSR - Solid State Recorders

STR - Star Trackers

SVM - Service Module

TBD - To Be Determined

WFE - WaveFront Error

Chapter 8. Acknowledgements

This manual has been written by Pedro García-Lario, Ana M. Heras, Miguel Sánchez-Portal and Mark Kidger (who acted as overall editor) and based on a structure produced by Timo Prusti.

The input of the instrument calibration scientists at the Herschel Science Centre and of Larry O'Rourke has been fundamental in preparing this document and checking the information presented here. Several Herschel Science Team members have made careful and thoughtful comments on the contents of the original draft document - their time and effort is greatly appreciated.

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Chapter 9. Change record

- 2007/02/14: slight change Section 6.4.3 to clarify rules on permitted chainings.
- 2007/02/15: Inconsistency noticed between HSpot and PACS documentation. Short wavelength cut-off for PACS changed in Section 5.3 to be consistent with HSpot (also changed in PACS Manual by BA). Resolution information updated to give information on 1st, 2nd and 3rd order performance.
- 2007/04/11: Resolution information updated to give updated range information on 1st, 2nd and 3rd order performance in Section 5.3 to be consistent with values defined in SCR-3091.
- 2007/04/30: A sub-section is added Section 6.2.2.1 to explain the origin of NAIF IDs.
- 2007/05/29: Some typos corrected in Chapter 3.
- 2007/05/31:

  Updates of concatenation rules in Section 6.4.3.

  Updates of overhead rules and application in Section 6.6.

  Updates of calibration overhead rules and application in Section 6.6.3.

  Updates of constrained observation rules and application in Section 6.6.4.

  Correct HIFI exclusion half-angles in Table 1.3.

  Add SPIRE PACS parallel mode exclusion half-angles as a footnote in Table 1.3.

  Update PACS sensitivities in Table 5.2.
- 2007/08/01:

  Update to the proposal submission procedure in Section 6.1.2 to take into account the fact that proposers must now use the HerschelFORM PDFLatex pakage to prepare their scientific case.

  Update to the observing modes described in Section 6.2 to eliminate the cluster and shadow observing target types that currently seem unlikely to be implemented.

  Add a section Section 6.2.2.2 on the accuracy of the available ephemerides for moving targets.

  Add a section Section 6.2.2.3 on the required accuracy of ephemerides for moving targets for them to be observable by Herschel.