HERSCHEL/PLANCK

SATELLITE USER MANUAL

CHAPTER 1 INTRODUCTION AND MISSION DEFINITION

TABLE OF CONTENTS

LISTE OF FIGURES

LISTE OF TABLES

1. INTRODUCTION AND MISSION DEFINITION

1.1. THE MISSION DEFINITION

The aim of the HERSCHEL and PLANCK missions is to perform astronomical investigations in the infrared and sub millimetre wavelength range.

HERSCHEL

The HERSCHEL mission (previously called **FIRST**: Far Infra-Red and Sub-millimetre Telescope) has been approved by the ESA Science Programme Committee (SPC) in November 1993 as the fourth cornerstone mission in ESA's long term space science plan "Horizon 2000". HERSCHEL will open up the last major part of the electromagnetic spectrum, the sub-millimetre and far-infrared, which is still mainly inaccessible for observational astronomers. HERSCHEL will be a multi-purpose mission offering unique capabilities to a large part of the astronomical community.

The spacecraft will carry three HERSCHEL instruments for high and medium resolution spectroscopy, imaging and photometry over the sub-millimetre and far-infrared range dedicated to the HERSCHEL mission. A 3.5 m. cassegrain telescope will focus the incoming radiation on the Focal Plane Units (FPU) of these instruments. The spacecraft must provide cooling of the focal plane units down to temperatures of 1.7 K. The necessary cooling power is provided by a superfluid helium cryostat, which contains the three focal plane units.

PLANCK

The COBRAS-SAMBA mission was selected by the ESA Science Programme Committee (SPC) in April 1996, as Medium Project 3 of the ESA's long term Horizon 2000 and has been confirmed by the SPC in November 1996. The mission has been subsequently renamed **PLANCK**.

PLANCK will provide a definitive high-angular resolution map of the cosmic microwave background anisotropies over at least 95 % of the sky and over a wide frequency range.

The spacecraft will carry two PLANCK instruments to image the sky, one covering 25 to 115 GHz based on cryogenic HEMT amplifiers, and the second covering 85 to 950 GHz based on bolometers cooled to 0.1 K. A 1.5 m diameter offset telescope will focus the incoming radiation on the focal plane shared by the two instruments.

Since HERSCHEL and PLANCK use a similar orbit, it is possible to combine the two missions ("Carrier" concept) by launching them together. Satellites are launched by Ariane V. They will operationally travel Lissajous orbits around Lagrange point L2 of the Sun-Earth system.

The two spacecraft will be operated by a Missions Operations Centre (MOC) provided by ESOC. The MOC generates the commands to be uplinked to both satellites based on inputs from the HERSCHEL Science Centre, the HERSCHEL Instrument Control Centres (ICC), the PLANCK Data Processing Centres (DPCs) and its own subsystems (Mission Planning System and Flight Dynamics System). It receives and processes the Housekeeping information and transfers the scientific data from both spacecraft.

HERSCHEL Scientific Mission

The HERSCHEL wavelength region of the spectrum, 80-670 µm, bridges the gap between what can be observed from current and future ground-based and airborne (e.g. SOFIA) facilities, and that of other space missions (e.g. ISO, SWAS, Odin, WIRE, SIRTF and IRIS). This band is primarily sensitive to continuum and line radiation from relatively cool, diffuse media, such as interstellar and circumstellar dust and gas. Black-bodies with temperatures between 5 K and 50 K peak here, and gases with temperatures between 10 and a few hundred K emit their brightest molecular and atomic emission lines in this wavelength range.

Broadband thermal radiation from small dust grains is the most common continuum emission process in this band. Short wavelength (ultraviolet, visible and near-infrared) photons are effectively absorbed by the dust grains and then re-emitted as a modified grey-body spectrum in the far-infrared. Only a small amount of dust suffices to absorb the short-wavelength radiation in this way (hydrogen column density greater than 10^{21} per cm^2) so that even classes of galaxies and quasars emit a significant, or even dominant, fraction of their radiation in the far-infrared. In addition, the spectral energy distribution of the dust emission gives quantitative information on the temperature distribution of dust particles and thus on their composition/size and spatial distribution.

The submillimetre flux is a direct measure of the mass of the emitting dust. Bright submillimetre emission of low effective temperature is thus a unique signpost of large dust concentrations, such as in protostars or circumstellar disks, or large amounts of interstellar gas in galactic nuclei. It is a unique calorimetric tool for deriving the luminosities of a wide variety of obscured or embedded astronomical sources.

Thermal bremsstrahlung in ~10^4 K ionised hydrogen plasma (HII) regions, synchroton radiation from relativistic electrons gyrating around magnetic fields and inverse Compton-scattered radio emission can also be quite intense whenever the sources are unusually dense or compact. Submillimetre continuum measurements are thus unique probes of the most recently formed stars, or of the centermost regions of Active Galactic Nuclei (AGNs) and quasars. The submillimetre emission in AGNs originates within 0.1 pc of the central black hole, inside the broad-line region observed in the visible/ultraviolet and near the X-ray emission zone.

The hybrides and several molecular ions are key species in various models of interstellar and circumstellar chemistry and their abundances can be used to distinguish between chemical models. The absolute and relative line intensities of submillimetre and far infrared spectral lines will allow determinations of the physical conditions, chemical composition and energy balance of interstellar, circumstellar and planetary gas components with unprecedented quality and detail. The line emission provides a unique fingerprint of the processes possibly involved in its excitation, such as dissociative or magnetic shocks, photo-ionisation or photo-dissociation by ultraviolet photons, X-ray excitation or cosmic ray impact.

PLANCK Scientific Mission

In late 1992 the COBE team announced the detection of intrinsic temperature fluctuations in the Cosmic Microwave Background (CMB), observed on the sky at angular scales larger than ~ 7^o, and at a brightness level $/T\sim10^{-5}$. These fluctuations have been interpreted as due to differential gravitational redshift of photons scattered out of an inhomogeneously dense medium, and thus map the spectrum of density fluctuations in the Universe at a very early epoch. This long-sought result has established the Inflationary Big Bang model of the origin and evolution of the Universe as the theoretical paradigm. However, in spite of the importance of the COBE measurement, many fundamental cosmological questions remain open. In particular, the COBE resolution does not probe the size scale of the vast majority of structures that we see in the Universe today, e.g. galaxies and clusters of galaxies. The main objective of the PLANCK mission is to build on the pioneering work of COBE, and map the fluctuations of the CMB with an accuracy that is set by fundamental astrophysical limits.

Mapping the fluctuations of the CMB with high angular resolution and high sensitivity would give credible answers to such questions as: the initial conditions for structure evolution, the origin of primordial fluctuations, the existence of topological defects, and the nature and amount of dark matter. PLANCK will set constraints on theories of particle physics at energies larger than 10^{15} GeV, which cannot be reached by any conceivable experiment on Earth. Finally, the ability to measure to high accuracy the angular power spectrum of the CMB fluctuations will allow the determination of fundamental cosmological parameters such as the density parameter ($_0$), the Hubble constant (H_0), and the cosmological parameter ( ), with an uncertainty of order a few percent.

The observational goal of the PLANCK mission is to mount a single space-based experiment which will survey the majority of the sky with an angular resolution better than 10 arcminutes, a sensitivity better than $/T\sim2x10^{-6}$, and covering a frequency range which is wide enough to encompass and deconvolve all possible foreground sources of emission. The main scientific result of the mission will be a near--all--sky map of the fluctuations of the CMB in at least three frequency channels.

PLANCK will not only yield CMB anisotropies, but also near-all-sky maps of all the major sources of microwave emission, opening a broad expanse of astrophysical topics to scrutiny. These maps will constitute a product, which is comparable to the IRAS and COBE-DIRBE maps at shorter wavelengths. The IRAS data have been in use by the community for over 15 years with a scientific output which has remained roughly constant throughout this period. The PLANCK data set will have a similar impact on many areas of astrophysics. In particular, the physics of dust at long wavelengths and the relative distribution of interstellar matter (neutral and ionized) and magnetic fields will be investigated using dust, free-free and synchrotron maps. In the field of star formation, PLANCK will provide a systematic search of the sky for dense, cold condensations which are the first stage in the star formation process. One specific and local distortion of the CMB which will be mapped by PLANCK is the Sunyaev-Zeldovich (SZ) effect arising from the Compton interaction of CMB photons with the hot gas of clusters of galaxies. The very well defined spectral shape of the SZ effect allows it to be cleanly separated from the primordial anisotropy.

The physics of gas condensation in cluster-size potential wells is an important element in the quest to understand the physics of structure formation and ultimately of galaxy formation. MM observatory for such studies: the PLANCK SZ measurements are in fact more sensitive than XMM for the detection of clusters at redshifts larger than 0.5, and to detect the gas in the outskirts of the clusters, but X-ray data will be needed to determine the redshift, the gas temperature, and for studies of the physics of the central cores of clusters. From the SZ data can also be extracted a signal which is sensitive to deviations of cluster velocities from the Hubble flow: the sensitivity of PLANCK will allow the determination of the large scale peculiar velocity fields as traced by ensembles of clusters. Finally the survey will detect several thousands of extragalactic sources in a frequency range little observed so far. It will find many new sources and considerably increase our knowledge of the spectra of star burst galaxies, AGNs, radio galaxies and quasars in the millimetre and submillimetre wavelength range.

1.1.1. Scientific objectives

HERSCHEL mission

HERSCHEL will operate as an observatory (e.g. like ISO, XMM) and the HERSCHEL instruments will be primarily sensitive to cool matter. Low temperatures are characteristic of a significant fraction of the visible mass in the Universe, including dense interstellar clouds and embedded protostellar condensations, planets, comets, outer atmospheres of evolved, cool stars and nuclei of active galaxies. From such general considerations it is fairly clear that HERSCHEL will make key contributions to several fundamental problems of modern astrophysics.

Observation time from a space platform is particularly precious. The science objectives of HERSCHEL have been constantly discussed and reviewed; the outcome of the assessments made is that the key scientific topics to be addressed by HERSCHEL include (but are not necessarily limited to):

- Deep broadband 100-500 µm surveys and related research. The main goal of research in this area will be a detailed investigation of the formation and evolution of galaxy bulges and elliptical galaxies in the first third of the present age of the Universe. Furthermore, the possibility of discovery of new classes of objects is great.

- Follow-up spectroscopy of especially interesting program objects discovered in the survey. The far infrared and submillimetre band contains the brightest cooling lines of interstellar gas which give very important information on the physical processes and energy production mechanisms (e.g. AGN vs. star formation) in galaxies.

- Detailed studies of the physics and chemistry of the interstellar medium in galaxies, both locally in our own Galaxy, as well as in external galaxies, including objects at high redshift. This includes implicitly the important question of how stars form out of molecular clouds in various environments.

- Observational astrochemistry (of gas and dust) as a quantitative tool for investigating the physical and chemical processes involved in star formation and early stellar evolution (e.g. cloud collapse, freeze out, disk formation, dust coagulation, and planetesimal formation).

- Detailed high resolution spectroscopy of a number of comets, high resolution molecular spectroscopy of the cool outer planets, and searches for Kuiper-belt objects.

From the past experience it is also clear that the “discovery potential” is significant when a new capability is being exploited for the first time. Observations have never been performed in space in the “prime band” of HERSCHEL, thus HERSCHEL will be breaking new ground since a space facility is essential in this wavelength regime.

PLANCK mission

The observational objectives of PLANCK are:

- to map over the whole sky the temperature anisotropies of the Cosmic Microwave Background, at all angular scales larger than 10 arcminutes, and with an accuracy set by fundamental astrophysical limits

- to map over the whole sky all major Galactic and extragalactic sources of emission at the wavelengths measured by PLANCK

- to characterise the polarisation state of the CMB (goal)

It should be noted that:

- PLANCK is not intended to measure the average temperature of the CMB, but only deviations from it.

- It is also not intended to measure in detail the spectrum of the CMB.

- The whole sky is defined to be at least 95 % of the full 4 sphere.

- By fundamental astrophysical limits is meant the confusion noise due to unresolved structure in astrophysical (galactic and extragalactic) sources of emission at the wavelengths where the CMB spectrum peaks.

- Measuring CMB polarisation is a considerable experimental challenge and it has never yet been detected. Therefore this measurement is considered a goal of PLANCK, the implementation of which should not drive the design of the mission.

The major scientific products of PLANCK will consist at the very least of:

- Whole-sky maps at each frequency channel present in PLANCK

- A whole-sky map of the temperature anisotropies of the CMB (and of their Stokes parameters)

- A whole-sky map of Galactic synchrotron, free-free and dust emission
- A whole-sky catalogue of extragalactic compact and point sources
- A whole-sky map of the S-Z effect from clusters of galaxies.

The satellite will operate in sky survey mode, scanning at least 95 % of the sky twice over in 15 months to image the temperature anisotropies of the cosmic microwave background radiation in ten frequency channels between 20 and 1000 GigaHertz, with a sensitivity and angular resolution which allow the separation of the cosmological signal from all other sources of confusion.

To achieve the scientific objectives of PLANCK it is required that the payload instruments fulfil the following essential requirements:

- The **angular resolution** achieved must be of order 10' or better at the frequencies where the (CMB) Cosmic Microwave Background signal is dominant (i.e. between 100 and 350 GHz). This requirement sets the size of the effective aperture of the telescope to be of order 1 meter in diameter. Furthermore, the PLANCK instruments must sample the sky with a spatial frequency compatible with the final 10’ resolution.

- The **frequency coverage** must be wide enough to provide robust removal of the foregrounds. Simulations indicate that the range 25-1000 GHz is adequately large. To achieve this large range requires two technologically different types of detectors: tuned radio receivers at low frequencies and bolometers at high frequencies. While it seems possible to use bolometers at frequencies as low as 50 GHz, achieving the sensitivity levels required (see below) at 30 GHz appears very difficult with bolometers; similarly, the most sensitive applicable radio techniques (High Electron Mobility Transistor, or HEMT, amplifiers) cannot presently be pushed to frequencies much higher than 150 GHz. Thus it is quite clear that the optimum anisotropy experiment should include two instruments. In addition to the scientific gain, when compared to a single-instrument payload PLANCK will present two significant advantages: the reliability of the mission will be much enhanced (yielding results even in the event of failure of one of the instruments), and a pre-designed frequency overlap between the two techniques will contribute a very useful cross-check of the instrumental sensitivity to systematic effects.

- The **sensitivity** must be sufficient for adequate detection of the CMB anisotropy. Note that the uncertainty in the determination of the CMB anisotropy will be larger than the instrumental sensitivity at any observed frequency, due to the presence of foreground confusion sources and potential systematic effects. A useful criterion on the instrumental sensitivity is that it should be smaller than the confusion noise level contributed by sources of foreground emission in the “cleanest” regions of the sky, guaranteeing the best possible signal-to-noise level over the whole sky.

Contaminating foreground fluctuations in the cleanest 20 % of the sky are expected to contribute a signal larger than ~5 microK at 90 GHz (though this depends both on frequency and angular scale). We thus set a requirement of achieving an instrumental sensitivity level better than deltaT/T ~ $2X10^{-6}$ in the CMB channels (~100 to ~350 GHz). In non-CMB channels the instrumental sensitivity must be such as to allow, over a large fraction of the sky, the spectral extrapolation and removal of foreground emission signals in the CMB channels, without adding significantly to the uncertainties on the CMB anisotropies.

- Systematic effects must be maintained at a level such that they do not add significantly to the instrumental sensitivity. The main sources of unwanted signal are: straylight (both due to celestial sources and to self-emission), thermal variations and interference due to the TM/TC system. The spacecraft and payload must be designed with the goal to reduce the instrumental sensitivity to systematic effects. In particular those effects, which produce signals at frequencies larger than that of the observing pattern, cannot be easily distinguished from real signals and thus introduce an additional uncertainty that must be minimised.

1.1.2. Scientific instrumentation

The on-board instruments and their ground support equipment are conceived, manufactured, tested and delivered by Scientific Institutes and National Agencies.

Similarly, the scientific observations will be planned and the instruments operated by Scientific Institutes and National Agencies. The individual instruments are listed in Table 1-1 below.

The first three instruments in Table 1-1 belong to the HERSCHEL mission, the two remaining instruments to the PLANCK mission.

NAME	CHARACTERISTICS
Heterodyne Instrument for **HERSCHEL (HIFI)**	A heterodyne instrument which performs high to very high resolution spectroscopy in approx. 500 - 1900 GHz (160 – 600 µm) range. It is a multi-channel SIS/HEB mixer receiver with solid state local oscillators and a complement of back-end spectrometers. The SIS and HEB mixers need to be operated at a temperature of around 2 K.
HERSCHEL Photo-conductor Array Camera and Spectrometer **(PACS)**	A direct detection instrument which performs imaging line spectroscopy and photometry in the 60* - 210 m range using two bolometer arrays for photometry and two 16 x 25 stressed “bulk” Ge:Ga photo-conductor detector arrays and an image slicer in combination with a long-slit grating spectrometer. The photo-conductors need to be cooled to around 1.7 K while the bolometers have an operating temperature of 0.3 K.
HERSCHEL Spectral and Photometric Imaging Receiver **(SPIRE)**	A direct detection instrument which performs imaging photometry in the 200 – 670 µm range, simultaneously covering the same field in three bands, spectroscopy in the 200 - 670 µm range, using bolometer detector arrays. The bolometers have an operating temperature of approx. 0.3 K.
PLANCK High Frequency Instrument **(HFI)**	An array of bolometers cooled to 0.1 K by a series of active coolers, and covering the frequency range 85 - 1000 GHz, grouped into six channels.
PLANCK Low Frequency Instrument **(LFI)**	An array of tuned receivers based on HEMT low-noise amplifier technology operating at 20 K, and covering the frequency range 25 – 110 GHz, grouped into four channels. The 20 K cooler forms also the first stage of the HFI cooling chain.

Table 1-1 Payload description

The instruments with the satellite are described in the instrument sections.

1.2. THE MISSION DESCRIPTION

A new injection strategy is currently being analysed by ESA to allow fast Planck transfer to L2, allowing earlier start of scientific mission. Another advantage of this strategy is to reduce the maximum excursion of the SSCE during the beginning of mission, thus easing communication during commissioning and performance verification phase. The drawback of this new strategy is to require additional fuel.

A new Crema corresponding to this new strategy has not yet been released. So, the following sections are still based on the Crema 3.1 [AD05]. The only exception is for the fuel budget which is based on the new delta-V budget agreed with ESA during PM#41.

1.2.1. Reference operational orbits

Both HERSCHEL and PLANCK spacecraft are planned to operate from Lissajous orbits around the L2 Lagrange point of the Sun + Earth system. As shown in Figure 1-1, this point is aligned with the Earth and the Sun and located at 1500000 km from the Earth, away from the Sun.

Such orbits present the following advantages for the satellite operations:

- thanks to the Earth and Sun almost constant distances, the thermal environment is very stable. The thermal radiation from the Earth are reduced and induces a cold environment which is favourable for operating cryogenic satellites such as HERSCHEL and PLANCK
- the radiation environment is very low compared to an eccentric orbit such as ISO or XMM, or even compared to GEO orbits
- as the Sun and the Earth remain close together from the spacecraft, the shielding of the Sun thermal radiation will also prevent straylight effects from the Earth. The satellite communication with the Earth is facilitated, as the satellite remains Sun pointed.

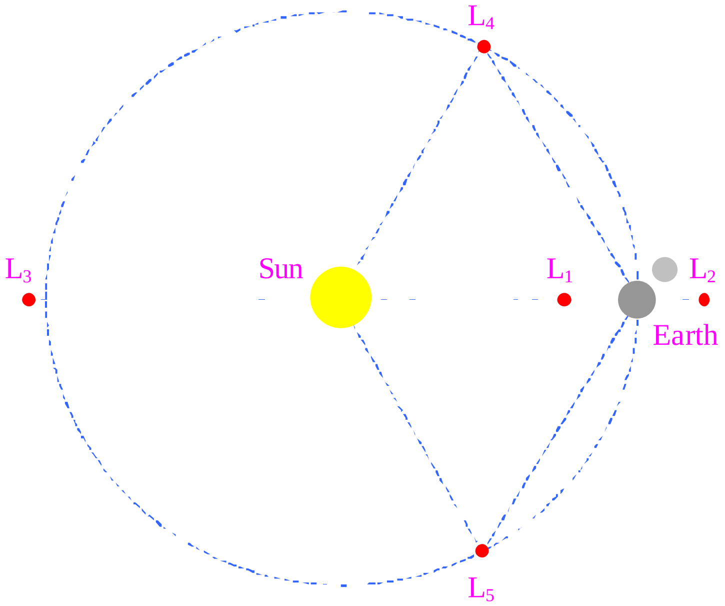


Figure 1-1 Lissajous orbit at L2 Lagrange point

Both spacecraft are not located at L2 Lagrange point, but orbiting around that point. The HERSCHEL and PLANCK orbits are described in next sections, in the Earth rotating frame and also in the Inertial frame. Note that the three planar projections of HERSCHEL and PLANCK trajectories use the same spatial scale.

Table 1-2 details the operational lifetime requirements for HERSCHEL and PLANCK mission.

Operational Lifetime	**HERSCHEL**	**PLANCK**
Required Standard Lifetime	3.5 years	1.75 years (21 months)
Required Extended Lifetime	4.5 years	2.5 years

Table 1-2 Required operational lifetime for HERSCHEL and PLANCK missions

1.2.1.1. HERSCHEL operational orbit

A large Lissajous orbit has been selected for HERSCHEL. This orbit is characterised by large amplitudes along X,Y and Z axes depending on the launch date/hour: typical HERSCHEL Lissajous dimensions will be around 800000 km in Y direction and around 500000 km in out of ecliptic plane (Z direction).

Figure 1-2 shows an example of orbit evolution of HERSCHEL from launch to 4.75 years of propagation in Earth centred rotating frame and in Earth centred inertial frame. The large amplitudes imply that the maximum Sun-Satellite-Earth angle can reach values above 30 deg (MISS-081 from the SRS specifies 40 deg) and that the declination to Earth can be up to 40-50 deg.

This orbit can be reached without insertion manoeuvre.

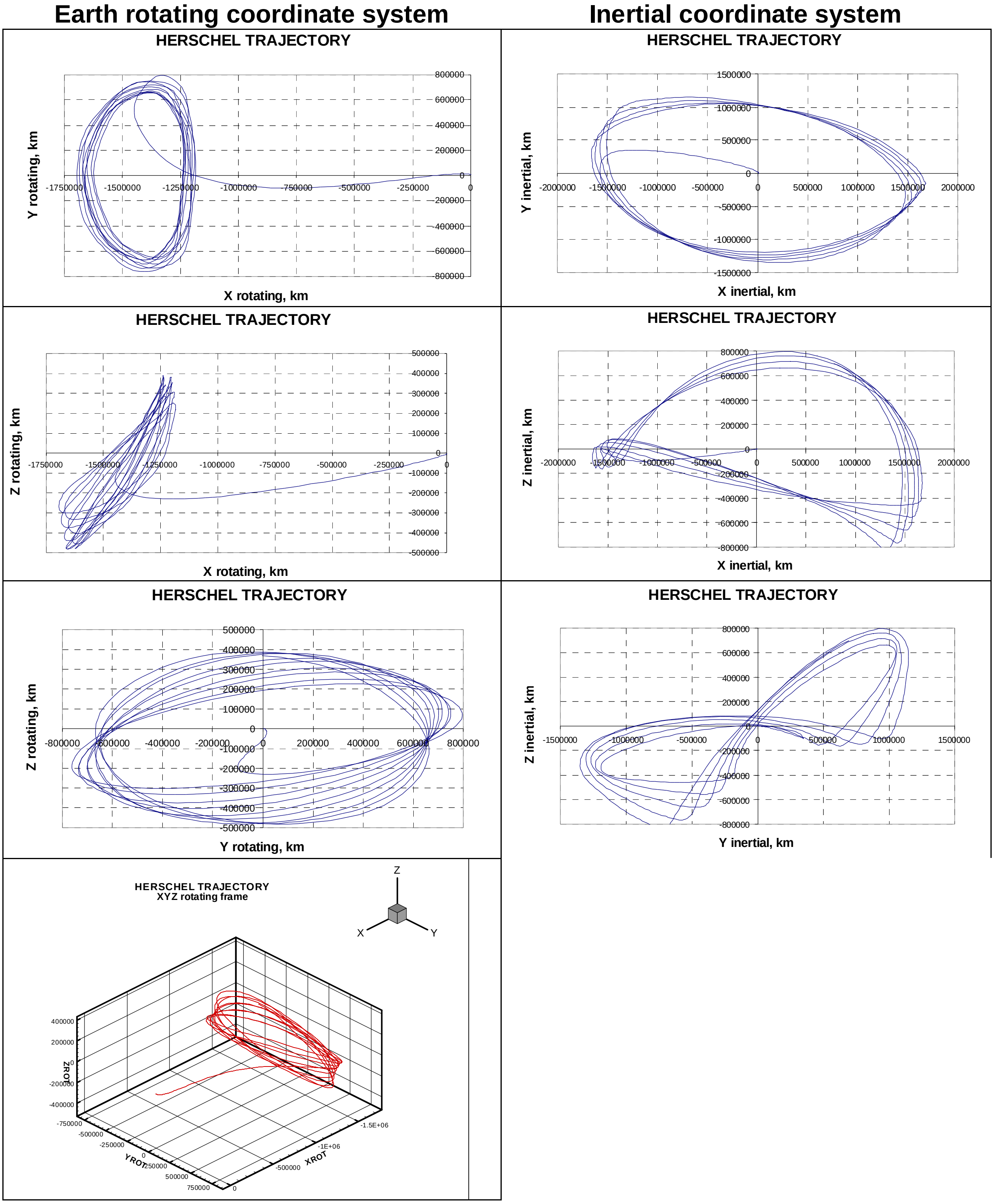


Figure 1-2 Typical HERSCHEL large Lissajous orbit around L2

1.2.1.2. PLANCK operational orbit

PLANCK is a Sun-pointed spacecraft with little manoeuvrability. In order to prevent the Earth to enter the PLANCK field of view and generate unacceptable straylight, the chosen baseline is a Small Lissajous orbit with a Sun-Satellite-Earth angle limited to 15 deg. This imposes an insertion manoeuvre at the arrival at L2 to reduce orbit amplitude.

Figure 1-3 shows an example of a 15 deg Lissajous orbit from launch to 2.75 years of propagation in Earth centred rotating frame and in Earth centred inertial frame. In this case, the Y amplitude is 330000 km, and the Z amplitude is 250000 km.

These amplitudes are largely dependant on launch date. For example, the Z amplitude may vary from 150000 to 500000 Km with launch varying from 15/01/08 to 22/02/08.

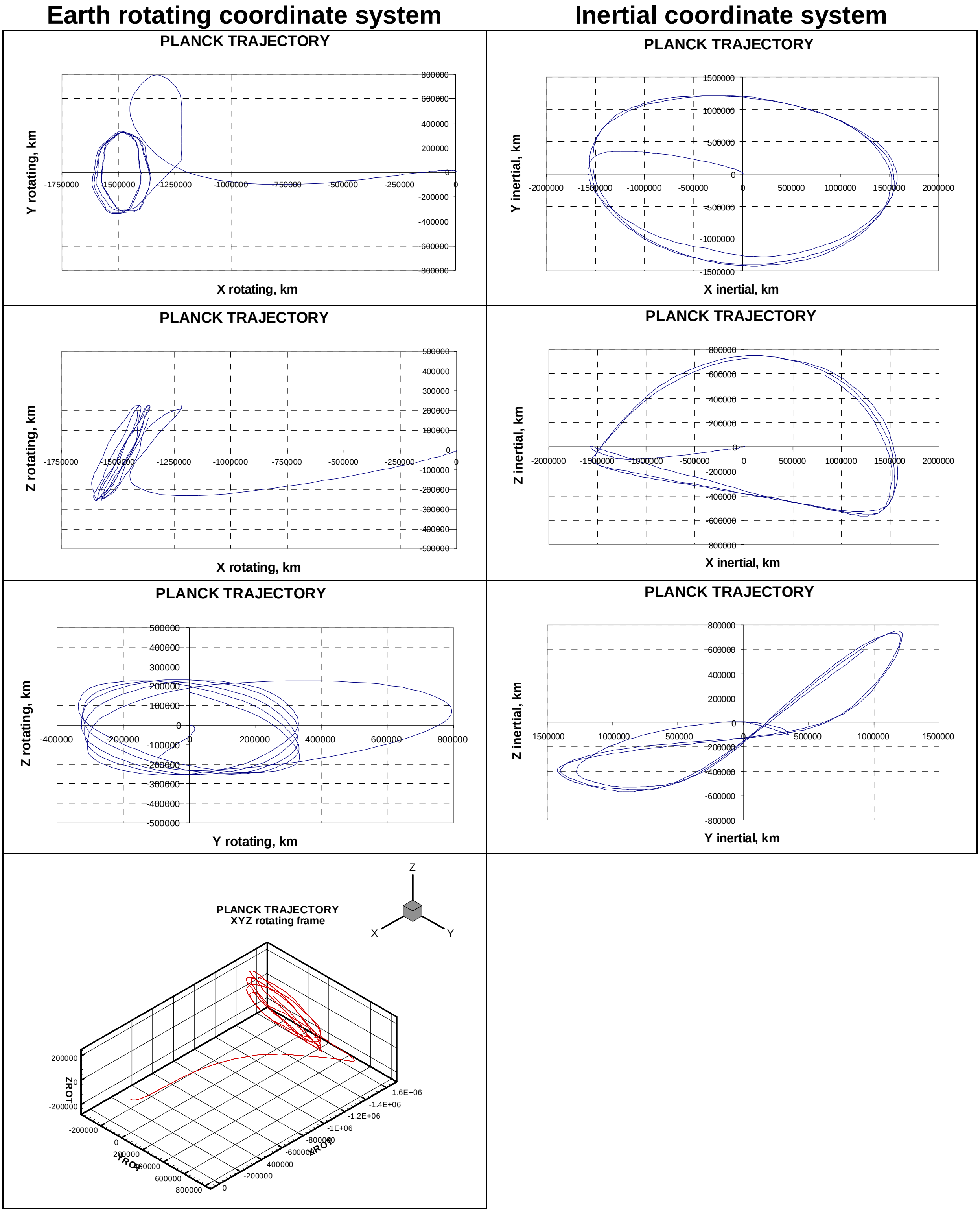


Figure 1-3 Typical PLANCK small Lissajous orbit around L2

The Sun-Satellite-Earth angle is limited to 15 deg for PLANCK.

1.2.2. Launch phase

The engine of the cryogenic main core stage, Vulcain 2, is ignited at H0. During 7.05 seconds, the on-board computer checks the good behavior of the engine and authorizes the lift-off by the ignition of the two solid rocket boosters.

The boosters separation is triggered by an acceleration threshold detection and the fairing is released approximately one minute later when the aerothermal flux becomes lower than the required flux.

The main stage shutdown occurs when the intermediate target orbit is aimed and the separation happens 6 seconds after.

After its separation, the main stage is put in a flat spin mode by opening a lateral venting hole in the hydrogen tank. This control procedure provides a re-entry and a splashdown in the Atlantic Ocean.

The upper stage ignition occurs a few seconds after main stage separation. The upper stage cut-off command occurs when the guidance algorithm detects the final target orbit.
The separation sequence of the payloads begins 2 seconds later.

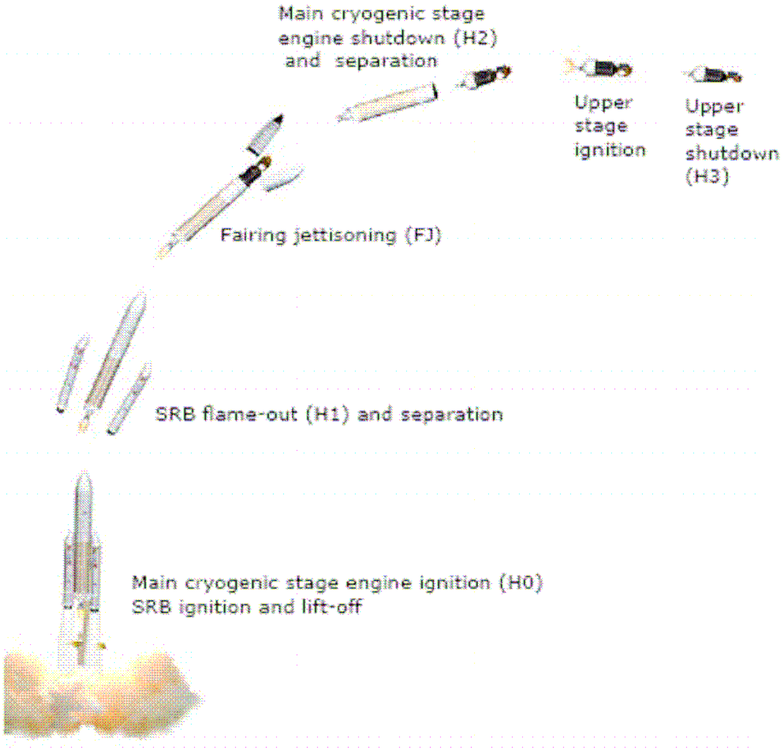


Figure 1-4 Ariane 5 typical sequence of events

The following table provides a sequence of events resulting from RAMP between the Vulcain engine ignition to the end of the launch vehicle mission. Time and altitude are preliminary.

EVENT	COUNT	TIME (s) ALTITUDES A5-ECA RAMP results (Optimal case)	
Inertial platform release		- 3	0
EPC Vulcain engine ignition command	H0	0	
EAP ignition and Lift-Off		7.05	
End of vertical rise, beginning of pitch motion		12.05	
Atmospheric flight at zero angle of attack		25.32	
Maximum dynamic pressure		68.0	
Launch vehicle acceleration threshold detection	H1	139.78	65.84
EAP separation		140.56	
Beginning of guidance		145.86	
Fairing jettisoning		190.62	104.98
End of EPC main thrust phase	H2	536.63	
EPC separation		542.63	160.98
ESC-A Ignition		549.63	159.67
2nd peak of aeroflux		767.00	
ESC-A shutdown -Injection	H3	1495.35	968.44
Composite orientation to separation attitude		1508.25	
HERSCHEL separation	H4.1	1629.25	
Composite orientation		1639.05	
SYLDA-5 separation	H4.2	1789.35	
Composite reorientation		1799.75	
PLANCK separation	H4.3	1910.35	
ESC-A avoidance manoeuvres		1936.25	
End of launch vehicle mission		2507.05	

Table 1-3 Launch Sequence

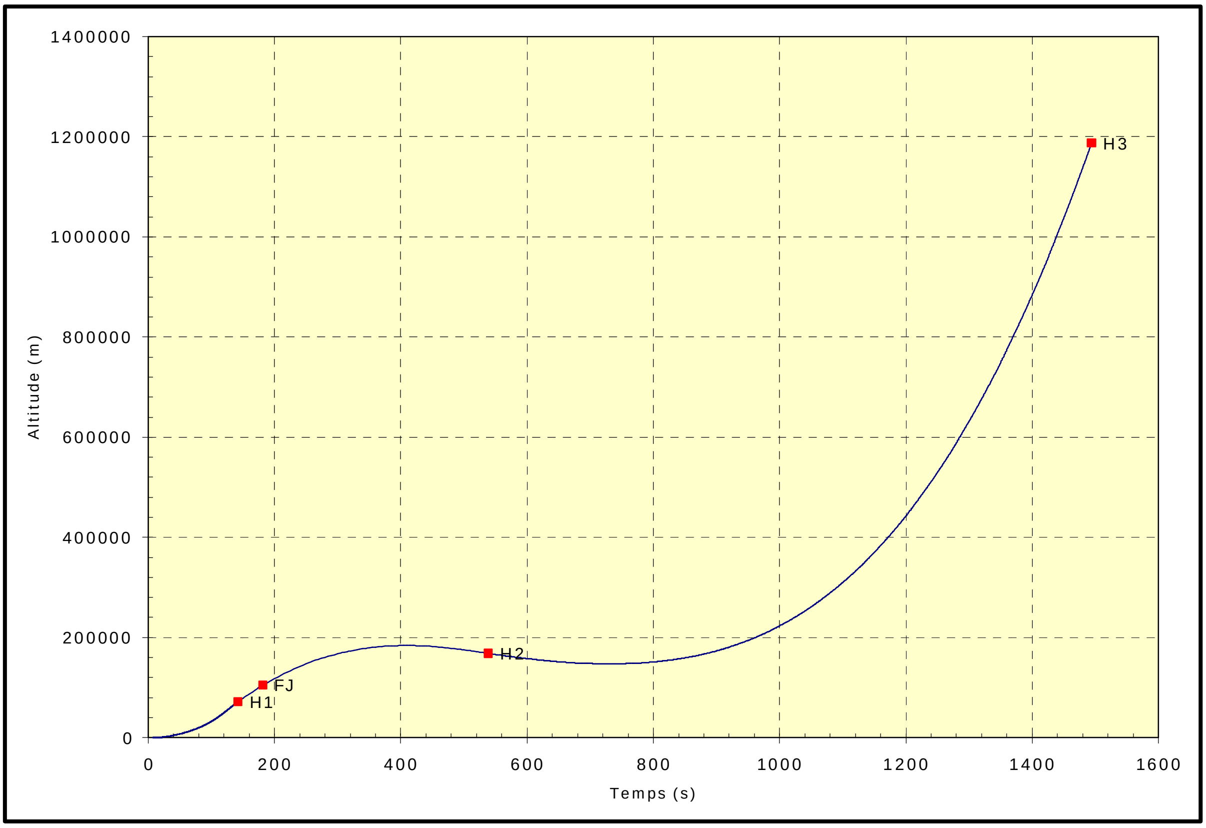


Table 1-4 Altitude vs time during launch sequence

1.2.2.1. Separation sequence

A detail of the separation sequence is given in the following table: Timing is preliminary and shall be reviewed.

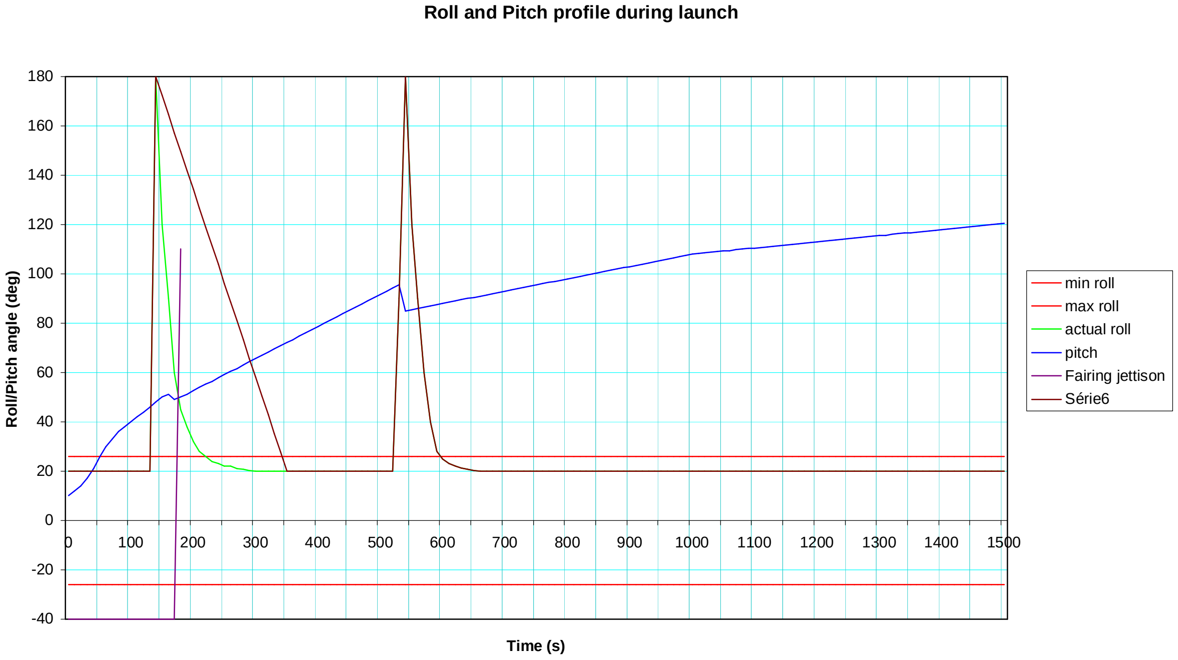
Type of phase	Timing	Attitude	Feared event	Attitude constraints
Launcher orientation	H3+2s to H3+133.3 s		H-EPLM illumination	-26 < Roll < +26 20 < Pitch < 140 from X axis
HERSCHEL separation (H4.1)	H3+133.9 s	HERSCHEL Z axis Sun pointed	H-EPLM illumination	For separation conditions see below
Stand-by	H3+133.9s to H3+143.7 s		PPLM illumination through SYLDA hole	Sun centre direction between 80 deg and 180 from launcher X_L axis.
Launcher orientation	H3+143.7 s to H3+294 s		PPLM illumination through SYLDA hole	Sun centre direction between 80 deg and 180 from launcher X_L axis.
SYLDA separation (H4.2)	H3+294.4 s	At 3 deg from PLANCK separation attitude		Sun centre direction at less than 10 deg from PLANCK –X axis
Stand-by	H3+294.4 s to H3+304.4			Sun centre direction at less than 10 deg from PLANCK –X axis
Launcher orientation	H3+304.4 to H3+374.7			Sun centre direction at less than 10 deg from PLANCK –X axis
Spin up (6°/s)	H3+374.7 to H3+415 s			Sun centre direction at less than 10 deg from PLANCK –X axis
PLANCK separation (H4.3)	H3+415.3 s	PLANCK –X axis Sun pointed		For separation conditions see below

Table 1-5 Separation sequence

The roll and pitch attitudes during the ascent phase are mainly driven by the HERSCHEL sun aspects constraints.

The appropriate pitch angle is obtained through the argument of perigee adjustment.

The roll and pitch profile during launch will be in accordance with the following figure.



HERSCHEL +Zs axis is separated in 3-axis mode with Zs pointed to the sun and –Xs to the Earth.

Prior to separation of PLANCK from the launcher, a slow spin-up around the S/C X axis to a spin rate at 1 rpm is required. The direction of the spin is counter-clockwise (from +Y axis to +Z axis) looking on top of the S/C (+ X-axis).

The –Xs side (Solar Array location) of PLANCK shall be totally illuminated by the Sun less than 5 minutes after separation.

kinematics conditions at separation:

HERSCHEL

General Characteristics just after separation		RAMP result Mean ±3σ
Longitudinal geometrical axis depointing	(°)	0.11
Longitudinal angular rate	(°/s)	±0.25
Transverse angular rate	(°/s)	0.48
Relative velocity between S/C and L/V	(m/s)	0.569±0.0102

Table 1-6 HERSCHEL conditions at separation

PLANCK

General Characteristics just after separation		RAMP result Mean ±3σ
Spin rate	(°/s)	5.999
Spin rate accuracy	(°/s)	±0.087
Transverse angular rate (in plane magnitude)	(°/s)	0.651
Relative velocity between S/C and L/V	(m/s)	0.525±0.0177

Table 1-7 PLANCK conditions at separation

1.2.2.2. PLANCK illumination risks

Two kinds of PLANCK illumination risks are identified. The first one consists on Sun illumination through SYLDA-5 holes after the fairing jettisoning and during the roll transient phase, and the second one is the PLM illumination after PLANCK separation.

The first risk reduction imposes constraints on the spacecraft clocking position with respect to the launcher.

Considering the clocking described in the Section 2.5.1, studies have shown that Sun illumination is acceptable for the spacecraft.

With the separation conditions agreed by Arianespace and confirmed during RAMP, the PPLM will be illuminated after separation. As the ACMS is initiated after 300 s, Planck will be initially freely nutating. Test of worst case separation cases on the AILF by ACMS subcontractor has shown that a maximum Sun Aspect Angle of 21 deg can be reached. But once the ACMS is initiated the SAA quickly reduces below 10 deg. The SAA is between 10 and 21 deg for a duration of less than 400 s. Thermal analyses have shown that SAA of up to 25 deg for 400 s was generating a small temperature variation, within flight limits.

1.2.3. Transfer phase

This phase begins at satellite separation from launcher and ends at the injection of the satellites on their operational orbit around L2. For PLANCK, this phase includes also the orbit insertion manoeuvre performed to reach the small Lissajous orbit with SSCE of 15 deg.

1.2.3.1. Environment conditions

This section presents environment conditions of the transfer phase to L2 operational orbit: distance from Earth and Moon, Sun-satellite-Earth angle, and declination to Earth equator.

The following figures correspond to typical evolution of these parameters: the precise variation of these environment conditions will depend of course of the final launch date/time.

1.2.3.1.1. Distance to Earth and Moon

The Figure 1-5 presents the distance to the Earth, which will drive the telecommunications and the radiation and thermal environment, and also the distance to the Moon. The left curves represents HERSCHEL, and the right ones PLANCK during the transfer phase (about 6 months). Note that the distances to Earth and Moon are different for HERSCHEL and PLANCK satellites after the PLANCK insertion manoeuvre around day 100 after separation.

As required HERSCHEL distance to Earth remains below 1.8 Mkm and PLANCK distance to Earth remains below 1.6 Mkm.

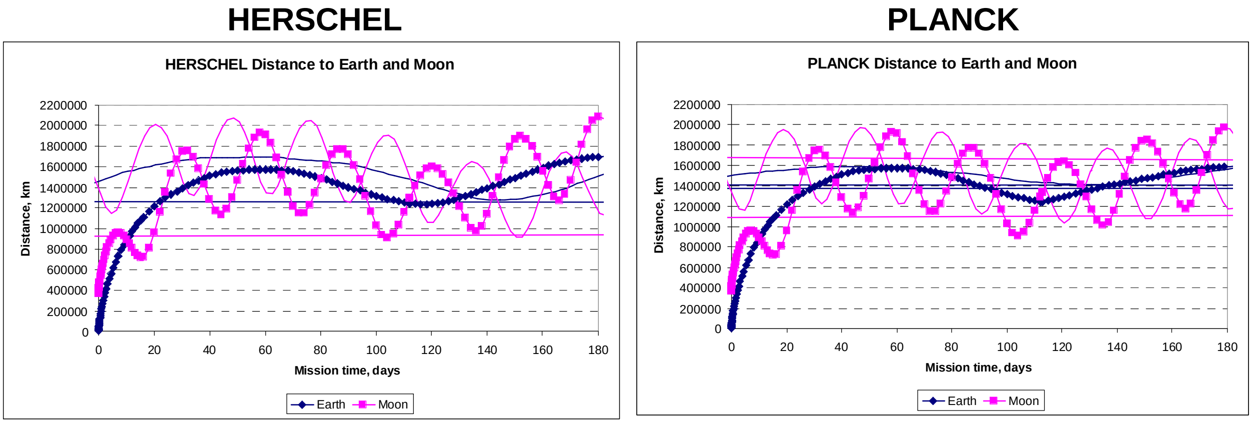


Figure 1-5 Typical HERSCHEL and PLANCK distance to Earth and Moon during transfer phase

1.2.3.1.2. Sun-Satellite-Earth angle

The Sun-Satellite-Earth aspect angle is very constrained for both spacecraft due to the nature of the mission and the on-board equipment. This angle has to be checked during all the phases of the mission and particularly during the transfer when it is submitted to large variations.

Figure 1-6 shows the Sun-Satellite-Earth angle for HERSCHEL and PLANCK during the transfer phase.

Before PLANCK insertion manoeuvre, the Sun-Satellite-Earth angle reaches the maximum value of 31 deg around day 68 after Launch. The PLANCK insertion manoeuvre reduces the Sun-Satellite-Earth angle down to a maximum value of 15 deg.

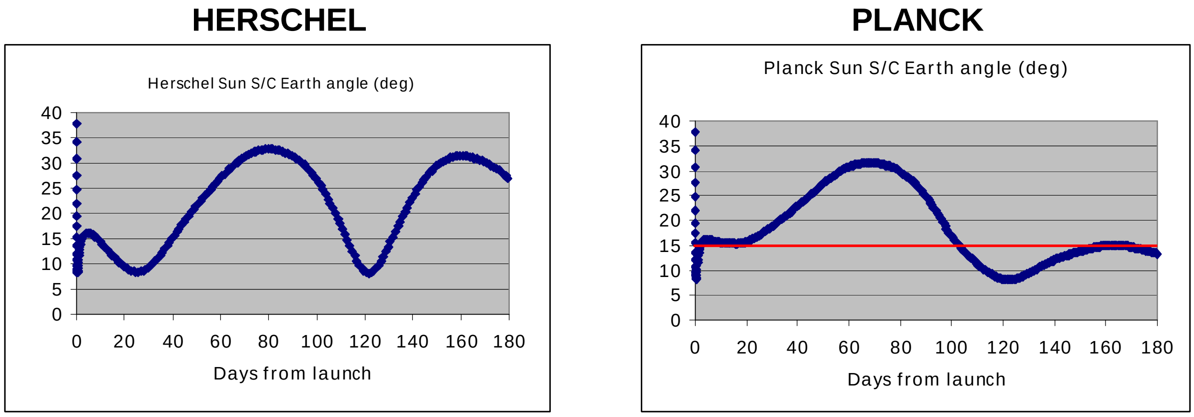


Figure 1-6 HERSCHEL and PLANCK Sun-satellite-Earth angle during transfer phase

1.2.3.1.3. Declination to Earth

Figure 1-7 presents the declination to the Earth, which will drive the telecommunications. Dedicated analysis on station visibility analysis is presented further in Section 1.2.3.1.4.

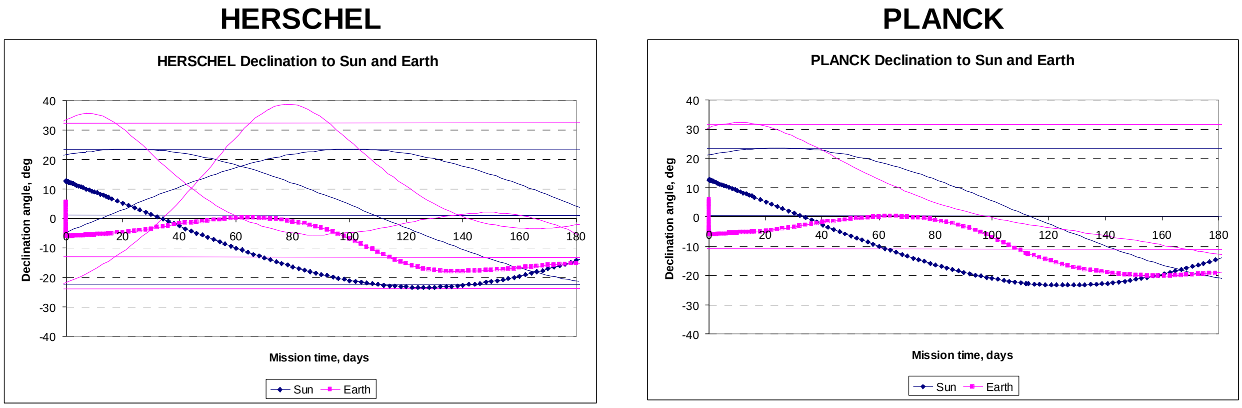


Figure 1-7 HERSCHEL and PLANCK declination to Earth during transfer phase

1.2.3.1.4. Eclipses by the Moon

Depending on launch date, the Moon may eclipse the Sun during a short time (Sun - S/C Moon angle lower than 1°). The Figure below shows an example of Sun - S/C - Moon angle during transfer for 30 launch dates from the 28/02/08. In these particular cases, there is no eclipse foreseen but the calculation shall have to be performed again with the final launch date. Same rationale applies to the Earth occultation by the Moon.

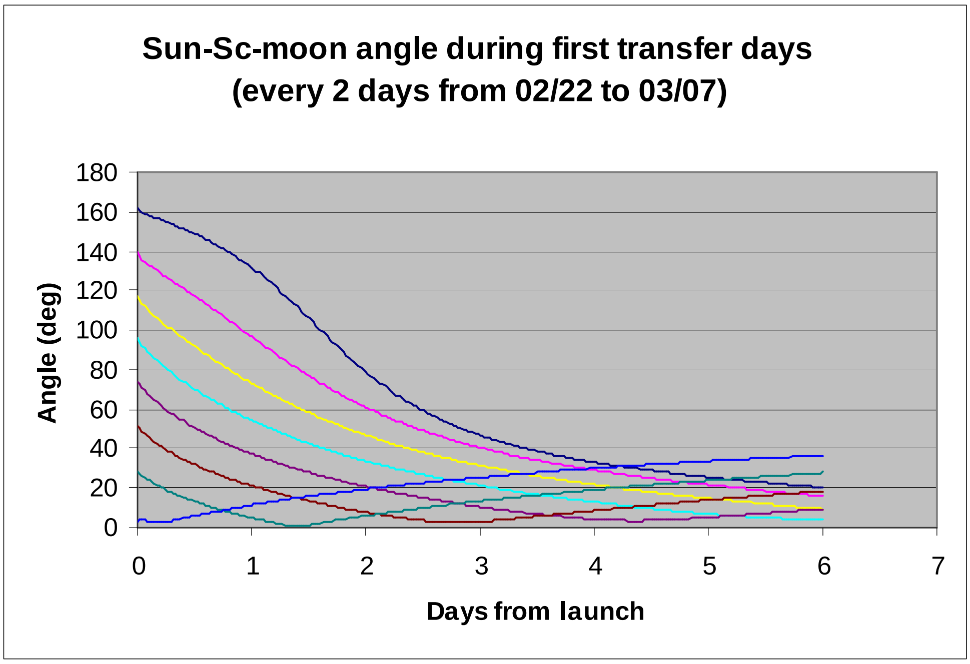


Figure 1-8 SSCM angle during first days after separation

1.2.3.2. Telecommunications during transfer phase

1.2.3.2.1. Ground network definition

The ground station visibility during transfer is also a driving constraint for the mission. Both spacecraft will be controlled by the following ground stations: KOUROU, NEW NORCIA (baseline station in operational phase) and CEBREROS. These stations belong to the ESA network and their locations are illustrated in Table 1-8 and Figure 1-9. The minimum elevation mask is taken equal to 10 deg for each station.

Note that the minimum elevation from ground station at which communication can be performed can go down from 10° to 5° as permitted for non-deep-space missions. Related link budgets are pending on SRS (SPTT-155) and SG-ICD updates for elevation angle.

GROUND STATION	KOUROU	NEW NORCIA	VILLAFRANCA
Longitude, deg	- 52.63	115.88	- 4.23
Latitude, deg	5.10	- 30.20	45.27
Min. elevation, deg	10	10	10

Table 1-8 Ground stations network location

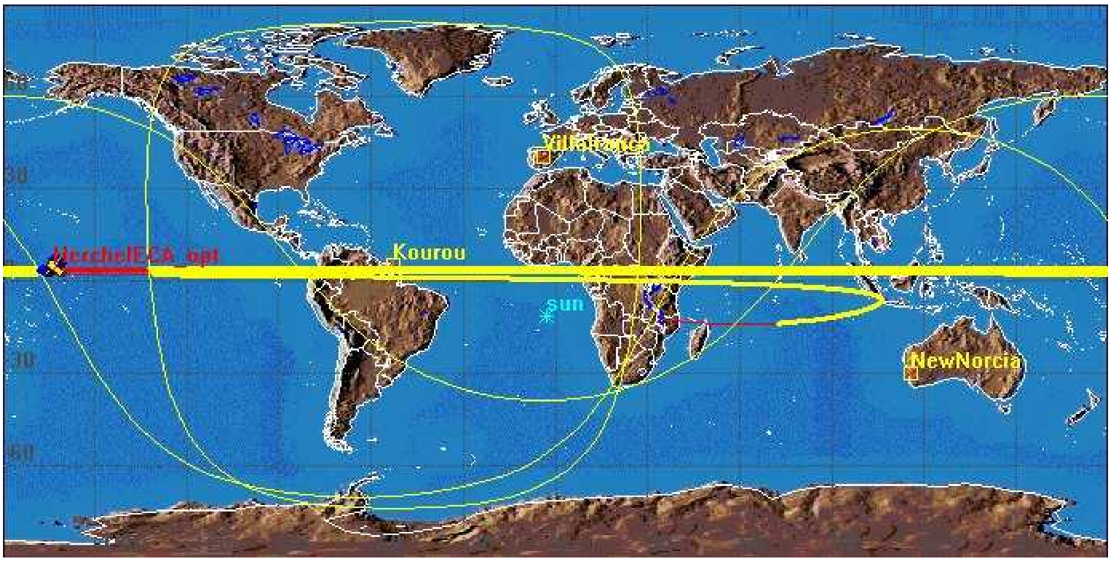


Figure 1-9 Ground station coverage during the first days of the transfer

Figure 1-10 shows that both spacecrafts are always in visibility of one station (ground track represented in bold yellow) except:

- from launcher separation above Africa to first New Norcia visibility (~12 minutes)
- everyday above Pacific Ocean.

1.2.3.2.2. HERSCHEL and PLANCK visibility by NEW NORCIA

The following figure presents the evolution of the start/end times of daily visibility slots with New Norcia during the transfer phase and the first year of the operational phase. New Norcia visibility slots occur the afternoon (in UT).

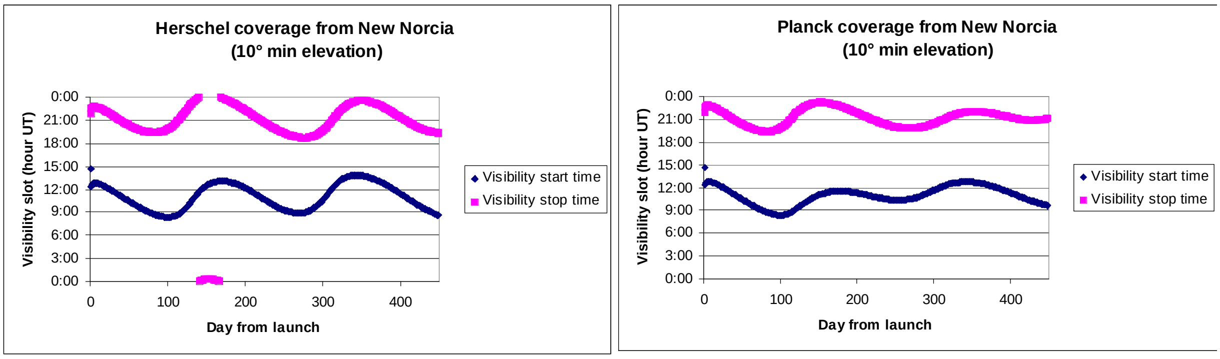


Figure 1-10 HERSCHEL/PLANCK coverage from New Norcia

1.2.3.2.3. HERSCHEL and PLANCK visibility by CEBREROS

The following figure presents the evolution of the start/end times of daily visibility slots with Villafranca during the transfer phase and the first year of the operational phase. Cebreros visibility slots are equivalent to the Villafranca one's and occur around midnight (in UT).

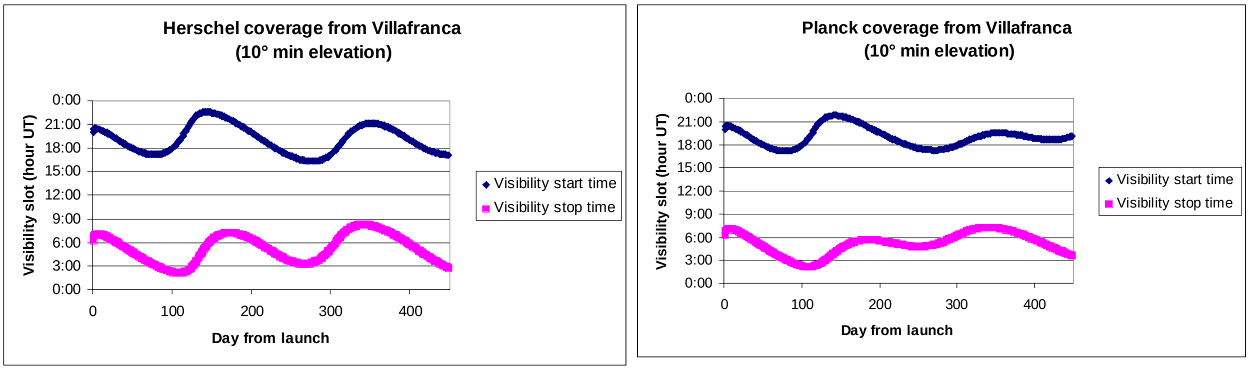


Figure 1-11 HERSCHEL/PLANCK coverage from Villafranca/Cebreros

1.2.3.2.4. HERSCHEL and PLANCK visibility by KOUROU

The following figure presents the evolution of the start/end times of daily visibility slots with Kourou during the transfer phase and the first year of the operational phase. Kourou visibility slots occur at the end of the night (in UT).

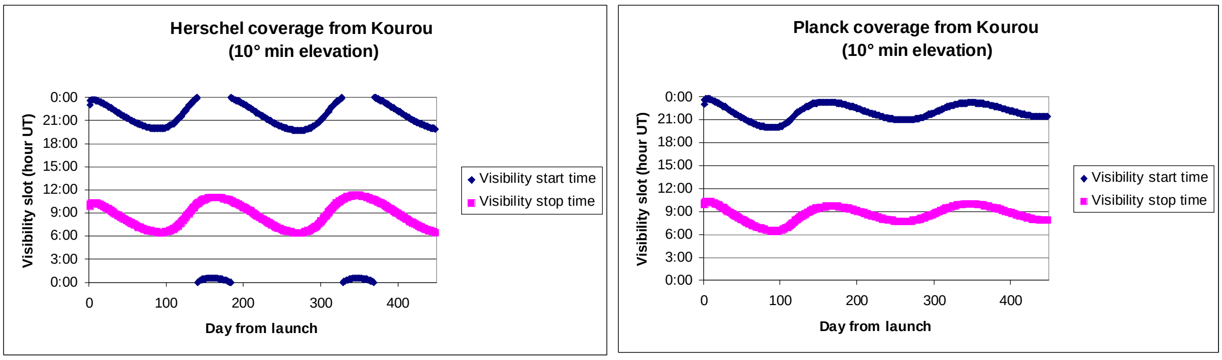


Figure 1-12 HERSCHEL/PLANCK coverage from Kourou

1.2.3.2.5. Synthesis of the visibility analysis

As illustrated in Figure 1-13 the duration of each station visibility slot during the transfer phase is typically between 5 and 13 hours per day: it depends on the station latitude and on the spacecraft declination with respect to Earth equatorial plane.

There are everyday some visibility holes above Pacific Ocean without contact with any of the three stations. The typical duration of these visibility holes is between 1h30 and 3 hours per day for PLANCK and HERSCHEL. The duration gets longer with high spacecraft declination: see Figure 1-14. These holes always happen the morning (in UT).

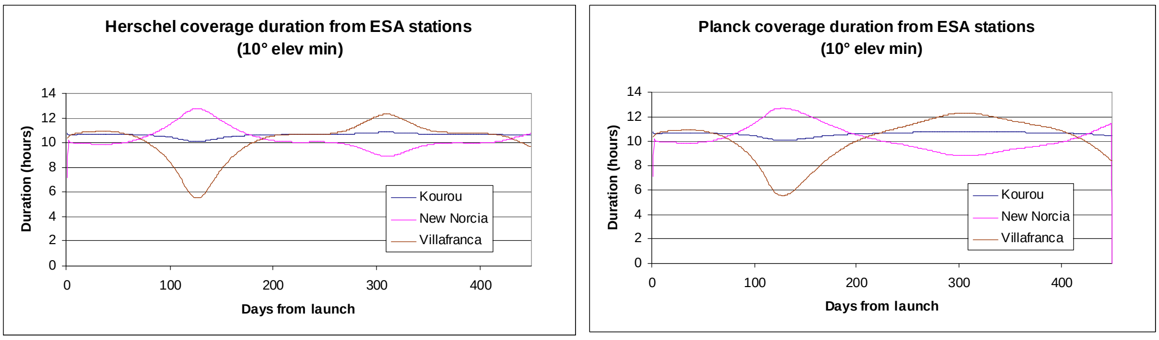


Figure 1-13 HERSCHEL/PLANCK coverage duration from ESA stations

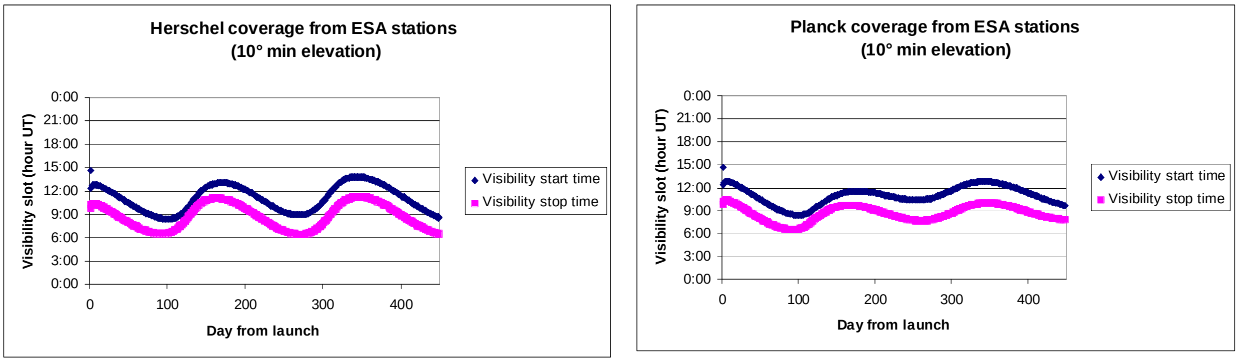


Figure 1-14 HERSCHEL/PLANCK cumulated coverage from ESA stations

Reduction of elevation angle provides improved visibility duration between 43 and 51 minutes for HERSCHEL. The Figure 1-15 presents the HERSCHEL coverage from ESA station for a minimum elevation of 5° and the related improvement.

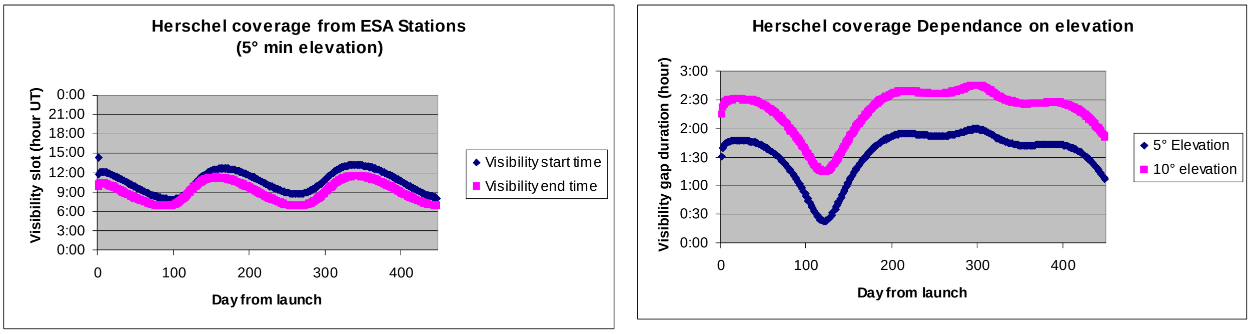


Figure 1-15 HERSCHEL elevation impact on station coverage

Figure 1-16 presents the evolution of the S/c-station distance over all the ground station coverage slots during the first week of transfer.

It shows that:

- The reception of TC at 4 kbps from Kourou or Villafranca up to 350000 km, means up to 50 hours **(~2 days)** after separation.
- The down-link of TM at 5 kbps to Kourou or Villafranca up to 750000 km, means up to 180 hours **(~7.5 days)** after separation.

Besides Figure 1-17 presents the evolution of the range rate for the first 10 days of the transfer. The range rate is the highest during the first New Norcia visibility (up to 5 km/s) and then sharply decreases below 1 km/s after about 10 days. The +/-0.5 km/s variation of the range rate during each slot is due to Earth rotation: it is the main contributor to the range rate after few tens of days on the transfer orbit.

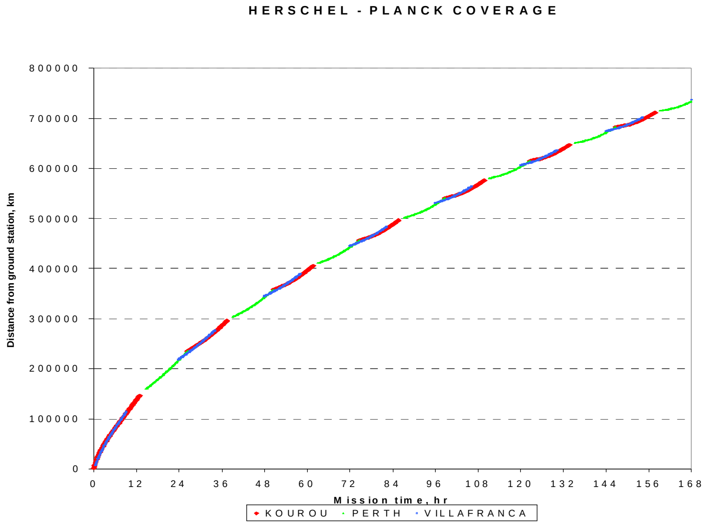


Figure 1-16 Ground stations visibility during first week of transfer

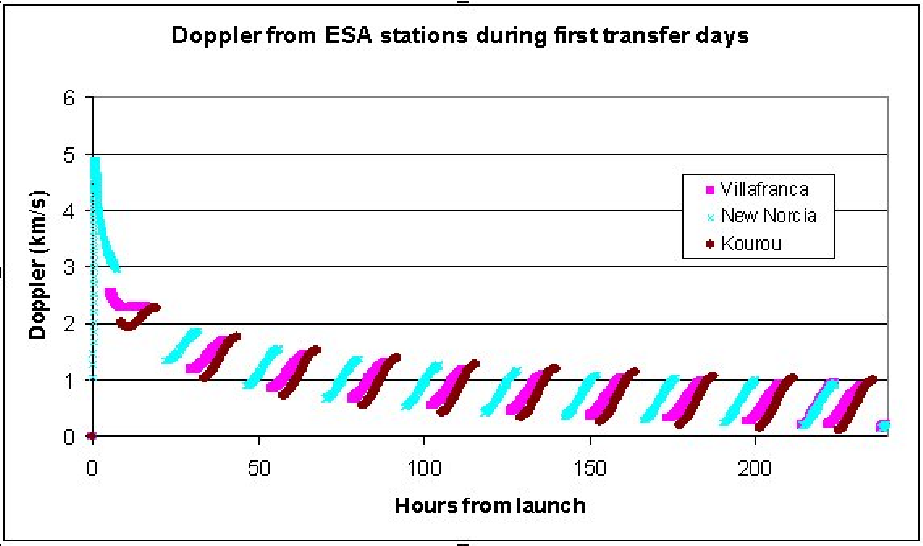


Figure 1-17 Doppler during first 10 days of transfer

1.2.3.2.6. Sun/satellite/station angle at separation

After launcher separation, HERSCHEL and PLANCK sunshields are both pointed in sun direction. The antenna used for the first station acquisition with New Norcia will depend on the variation of the sun-satellite-station angle just after the separation of the 2 satellites.

Since communication antennas are pointed either in sun direction (1 antenna) or in anti-sun direction (1 antenna for HERSCHEL, 2 antennas for PLANCK), a sun-satellite-station angle close to 90° is not very favourable: it means that satellite-station direction is on the edge of the antenna gain pattern or between two antennas.

The following figure presents the variation of sun-S/c-New Norcia angle during the first hour after the separation. New Norcia visibility (first station visibility slot after separation) begins about 12 minutes later. With a launch on 2007/08/15 at 13h, this angle is equal to 100° at the beginning of New Norcia visibility and then quickly decreases.

Consequently it is not possible to keep the same spacecraft antenna over the whole New Norcia pass. After separation + 18 minutes, this angle stays below 80° for the rest of the mission. Therefore the recommended strategy is to wait few minutes more and to cover the whole New Norcia visibility slot with the nominal sun-oriented antenna.

The same analysis has been performed for other launch dates/hours: it can be seen on the following figure that it impacts slightly the Sun-S/c-New Norcia angle after separation. However the same conclusions are applicable.

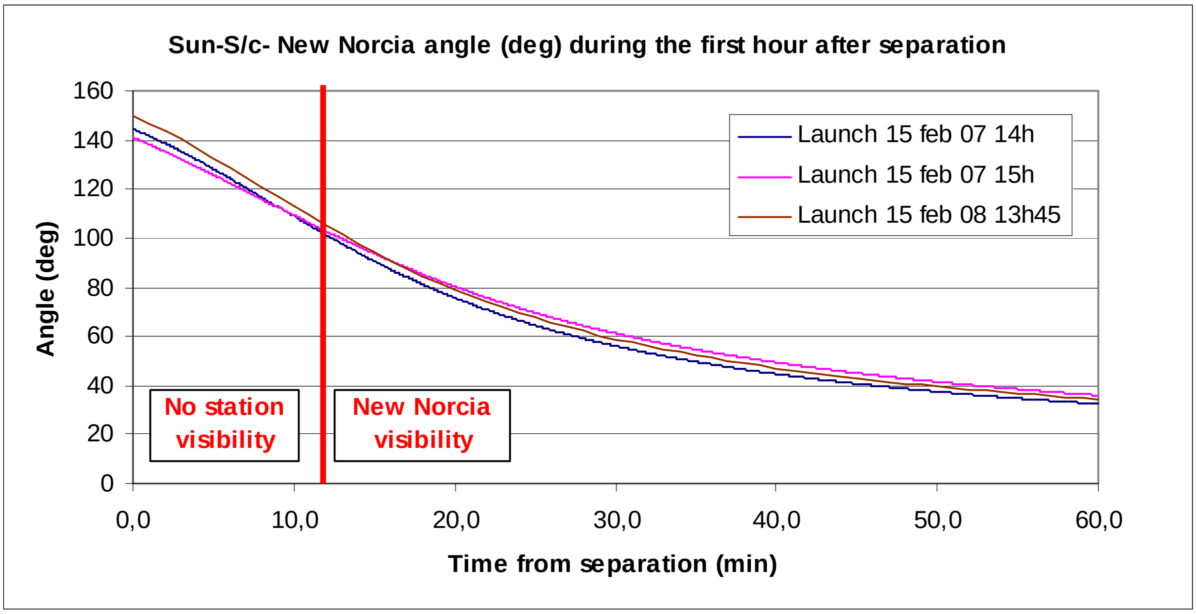


Figure 1-18 Sun-spacecraft-New Norcia angle after separation

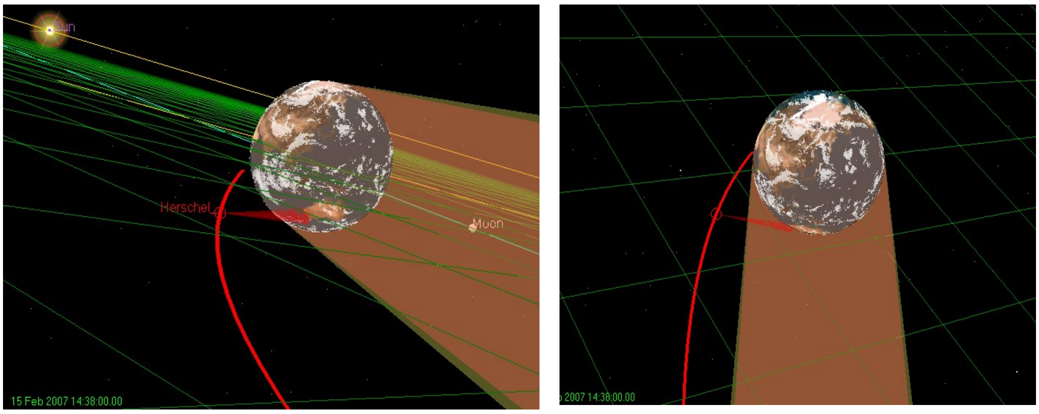


Figure 1-19 3d-View of Sun-sC-New Norcia geometry at beginning of visibility slot

1.2.3.2.7. SSCE constraint for data downlink

When no high rate telemetry is needed , omni-directional coverage is provided by the LGAs for both spacecraft.

Concerning MGA usage, the following table summarises the various possibilities:

GROUND STATION	DATA RATE	MAX ANGLE BETWEEN EARTH AND ANTENNA BORESIGHT	MAXIMUM SSCE FOR HERSCHEL	MAXIMUM SSCE FOR PLANCK
New Norcia	High	15 deg	45 deg	25 deg
New Norcia	Medium	15 deg	45 deg	25 deg
Kourou	Medium	10 deg	40 deg	20 deg

As shown in Section 1.2.3.1.2, the SSCE during transfer goes up to more than 30 deg. This is not a problem for HERSCHEL but it will limit the data transfer capability with PLANCK:

- SSCE is above 20 deg during typically 63 days without the possibility to have contact with Kourou at medium rate since day 33 after launch.
- SSCE is above 25 deg during typically 45 days without the possibility to have contact with New Norcia at medium or high rate since day 45 after launch.

At the time of maximum SSCE, the distance to Earth is close to the maximum so no improvement of the link budget can be expected. On the other hand the declination is close to 0, meaning a daily ground contact with New Norcia of 10.4 hours, equivalent to the one with Kourou (10.7 h). Commissioning phase is expected to be complete the 45th day. The performance verification will be stopped and can continue using New Norcia when the SSCE is between 20 and 25 deg. Taking into account a 2 months duration for the performance verification phase it will still finish before the 6 months allocated for transfer phase.

Note: with the new fast transfer to L2 strategy, the SCCE profile during the first will be modified with the goal to reduce the maximum SCCE. However, first results show that a maximum SCCE value of 32 deg can still be reach in some cases, thus leading to the need to use the LGA with a TM rate of 5 Kbps.

1.2.3.3. Star tracker blinding by the Moon

1.2.3.3.1. Dates and duration of the glares

For both spacecraft there is a 15-day long glare period during one Moon period of 28 days. The duration of the glare period is variable. The maximum duration occurs when the Moon is turning around Earth in the same direction as the spacecraft (see Figure 1-20). The glare period can last up to 3 days.

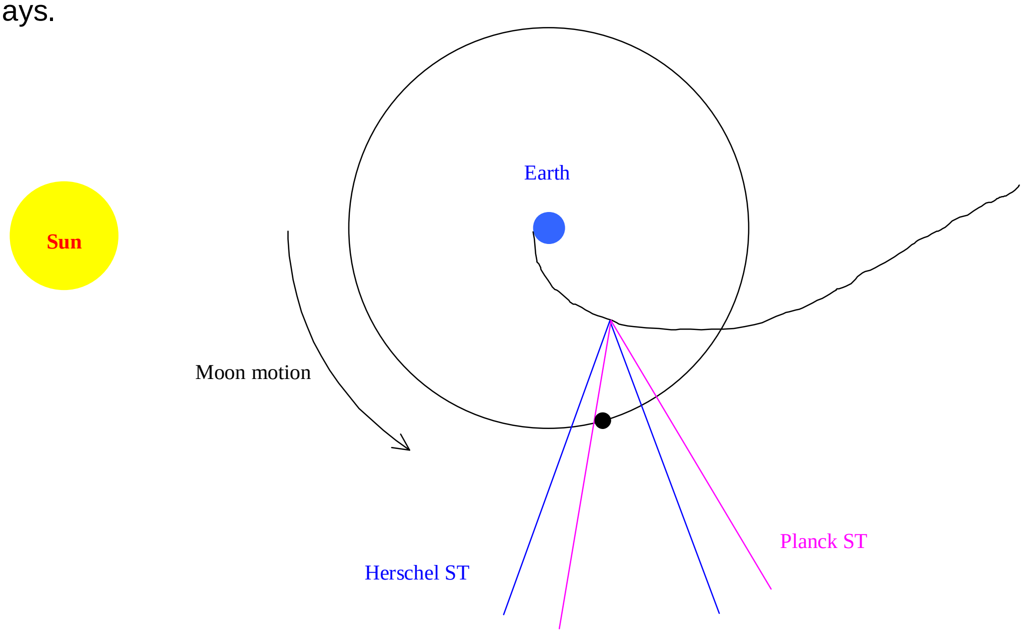


Figure 1-20 Simplified geometry of STR Moon blinding occurrences

The following figure shows Star mapper blinding at first orbit correction duiring the spring 2008.

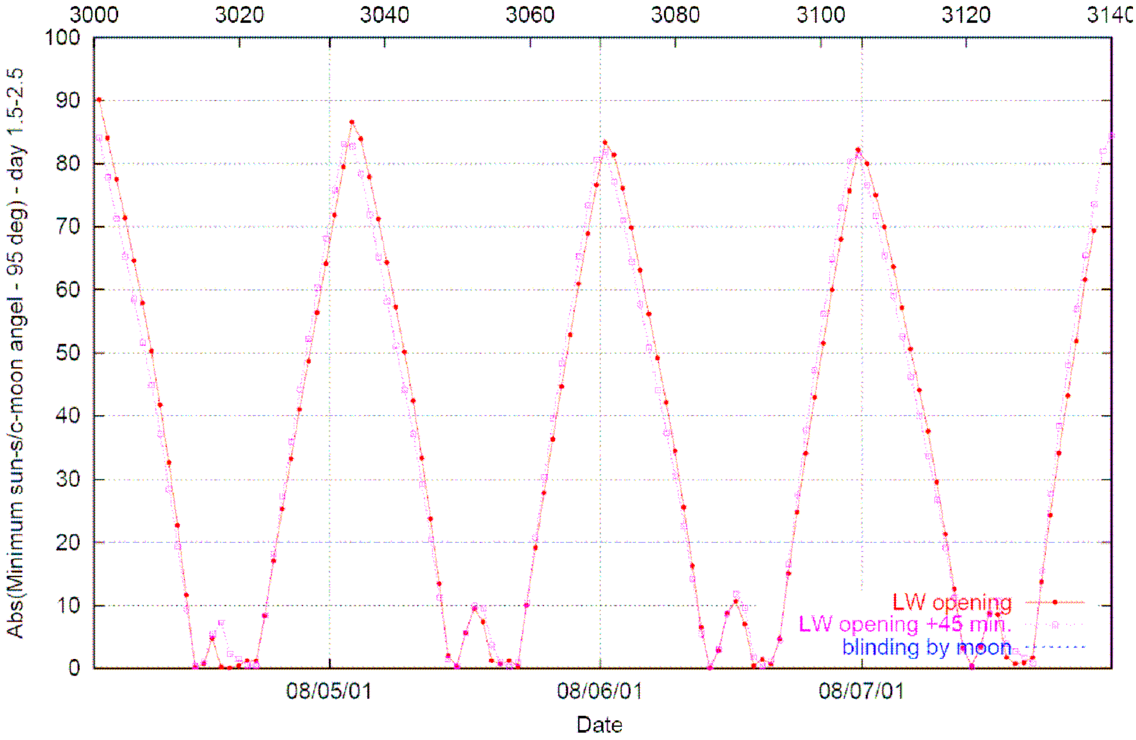


Figure 1-21 Star mapper blinding at first orbit correction

1.2.3.3.2. Resulting constraints for HERSCHEL

On Figure 1-22, limits of the unauthorised attitudes around Z for HERSCHEL during the glare periods for 6 possible launch dates. Unauthorised attitudes strongly vary with the launch date but unauthorised ranges of attitudes are very narrow: < about 40°.

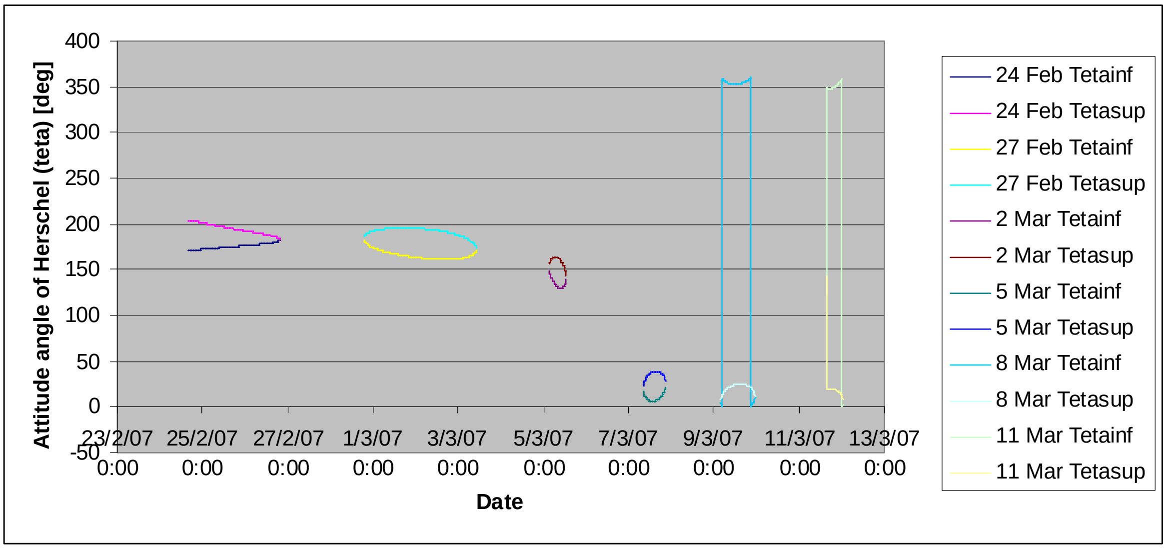


Figure 1-22 Unauthorised attitude ranges for HERSCHEL to avoid Moon blinding

Due to the manoeuvrability of HERSCHEL, the Moon interference will have to be taken into account when determining the attitude for the manœuvres of the first 2 days. As the SAA of these manœuvres is close to 180 deg, they will have to be decomposed into 2 manœuvres in any case. This will give more flexibility to find an attitude in which the STR is not blinded by the Moon. Another issue linked to the STR blinding by Moon is the fact that, in SAM, the spacecraft might stabilise in a position in which the STR is Moon (or Earth) blinded. This might hinder the SAM to OCM transition. The solution chosen to overcome this problem is to put a gyro bias during launch around Sun line to ensure that the S/C will not remain a fixed attitude in which the STR is blinded.

1.2.3.3.3. Resulting constraints for PLANCK

For PLANCK, the impact of the Moon interference is more severe. PLANCK will not be able to avoid glares during the glare periods since its attitude has to remain at a few degrees from Sun during delta-V manoeuvres. The baseline is to perform the correction of perigee velocity and of launcher dispersion 2 days after launch. In case of moon blinding, these manœuvres may need to be delayed up to day 4.5. The impact is an increase of manoeuvre amplitude which is included in the overall delta-V allocation.

1.2.4. Operational orbit

After transfer orbit phase, the mission phase begins at satellite insertion into operational orbit around L2.

1.2.4.1. Environment conditions

This section presents environment conditions on operational orbit: distance from Earth and Moon, Sun-satellite-Earth angle, and declination to Earth equator.

It is underlined that the following figures correspond to <u>typical</u> evolution of these parameters: the precise variation of these environment conditions will depend of course of the final launch date/time.

1.2.4.1.1. Distance to Earth and Moon

Figure 1-23 presents the distance to the Earth, which will drive the telecommunications and the radiation and thermal environment, and also the distance to the Moon. The left curves represents HERSCHEL, and the right ones PLANCK over 4.75 years of mission for HERSCHEL, and 2.75 years of mission for PLANCK. Note that the distance to the Earth and Moon are different for HERSCHEL and PLANCK satellites after the PLANCK insertion manoeuvre.

As required HERSCHEL distance to Earth remains below 1.8 Mkm and PLANCK distance to Earth remains below 1.6 Mkm.

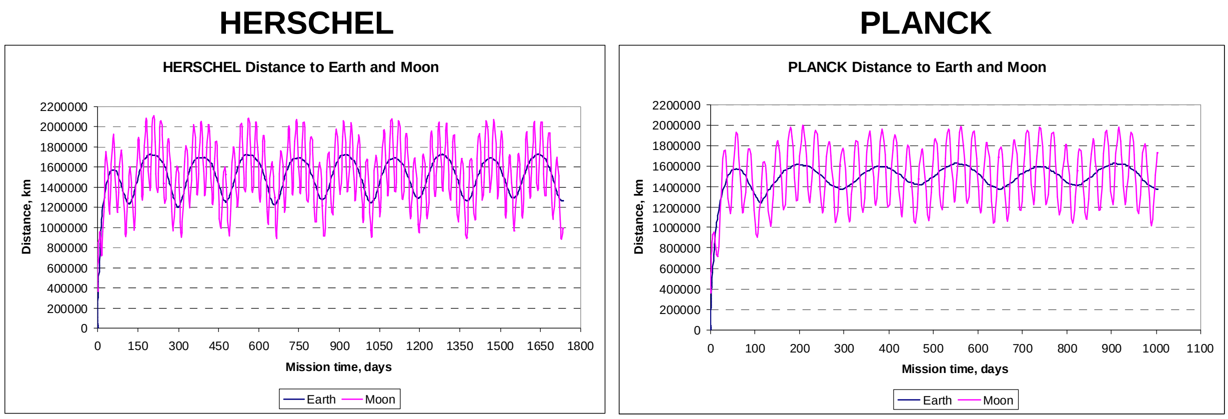


Figure 1-23 HERSCHEL and PLANCK distance to Earth and Moon on operational orbit

1.2.4.1.2. Sun-Satellite-Earth angle

The Sun-Satellite-Earth aspect angle is very constrained for both spacecraft due to the nature of the mission and the on-board equipment. It can be noticed in the following figures that maximum SSCE constraints of 30° for HERSCHEL and 15° for PLANCK are verified.

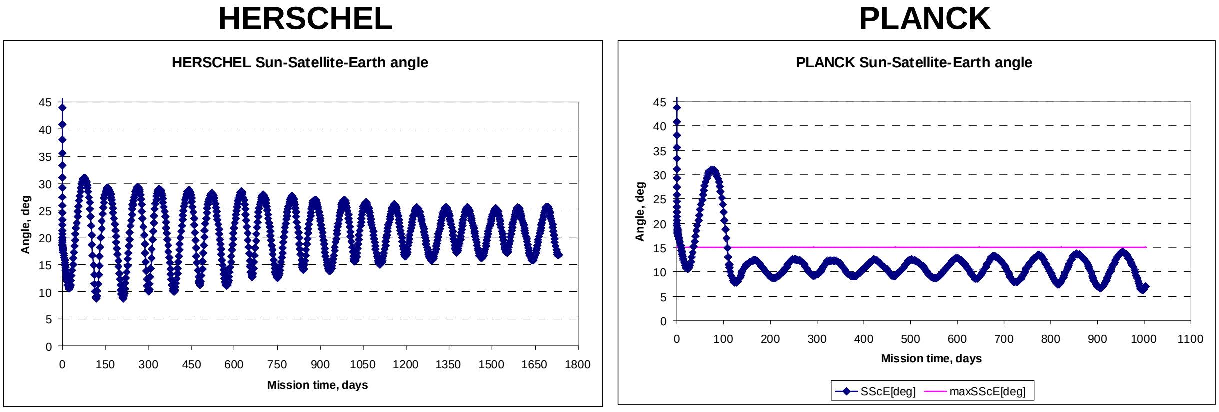
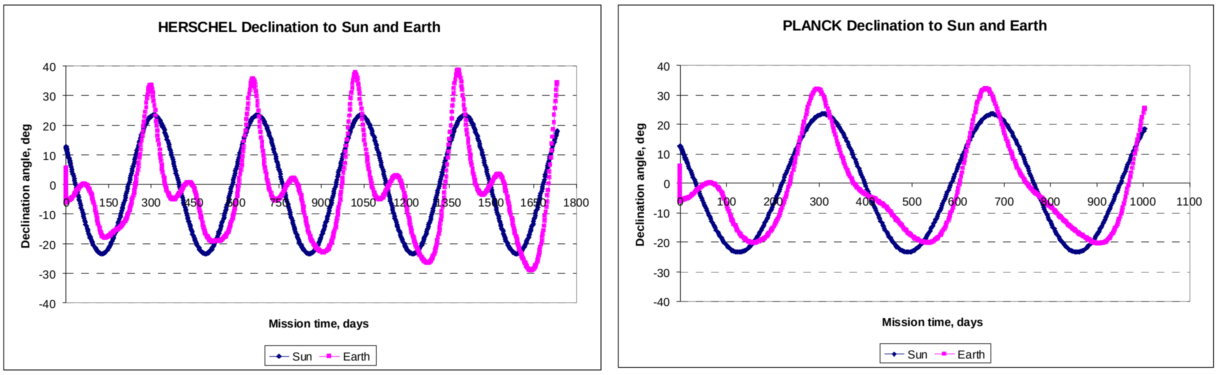


Figure 1-24 HERSCHEL and PLANCK Sun-satellite-Earth angle on operational orbit

1.2.4.1.3. Declination to Earth

Figure 1-25 presents the declination to the Earth, which will drive the telecommunications. Dedicated analysis on station visibility analysis is presented further in Section 1.2.4.2.



HERSCHEL **PLANCK**

Figure 1-25 HERSCHEL and PLANCK declination to Earth on operational orbit

1.2.4.2. Telecommunications during operational phase

See analysis of ground station visibility characteristics in Section 1.2.3.2.1.

During operational phase New Norcia is considered as the baseline ground station. As presented in the following figure, visibility problems with New Norcia (i.e. visibility slots shorter than 3 hours) occur when the spacecraft declination is above 45 deg. Contrary to the previous launch windows (based on A5 ECA with perigee shift and later launch time), the new launch window (based on A5 ECA without perigee shift) is fully compatible with a maximum declination below 41 deg over the full HERSCHEL lifetime. So daily visibility slots with elevation above 10 deg and duration longer than 3 hours are always available with New Norcia.

As mentioned in Section 1.2.3.1.1, the range rate (Doppler) on the operational orbit is small with respect to the beginning of the transfer phase. It is mainly due to the Earth rotation, and varies within about +/-0.5 km/s.

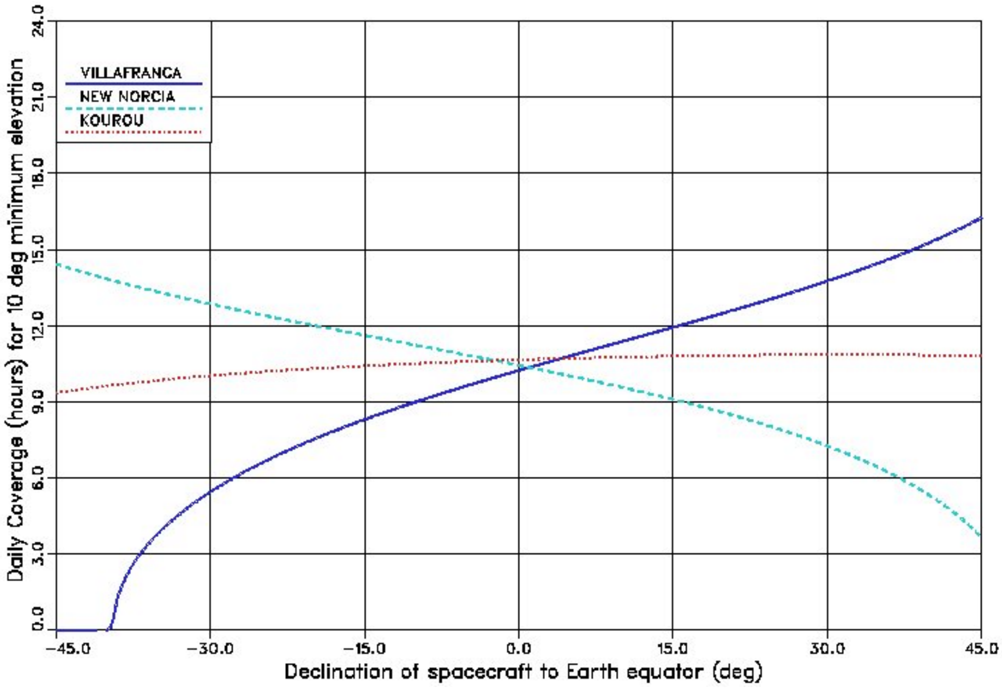


Figure 1-26 Daily coverage duration vs s/c declination - elev > 10 deg (from Crema)

1.2.4.3. Moon transit

During the orbital life, the moon may affect the mission by 2 effects:

- The moon may occult the Sun and then may reduce the power generation
- The moon may occult the Earth and then may interrupt the communication link.

Both effects are described below.

1.2.4.3.1. Sun occultation

When Sun-spacecraft-moon angle gets close to 0 deg, there can be some slots with partial sun eclipse by the Moon. Since sun apparent radius is 0.25 deg and since Moon apparent radius on the operational orbit is typically between 0.1 deg (distance moon-S/c: 1 000 000 km) and 0.05 deg (distance moon-S/c: 2 000 000 km), a partial eclipse can happen whenever the SSCM angle is below 0.35°.

As presented in CREMA, it is recommended to design spacecraft by assuming:

- For HERSCHEL there are no eclipses by the moon in the operational orbit except for one launch date.

- For PLANCK there will be typically two eclipses by the moon per year. In extreme cases there may be up to about 10 eclipses during the 2 years mission. Refer to the technical note H-P-1-ASP-TN-0855 (is 2 1/02/2007) no constraint are identified regarding the moon transist

- It is recommended to cover eclipses of up to 10 hours, with a depth up to 10% by the spacecraft design (13% if normalised to the power at 1 AU), and to allocate 5 m/s in the propellant budget to avoid the others.

The selected strategy for PLANCK during the moon transit is to do nothing (ref the TN above)

In case of eclipse duration over 10 hours, a manoeuvre of a fixed size (5 m/s) is applied at a fixed time (scan over times in first revolution, 10 days step) in a fixed direction in the plane spanned by the non-escape direction and the out-of-ecliptic vector (as proposed in CreMA).

1.2.4.3.2. Earth occultation

According to CREMA, the Moon may also interrupt the communication link to the ground station. Figure 3.71 from CREMA shows the Earth-spacecraft-Moon angle minus the angular size (half cone angle) of the Moon as seen from the spacecraft, for a 2007/9/9 launch case. It can be seen on Figure 1-27 that this angle will become less than zero only once per year.

The duration of such an occultation by the Moon is about 1 hour.

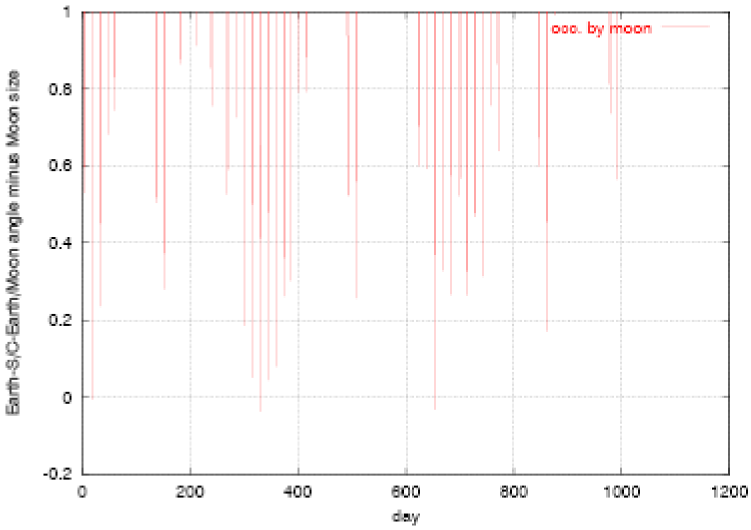


Figure 1-27 Occultations of the Earth by the Moon

1.2.4.4. Operational orbit maintenance strategy

The objective of the orbit maintenance strategy is to correct the deviations observed on the satellites. Due to the instability of the Lagrangian point, it is necessary to correct these orbit deviations without too much time delay and with a good accuracy.

The Lissajous orbits are not stable orbits: if one solves the linear equation for arbitrary initial conditions, exponential terms with positive exponent appear in the solution for the X and Y components. The initial conditions have to be carefully chosen to get a non-escape orbit with periodic terms and decreasing exponential terms only in the solution.

It can also be proven that any Delta-V performed along a specific direction in the [X, Y] plane, called the non-escape direction, produces a transfer from a non-escape orbit to another non-escape orbit with a different amplitude. This non-escape direction lies in the [X, Y] plane at an angle 61.6 deg from the X axis (see Figure 1-28).

On the other hand, Delta-V performed along the escape direction, perpendicular to the non-escape direction, produce a transfer from a non-escape orbit to an escape orbit or vice versa.

The escape direction, with an angle of 28.4 deg to the X axis, is the one used for orbit maintenance: it allows to cancel any unstable terms appearing in the orbit due to external disturbances.

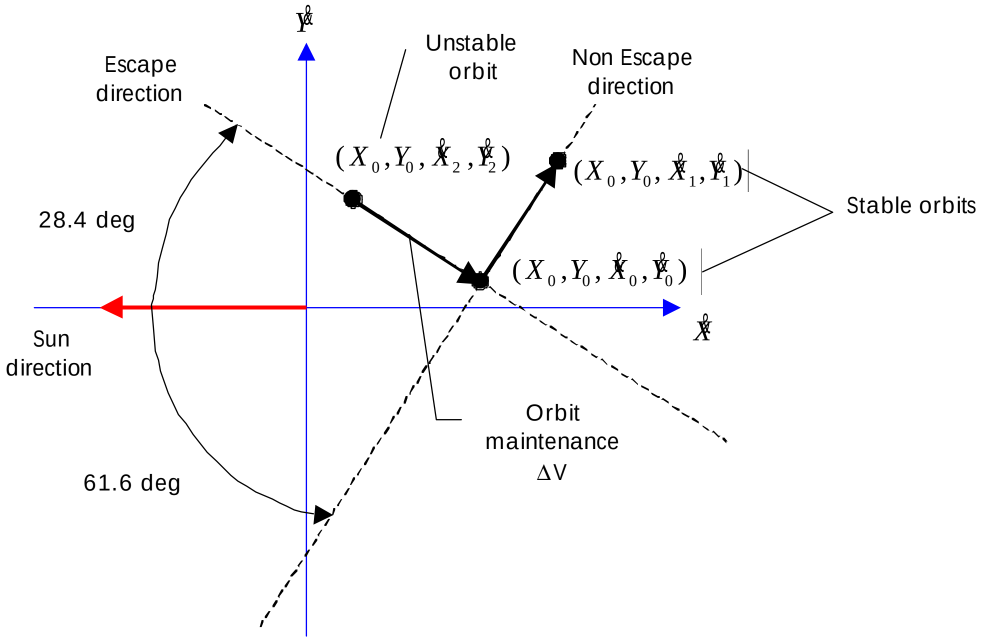


Figure 1-28 Escape and non-escape directions in the XYZ Earth rotating frame

One major factor is the eclipse avoidance that is ensured by the orbit maintenance strategy. This is performed by eclipse avoidance manoeuvre that can be performed, for instance, along the non-escape direction.

Several methods have been applied to compute the orbit correction strategy for both spacecraft. The results give an orbit maintenance cycle including one manoeuvre per month. The amplitudes of the correction may vary but averaged value of 1 m/s per year for both spacecraft has been selected.

The wheel off-loading thrust affects the orbit maintenance strategy since they can generate delta-V along escape direction. The impact has been investigated in RD-01: allocations of 4.4 m/s and 2 m/s respectively for HERSCHEL and PLANCK are taken in the delta-V budget to cover this effect.

1.2.4.5. Mission delta-V budget

This paragraph synthesises the Delta-V results for both spacecraft that will allow computing the satellite mass budget breakdown from beginning of life to end of life.

It includes the contributions from the transfer phase and also the orbit maintenance contribution explained in Section 1.2.4.4.

With the new method of fast transfer to L2, the approach for delta-V budget has been modified for Planck. A total allocation of 406 m/s is taken into account, which includes all the orbit acquisition manoeuvres. This takes into account the thrusters efficiency and no margin has to be taken on top of it. For Planck orbit maintenance, 1m/s per year has to be taken into account.

For Herschel, the delta-V budget is broken down into the various manoeuvres. Due to the need of Planck delta-V optimisation, the launcher perigee velocity for Planck and thus Herschel has been reduced by 2 m/s: this generates a penalty of 16 m/s on the perigee velocity variation for Herschel. For Herschel orbit maintenance, 3 m/s per year has to be taken into account.

Table 1-9 present the Delta-V budgets for HERSCHEL and PLANCK for the direct injection scenario with the A5-ECA launcher.

MANOEUVRE	HERSCHEL DELTA-V (M/SEC)	DIRECTION OF DELTA-V (SUN ASPECT)
Perigee velocity correction Day 2	42	[145-175] deg
Removal LV dispersions Day 2	45	[145-170] deg
Manoeuvre 2 Day 12	3	[0-180] deg
Mid course corrections $T_{injection}$ – 20 days	2	[0-180] deg
Orbit maintenance for extended lifetime	13.5	28.4 or 208.4 deg
Orbit maintenance due to attitude control	7.8	28.4 or 208.4 deg
Total	**113.3**	

MANOEUVRE	**PLANCK DELTA-V (M/SEC)**
Overall allocation for orbit acquisition	406
Orbit maintenance for extended lifetime	2.5
Orbit maintenance due to attitude control	2
Total	**410.5**

Table 1-9 Delta-V budget for HERSCHEL and Planck (A5-ECA, 15 deg orbit)

1.2.5. Orbit determination

1.2.5.1. LEOP and transfer orbit determination

The first acquisition of the spacecraft will be from New Norcia station around 18 minutes after separation.

The following figure shows elevation versus azimuth for the first ground station pass from New Norcia.

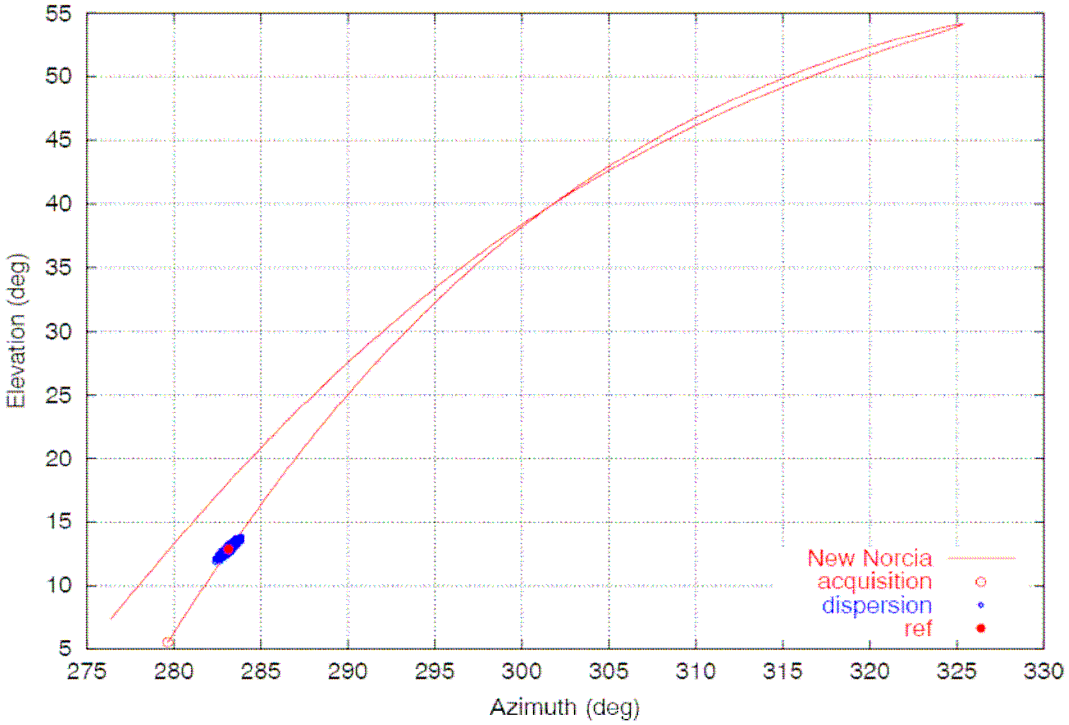


Figure 1-29 First tracking path from New Norcia

The corresponding dispersion (3σ) at tracking acquisition is given in the following table:

Azimuth	(deg)	0.76078
Elevation	(deg)	0.97435
Distance	(km)	131.8175 1
Dopler	(km/s)	0.09963
Long track	(deg)	1.20528
Cross track	(deg)	0.27469

Table 1-10 Tracking dispersion values

Due to the increasing distance, the cross track error reduces and the long track error increases for the first few minutes and then reduces. This is shown in the following figure.

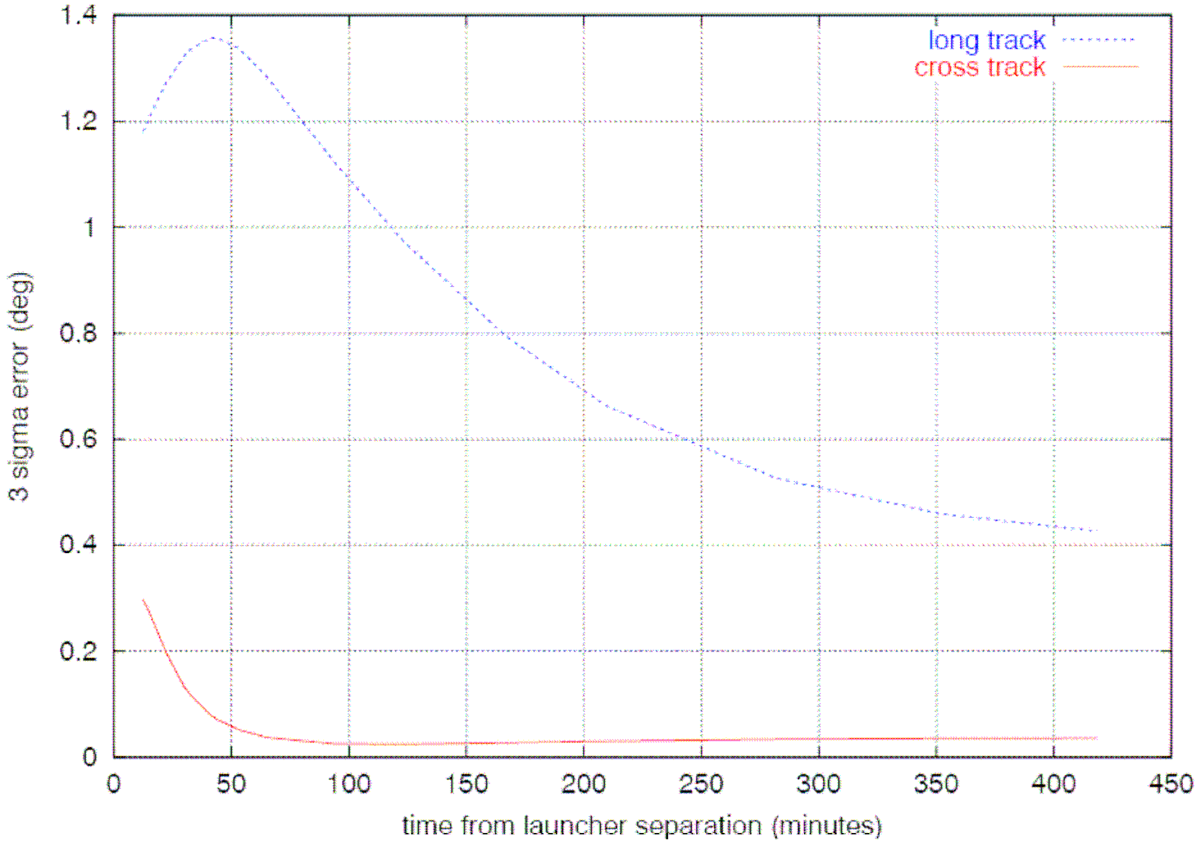


Figure 1-30 Long track and cross track error as a function of time

1.2.5.2. Operational orbit determination

On operational Lissajous orbit, orbit determination will be performed routinely everyday on the basis of tracking data acquired at each New Norcia visibility slot.

- Two ranging measurements (5 minutes each) can be performed at the start and at the end of New Norcia visibility slot. The reduction to 2 range points was done because the link budget did not allow ranging and commanding at the same time. It is assumed that:
  - range noise is below 2 m (1-sigma) above 15° elevation
  - range noise is below 20 m (1-sigma) under 15° elevation
  - and bias below 20 m (1-sigma).

  Note: according to CREMA 3.1 a second range point per station pass would not contribute much. Therefore only one ranging measurement per pass should be enough. This could lead to a scenario where ranging is executed either at the beginning or end of the pass, depending on the requirement about minimum elevation for good ranging results.

- Doppler tracking is done simultaneously with commanding and telemetry transmission during the New Norcia visibility interval. It is assumed that Doppler sample points are acquired every 10 min during 3 hours, and that:
  - Doppler noise = 0.1 mm/s (1-sigma) above 15° elevation
  - Doppler noise = 1 mm/s (1-sigma) under 15° elevation
  - And no Doppler bias.

It is noted that these assumptions (considered in Crema 3.0) are a little more optimistic than the Doppler noise error reachable with the TTC transponder (> 0.5 mm/s). It could have a small impact on orbit determination accuracy performances.

With Crema 3.0 assumptions recalled here above, the reachable orbit determination accuracy is (at 1-sigma):

- For HERSCHEL:
  - Position: 1-24 km
  - Velocity: 3-12 mm/s.
  - Distance: 45 m
- For PLANCK:
  - Position: 0.5-13 km
  - Velocity: 3-10 mm/s.
  - Distance: 30 m.

1.3. THE MISSION REQUIREMENTS AND CONSTRAINTS

1.3.1. Mission constraints

The following mission requirements/constraints were used as drivers in the design and implementation of the HERSCHEL and PLANCK satellites.

1.3.1.1. Orbit compatibility

The HERSCHEL and PLANCK spacecrafts will be launched at a time of day compatible with a Lissajous orbit around Lagrange point L2 of the Sun-Earth system.

1.3.1.2. In-orbit lifetime

The HERSCHEL and PLANCK platforms are designed to meet an in-orbit lifetime requirement of:

- 6 months transfer to L2 + 3 years nominal for HERSCHEL
- 6 months transfer to L2 + 15 months nominal for PLANCK.

All elements that are subject to degradation in orbit, together with consumables are sized to cope with a lifetime of:

- 4.5 years for HERSCHEL
- 2.5 years for PLANCK.

1.3.1.3. Commonality

The HERSCHEL and PLANCK platforms design is optimised to minimise the needs for changing the design of the SVM subsystems and/or units developed in the frame of the two projects.

1.3.1.4. Autonomy

HERSCHEL and PLANCK will operate for most of the lifetime without ground support.

The satellite autonomy is conceived to meet the requested 48 hours of autonomy (i.e. worst case when one daily ground contact is lost).

Implementation of the Mission TimeLine (MTL) concept (defined as a sequence of time-ordered telecommands up-linked from ground during each daily communication period), together with the FDIR functionality and the On Board Control Procedures (OBCPs) capability, will allow to control and manage the S/C functions and the scientific observation with the required autonomy.

1.3.1.5. Spacecraft survival mode

Both the satellites will be able to survive in a safe mode for at least 7 days without the need for ground intervention.

1.3.2. Attitude constraints

HERSCHEL and PLANCK being cryogenic satellites, their payload modules are nominally planned to be always in shadow. In addition, for increased thermal performance, coating materials with low emissivity are used in the PLM's; these materials will reach high temperature when exposed to the sun.

During Phase C/D, inputs from Arianespace has shown that the launcher cannot guarantee that the PLM's are always maintained in the shadow. This is especially true for the HERSCHEL PLM that can be exposed to the sun after fairing jettison. On the opposite, the PLANCK PLM remains shadowed under SYLDA for the whole flight: only conditions at separation from launcher can lead to Sun illumination of the PLM.

The following sections detail the attitude constraints for each satellite. Two main phases are considered:

- Launch
- In-orbit phase.

1.3.2.1. HERSCHEL attitude constraints

Launch phase

Two type of constraints have to be considered during the launch phase:

- Steady state attitude constraints
- Transient attitude variations.

In Roll, the steady state attitude excursions are due to:

- Launcher Roll attitude control
- Variation of the Sun direction over a day in the launch window
- Variation of the Sun direction with the launch date.

A value of ± 26 deg has been allocated to cover these effects.

In Pitch, the attitude constraints are set by to events:

- Sun Aspect Angle at fairing opening: a value of 20 deg is considered as the baseline for CDR. Considering a 5.5 deg launcher inaccuracy for this event, it means that a value of 25.5 deg SAA at fairing opening has to be considered for launch window determination. The SAA of 20 deg at fairing opening has been imposed by the need to increase launcher performance. The previous value was 50 deg.

- Sun Aspect Angle at H3: a maximum value of 140 deg SAA is considered. Considering a 3 deg launcher inaccuracy for this event, it means that the launch window has to be compliant with a maximum SAA at H3 of 137 deg.

The resulting allowed Sun directions are shown in the following figure. They are also applicable during the SCAR phase, from EPC shutdown to HERSCHEL separation from launcher.

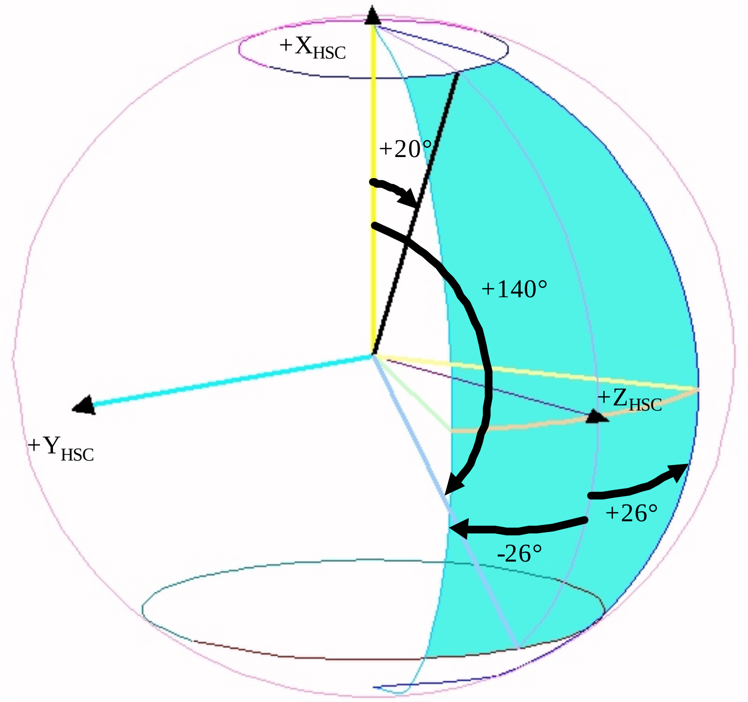


Figure 1-31 SAA constraints during launch

The transient attitude behaviour is due to the fact that during transient events (EAP separation, EPC separation) the roll attitude control is not strong enough to counteract the parasitic torque. This can lead to a complete rotation in roll of the spacecraft. This is shown in the following Figure:

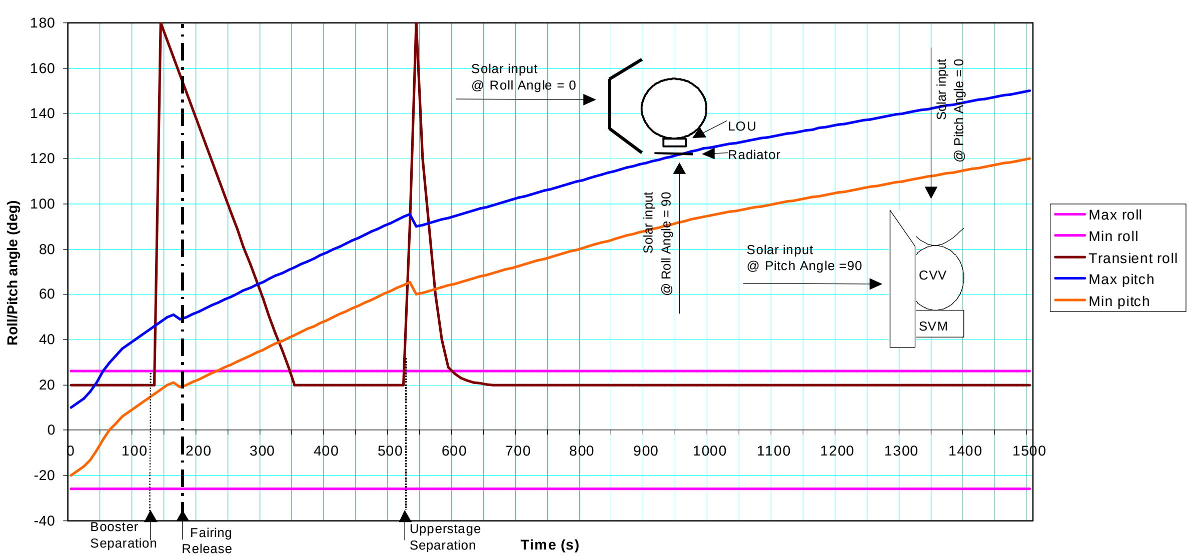


Figure 1-32 Roll and Pitch attitude during launch

The figure clearly shows the 2 transients:

- Booster separation: the transient begins before fairing separation but launcher is not yet back in its nominal attitude at the time of fairing jettison. The roll rate to consider during this phase is low: 0.5 deg/s
- EPC separation: for this case, a higher roll rate of 3 deg/s can be considered.

In-orbit phase

HERSCHEL is a three-axis stabilised, observatory type satellite. Its typical scientific mission consists in pointing successively at various targets in the sky according to a predefined schedule.

At any time in the mission, the whole sky is not accessible. This is due to the fact that the cold payload has to be protected from the Sun to remain operational. Any rotation around the Sun direction is allowed as it does not change the lighting conditions. Rotations around the perpendicular to the Sun direction are constrained in order to limit the size of the shield protecting the payload. The constraints are shown in Figure 1-33:

- between -1° and +1° from the (XHSC , ZHSC) plane
- between +60° and +120° from the +XHSC axis.

Full scientific performance has to be reached within this operational zone.

To allow flexibility for ACMS around this operational zone, it has been specified that no illumination of the H-EPLM shall occur for:

- between -5° and +5° from the (XHSC , ZHSC) plane
- between +58.5° and +121.5° from the +XHSC axis.

In addition, to take into account failures of the ACMS close to the operational zone limits, a contingency zone for transient shorter than 1 min has been defined:

- between -10° and +10° from the (XHSC , ZHSC) plane
- between +55° and +125° from the +XHSC axis.

These zones are shown in the following figure:

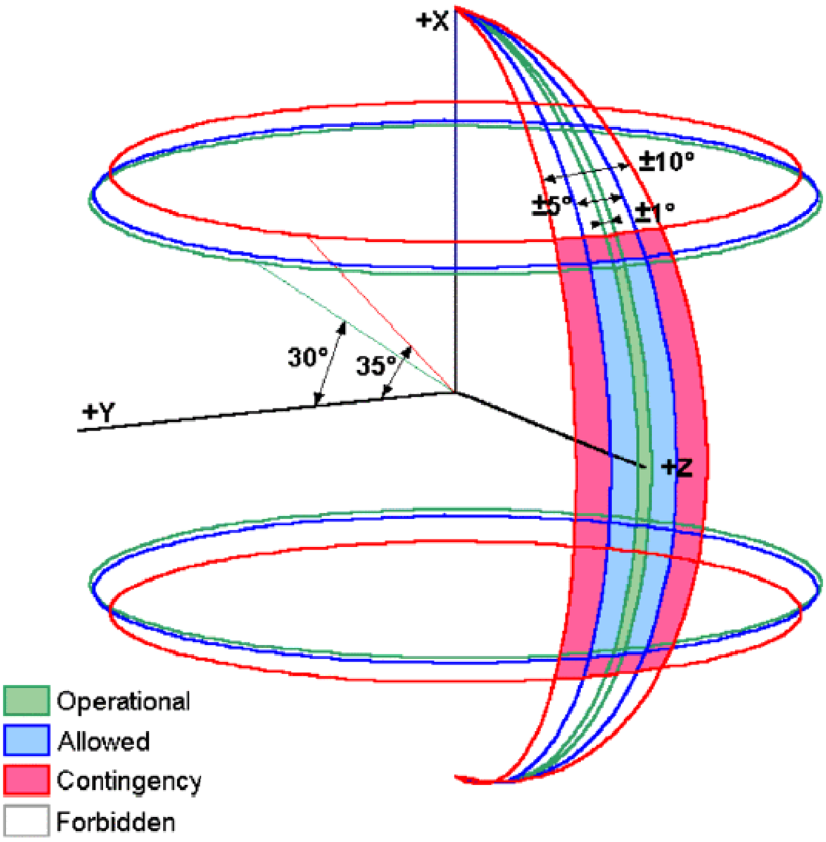


Figure 1-33 HERSCHEL Sun pointing zones

The HERSCHEL Sunshield/Sunshade protecting the payload has thus to be designed such that no part of the cryostat or telescope are hit by the Sun light for any Sun direction within the allowed one.

1.3.2.2. PLANCK attitude constraints

Launch phase

PLANCK is protected by the SYLDA up to HERSCHEL separation. At that time, the hole at the top of SYLDA 5 will be open with a risk of illumination of the PPLM top. The angle between the Sun and the launcher (Y_L, Z_L) plane shall be maintained below 10 deg.

In-orbit phase

The PLANCK attitude profile is very different from the one from HERSCHEL. PLANCK is a spinner that systematically scans the celestial sphere to produce a sky map. As shown in Figure 1-34, the PLANCK spin axis is normally opposite to the Sun, with the telescope line of sight at 85 deg from the spin axis. During one rotation, the instruments scan a sector of the celestial sphere with an angular diameter of 85 deg.

In order to view the celestial poles, it is thus mandatory to be able to depoint the spin axis by from the Sun direction. A scanning law that depoints the spin axis at 10 deg maximum from the Sun will be defined, in order to achieve scientific objectives. This means that the spacecraft has to be compatible with a maximum angle of 10 deg between the spin axis and the Sun. This is shown in Figure 1-35.

Due to the fact that PLANCK is in orbit around L2, it makes one rotation around the Sun per year. The spin axis has also to rotate at the same rate to remain Sun pointed. This is achieved by making regular precession manoeuvres that also includes out of plane motion to achieve the PLANCK scanning law. This scanning law is constrained by the fact that the angle between the spin negative axis (-XS) and the direction from satellite to Earth has to remain below 15 deg.

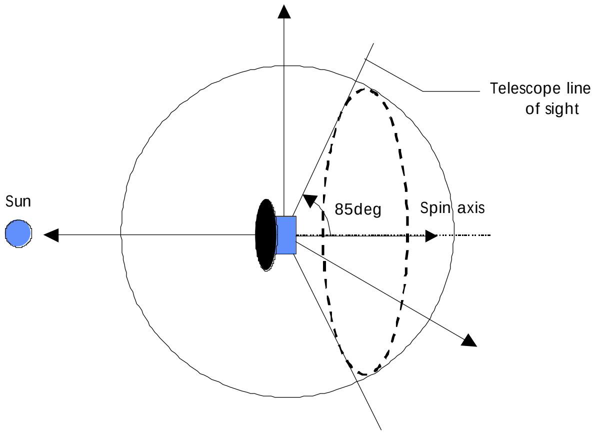


Figure 1-34 PLANCK observation strategy

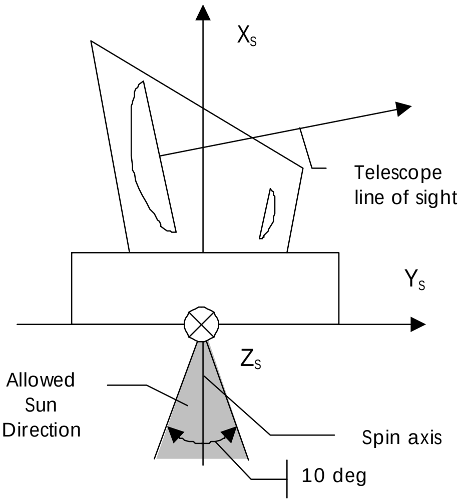


Figure 1-35 PLANCK attitude constraints: the sun in constrained to remain within 10 deg from the spin axis

1.3.3. Baseline launch window

The launch window is presented in Figure 1-36 and Figure 1-37. This corresponds to the injection strategy of Crema 3.1. It has been computed for the whole year 2007 (Jan to Dec). No significant differences appear in the 2008 launch window.

With the fast transfer to L2 strategy, the admissible days are the following:

- 24/07/08 - 08/09/08 (46 days)
- 03/10/08 - 24/01/09 (113 days)
- 23/02/09 - 05/03/09 (10 days)
- 30/03/09 - 28/04/09 (29 days)
- 06/07/09 - 23/07/09 (17 days)

With the fast transfer to L2 strategy, the launch hour is between 11:30 and 15:00 UTC, which corresponds to 7:58 to 11:28 in KOUROU local solar time. The standard daily slot for ARIANE 5 launch window is 45 min: this constraint is satisfied for all the days within the selected intervals.

The total launch window covers a duration of 6 months. The launch window is closed about 1 month around each Equinox due to eclipses occurrence.

The launch window is closed also during a large period in May to June because of PLANCK delta-V constraint.

Besides taking into account some additional constraints has refined this launch window:

- Remove points with eclipse avoidance manœuvres on HERSCHEL
- Remove dates with eclipse during transfer within the 45-min daily slot
- Remove dates with extreme perigee velocity variation (all remaining dates lead to a perigee velocity variation < +/- 3.5 m/s): this allows to reduce the number of ARIANE flight programs and/or the delta-V allocation for correction of perigee velocity variations (manœuvre at day 1).

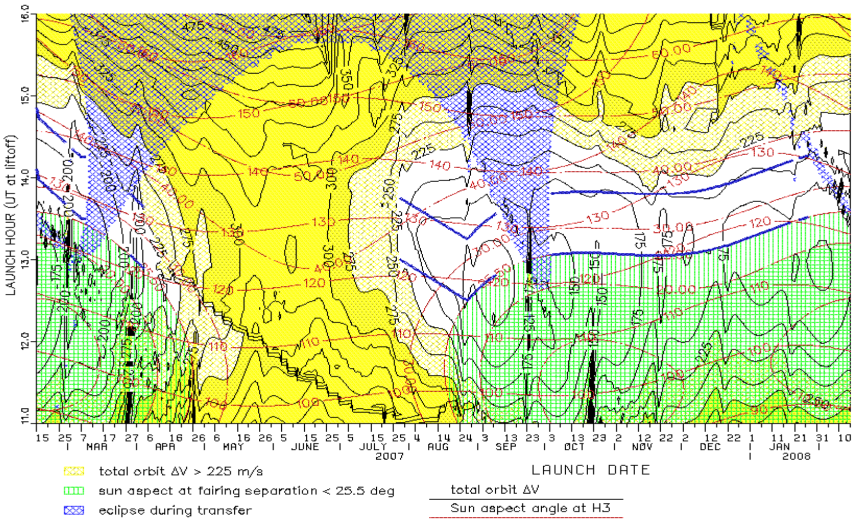


Figure 1-36 Year 2007 launch window for HERSCHEL and PLANCK (A5-ECA, PLANCK 15 deg)

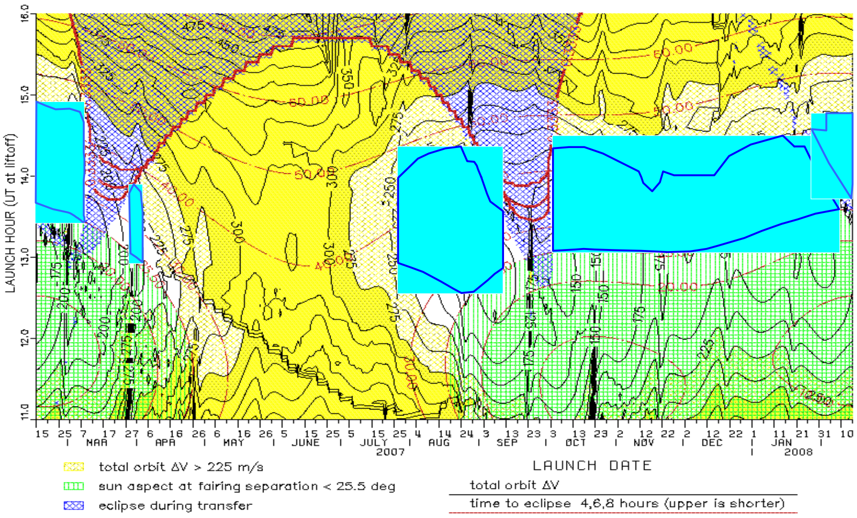


Figure 1-37 Launch window without refinements

1.3.4. SSCE constraint for data downlink

HERSCHEL

During observation phase, the HERSCHEL spacecraft is repointed to Earth before each DTCP in order to ensure optimal communications. The telemetry link is established via the MGA, in order to ensure high data rate link. This antenna is oriented along the spacecraft Z axis.

Since the MGA has an half cone aperture of 15 deg, in the worst case SSCE of 40 deg the Sun can be maintained at a maximum angle of 25 deg w.r.t. solar array normal. This is shown in Figure 1-38. At 15 deg aperture, the antenna gain is 16 dB which is compliant with the need for high data link rate with New Norcia. Going up to 30 deg Herschel de-pointing would allow to accommodate SSCE up to 45 deg.

For telecommunication with Kourou, higher antenna gain is needed: the link budget is positive with a maximum angle between antenna axis and Earth direction of 12 deg. So, with a maximum SCCE of 40 deg, a maximum SAA of 28 deg would be required for communications with Kourou. Going up to 30 deg Herschel de-pointing would allow to accommodate SSCE up to 42 deg.

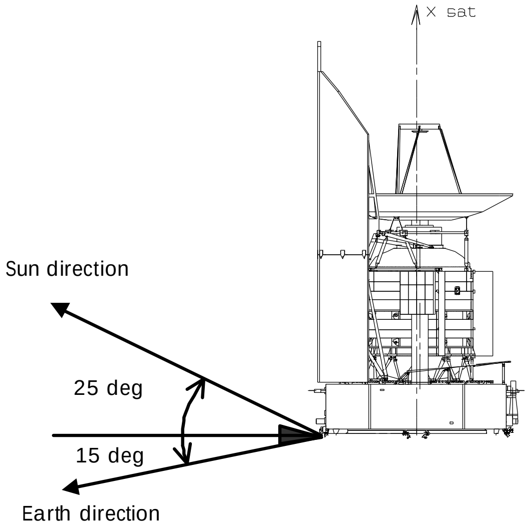


Figure 1-38 HERSCHEL communication with Earth (New Norcia case)

In the case of communication with New Norcia, the MGA has a half cone aperture of 15 deg. This means that if the SCCE is below 15 deg, free rotation around yaw (Z axis) is allowed: this is realised by aligning the Z axis with the Sun direction. Then, any rotation around Z axis will keep the Earth within the MGA field of view.

If the SSCE is above 15 deg, full freedom in yaw is not anymore available. However, the constraints to be respected are Sun in the (X,Z) plane and Earth with 15 deg from Z axis. For SSCE below 45 deg, these two constraints allow some freedom of rotation around Sun direction and around Y axis.

For HERSCHEL, a SAA constraint also applies if a DTCP longer than 3 hours has to be realised. In hot case with the Sun direction at 90+30 deg from X axis, the TWTA reaches its maximum operating temperature after 3 hours. During DTCP, it is always possible to maintain the Sun between 90 and 90-30 deg from X axis. This corresponds to a colder thermal case for the SVM due to the reduced Sun illumination.

In that case, it can be shown that even with the Sun at 90 deg from X axis, which is the hottest case in this range, the TWTA can stand a communication period of 13 hours per day in hot conditions. In summary, the operational constraints are the following:

- If the DTCP duration is limited to 3 hours, no constraint exists
- For DTCP duration longer than 3 hours, the operational constraint is to have the Sun between 90 and 90-30 deg from X axis.

PLANCK

During operational orbit, the satellite spin axis can be depointed by 10 deg from the Sun and the SSCE can be up to 15 deg with the increased PLANCK orbit size. Combining these two cases could lead to have the Earth at 25 deg from the spin axis. However, during operational orbit, mission planning will ensure that the Earth-spin axis angle remains 15 deg. With a -X pointed MGA, the Earth will be at maximum 15 deg from antenna axis during operational orbit as shown in Figure 1-39.

For communication with Kourou, mission analysis shall ensure that the angle between Earth and spin axis remains below 10 deg.

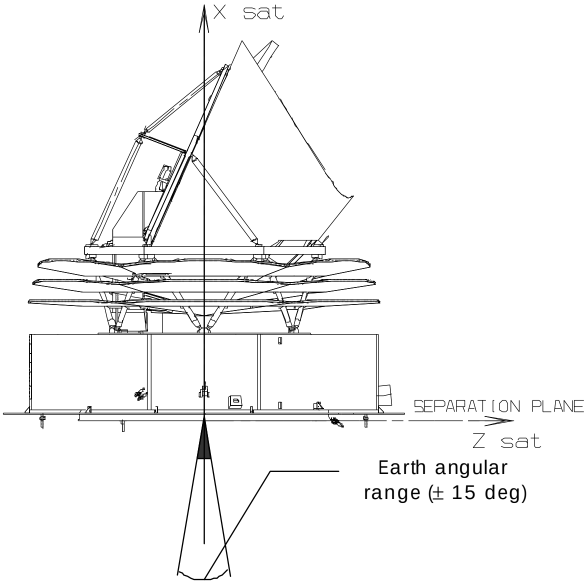


Figure 1-39 PLANCK communication with Earth

1.3.5. Planck 1N thruster constraints

During the qualification of the 1N thrusters it appeared that, at intermediate temperatures between 250°C and 400°C, the firing of the thruster could generate pressure pulses which, by fatigue, can lead to the rupture of the downstream mesh of the cat bed. This is due to the fact that, in this temperature range called Thermal Transition Range, there is a transition of the hydrazine decomposition mechanism from catalytic decomposition to thermal decomposition which generates unstabilities.

Consequently, the user manual of the 1N thrusters (User/Operation for the Herschel-Planck Reaction Control Subsystems (RCS), H-P-RILAM-MA-004) recommends to avoid operation of the 1N thrusters between 250°C and 400°C for pulses longer that 200 ms.

Corrective actions have been applied at system level to limit the impact of this limitation on operations but constraints remain on the way the 1N thrusters can be operated. Different constraints have been defined depending on the nature of the slew: slew part of the scanning law, small slew not part of the scanning law, large slews.

1.3.5.1. Slews part of the scanning law

This type of slews is executed using the HCM small slew manoeuvre. This manoeuvre uses only one 1N thruster at a time. It consists in 3 pulses with the following timing

- 1 minute maximum to wait for proper phasing of the satellite
- 1st main pulse
- 2 minutes waiting time to small intermediate pulse
- 1 minute waiting time to 2nd main pulse

Taking into account the temperature limitation and the cool-down time during pulses, the following tables gives the maximum amplitude which can be achieved as a function of mission epoch. The amplitude also depends on the branch which is used as the lever arm of nominal and redundant thrusters are not the same: 0.48 m for nominal thrusters (Branch A), 0.4 m for redundant thrusters (Branch B).

Tank pressure (bars)	Level arm (m)	Kinetic momentum (kg m^2)	Slew (arcmin)
22	0,48	329,3	3,7
18	0,48	325,8	3,8
12	0,48	316,4	3,7
5,5	0,48	301,6	3,6

Table 1-11 Maximum amplitude for a HCM small slew with nominal thrusters

Tank pressure (bars)	Level arm (m)	Kinetic momentum (kg m^2)	Slew (arcmin)
22	0,4	329,3	3,1
18	0,4	325,8	3,2
12	0,4	316,4	3,1
5,5	0,4	301,6	3,0

Table 1-12 Maximum amplitude for a HCM small slew with redundant thrusters

It can be seen that the maximum amplitude for a HCM slew is almost constant with tank pressure, between 3.6 and 3.8 arcmin for nominal thrusters, between 3.0 and 3.2 arcmin for redundant thrusters.

At the end of a maximum amplitude manoeuvre, the catbed temperature is 250°C. In order to wait for catbed cooldown to 160°C, the next manoeuvre shall not start less than 11 minutes after the end of the previous manoeuvre.

1.3.5.2. Small slews not part of the scanning law

For this type of manoeuvres, the HCM large slew will be used. The manoeuvre is performed using 2 thrusters. It consists in 3 identical pulses with 2 min OFF time between them. The manoeuvre timing is thus:

- 1 minute maximum to wait for proper phasing of the satellite
- 3 pulses in 4 minutes

Taking into account the temperature limitation and the cool-down time during pulses, the following tables gives the maximum amplitude which can be achieved as a function of mission epoch for nominal and redundant branch.

Tank pressure (bars)	Level arm (m)	Kinetic momentum (kg m^2)	Slew (arcmin)
22	0,48	329,3	8,0
18	0,48	325,8	8,2
12	0,48	316,4	8,0
5,5	0,48	301,6	7,7

Table 1-13 Maximum amplitude for a HCM large slew with nominal thrusters

Large slew	Level arm	Kinetic momentum	Slew (arcmin)
22	0,4	329,3	6,7
18	0,4	325,8	6,8
12	0,4	316,4	6,7
5,5	0,4	301,6	6,4

Table 1-14 Maximum amplitude for a HCM large slew with redundant thrusters

In terms of slew rate, it can be interesting to perform up to 3 manoeuvres in a row to perform slews of 23 to 24 arcmin with nominal thrusters and 19 to 20 arcmin for redundant thrusters. A cool-down time of 11 minutes shall be respected between manoeuvres to allow catbed temperature to come back to 160°C at the start of each manoeuvre.

The timings for such a case is the following
- 1st HCM large slew manoeuvre: 5 minutes
- Cool-down time: 11 minutes
- 2nd HCM large slew manoeuvre: 5 minutes
- Cool-down time: 11 minutes
- 3rd HCM large slew manoeuvre: 5 minutes
- Time for estimator to converge before returning to science: 7 minutes

This means that such a manoeuvre will take, in total, 44 minutes before return to science.

For larger manoeuvres, the use of HCM large slew is not recommended as it leads to a small slew rate, and OCM shall be used as defined in the next section.

1.3.5.3. Large slews

For slews larger than the ones which can be performed by chaining 3 HCM large slews, the use of OCM, using 20N thrusters is recommended. However, due to the depointing and residual nutation of the OCM manoeuvres themselves, the OCM domain is limit to 8 deg Sun Aspect Angles.

So, to perform large slews within the 8 deg SAA limit the sequence is the following:

- Slew with the 20N thrusters up to the desired target
- Time from OCM post delta-V to HCM TC: 10 minutes
- HCM TC: time for convergence of the attitude determination to compute the HCM manoeuvre: 4 min 10 s
- 6 minutes maximum waiting time for nutation damping
- Nutation damping manoeuvre with 6 min 30 s between the 2 pulses of the manoeuvre
- Catbeds cool down after nutation damping manoeuvre: 11 minutes
- HCM large slew: 5 minutes
- Catbeds cool down after HCM large slew: 11 minutes

If a manoeuvre beyond 8 deg SAA has to be planned, it has to be split into 2 manoeuvres

- OCM + HCM as described above
- Chaining of HCM large slews as described in 1.3.5.2. If one wants to go up to 10 deg SAA which defines the limit of the operational domain, more than 3 HCM large slews would need to be chained. Up to 15 are needed with the nominal thrusters and up to 19 are needed with the redundant thrusters.

1.4. THE MISSION PHASES AND THEIR PURPOSE

Three main mission phases have been identified both for HERSCHEL and PLANCK spacecrafts:

- **Launch Phase:** It corresponds to the wait phase of the OBSW up to the spacecraft separation from Ariane launcher.

- **Transfer Phase:** It is defined by:

  - Initial Orientation Phase (also called Launch Early Orbit Phase), which starts at launcher separation, gathers Sun acquisition, star acquisition and correction manoeuvres.

- Platform Commissioning and Performances Verification Phases are commanded to perform satellite orbit observation and any routine action when no scientific operations are performed.

Each of them will be defined by a specific platform configuration (i.e. a combination of ACMS configuration, TT&C configuration, power and thermal configuration, etc…).

- **Routine Scientific Phase:** It is defined to accomplish the spacecraft mission. It is composed by:
  - Science Commissioning Phase, during which instruments are calibrated
  - Observation Phase, during which all science data are stored in the Mass Memory
  - Telecommunication Phase, which corresponds to the communication with Earth including uplink of observation program, downlink of stored data and housekeeping activities.

The mission phases are summarised in Table 1-15.

- The phase start dates stem from the Reference Mission Scenario [RMS].
- The comments mainly stem from the Reference Mission Scenario [RMS].

Phase acronym	Phase name	Start event	Duration	End event	Comment
PLP	Pre-Launch Phase	H: L - 8 d P: L - 6 d	H: 9 d P: 7 d	L - 6 h	Corresponds to the POC
LAP	Launch Phase	L - 6 h	H: 6h + 1629.25 s P: 6h + 1910.35 s	Launcher separation countdown expiration (Planck launch phase is therefore a bit longer than the Herschel launch phase)	Launch duration from RAMP results
IOP	Initial Orbit Phase	H: L +1629.25 s P: L + 1910.35 s	12 d	Completion of the second navigation manoeuver (scheduled on L + 12 d).	HK data at low rate. No payload TM. New Norcia and Kourou for about 22 hours/day of coverage. 2 navigation manoeuvres (at L+2d and L+12d).
COP	Commissioning Phase	L + 12 d	H: 1 to 1.5 m P: 4 m	H: opening of cryo-cover P:	New Norcia and Kourou for about 10 hours/day of coverage Commissioning phase can in fact begin after the 1st navigation manoeuvre at L+2d
PVP	Performance Verification Phase	H: L + 12 + between 28 and 35 d (= between 1.5 and 2.5 m) P: L + 4.5 m	H: up to 2 m P: up to 2 m	Successful IOCR	New Norcia and Kourou for about 10 hours/day of coverage.
ROP	Routine Operations Phase	H: P:	H: P: 15 monthes (according to §2 of [PMPC])	To be defined by MOC. H: L + 3.5 y (Nominal, SPER-005 H) L + 6 y (Extended, SPER-025 H) P: L + 21 m (Nominal, SPER-010 P) L + 2.5 y (Extended, SPER-026 P)	New Norcia for about 3 hours/day (DTCP).
DIP	Disposal Phase	H: P:	infinite	N/A	

Table 1-15 Definitions of the phases

1.5. THE MISSION CONTROL CONCEPT

1.5.1. Operations concept

The HERSCHEL and PLANCK mission presents an intermediate status for operation between missions such as ISO or XMM/Integral which are in constant ground contact, and deep space missions like ROSETTA for which long period of autonomy are foreseen. The basic operation concept in which the 2 spacecraft in orbit around L2 are operated from one single ground station (nominally New Norcia) leads to a ground contact of 3 hours per day in average for each spacecraft (DTCP: Daily Telecommunication Period). When ground contact is not available (OP: Observation Period), the spacecraft is fully autonomous, performing science observation according to a pre-defined schedule uploaded during a preceding ground contact period. The spacecraft have been designed to cope with this autonomy requirement, allowing operation without ground contact for 48 hours, the goal being to maximise the scientific return and to put the spacecraft in safe condition in case of major anomaly only.

Another major driver is to maximise commonality in the way the two spacecraft are operated. Even if they may exhibit differences (HERSCHEL is a 3-axis stabilised spacecraft while PLANCK is a slow spinner), they share a number of commonalities:

- similar orbits around L2
- use of the same ground stations
- same sharing of daily operations between OP and DTCP
- common electrical and Command/Control architecture for HERSCHEL and PLANCK
- identical data rates to ground.

Commonality in operation concepts is intended to reduce the operational costs by allowing the use of the same procedure for the two spacecraft.

1.5.2. Spacecraft control

The HERSCHEL and PLANCK spacecraft will be operated from the MOC (Mission Operation Centre) at ESOC that interfaces with the HERSCHEL Science Centre (HSC) and HERSCHEL Instrument Control Centres (ICCs) and for PLANCK with the Data Processing Centres (DPC). Commanding of both spacecraft will be conducted by MOC based on inputs received from these centres. Housekeeping telemetry received from both platform and instruments will be processed by the MOC. Science telemetry as well as relevant housekeeping will be transferred to the scientific centres.

During scientific operation, both spacecraft will be operated from the New Norcia 35 m ground station. However other ground stations are envisaged during the various phases of mission. The planned usage of ground stations during the various phases of mission is shown in Table here after:

MISSION PHASE	GROUND STATION	
Initial orbit phase	ESA Network (Kourou/New Norcia/Villafranca)	
Commissioning phase	New Norcia/Kourou (routine)	Villafranca (emergency)
Performance verification phase	New Norcia/Kourou (routine)	Villafranca (emergency)
Routine operations phase	New Norcia 35 m (Prime station)	Villafranca/Kourou (emergency)

Table 1-16 Planned Usage of Ground Stations during the H-P Mission Phases

Communication to ground relies on X-Band link for both TM and TC. TM and TC are nominally via the Medium Gain Antenna (MGA). LGA's are back up to the MGA, authorize reduced bandwidth.

For telemetry, various modes are envisaged as shown in the following table. For commonality reasons, the same data rates have been selected for HERSCHEL and PLANCK. In addition, at the beginning of IOP, the TM medium rate will be punctually used via LGA towards New Norcia to download the HERSCHEL VMC images.

	ANTENNA	GROUND STATION	HERSCHEL	PLANCK	DATA TRANSMISSION
TM Hi-rate	MGA	New Norcia	1.5 Mbps	1.5 Mbps	Real time HK, Stored HK, Real time science, Stored Science
TM medium-rate	MGA	New Norcia/ Kourou	150 kbps	150 kbps	Real time HK + Stored HK + Real time science
		New Norcia	5 kbps	5 kbps	Real time essential HK
TM low-rate	LGA	Kourou	5 kpbs	5 kbps	During LEOP, up to 750 000 km Real time essential HK + stored S/C HK
		Kourou	500 bps	500 bps	Subsampled Real time essential HK.

Table 1-17 TM Rates

Nominal TC rate is 4 kbps via MGA when communicating via New Norcia, and 125 bps via LGA when Kourou is used. MGA use is limited during transfer by attitude constraints (see §1.3.3). In addition, TC rate of 4 kbps via LGA can be used from Kourou during LEOP, up to a distance of 350 000 km. The various TC modes are summarised in the following table; they are identical for HERSCHEL and PLANCK.

	S/C ANTENNA	GROUND STATION	DATA RATE	REMARKS
TC low rate	LGA	Kourou	125 bps	
	MGA (or LGA)	New Norcia		
TC nominal	LGA	Kourou	4 kbps	During LEOP, up to 350 000 km
	MGA	Kourou		

Table 1-18 TM Rates

The Figure hereafter illustrates the Space to Ground link for HERSCHEL and PLANCK satellites.

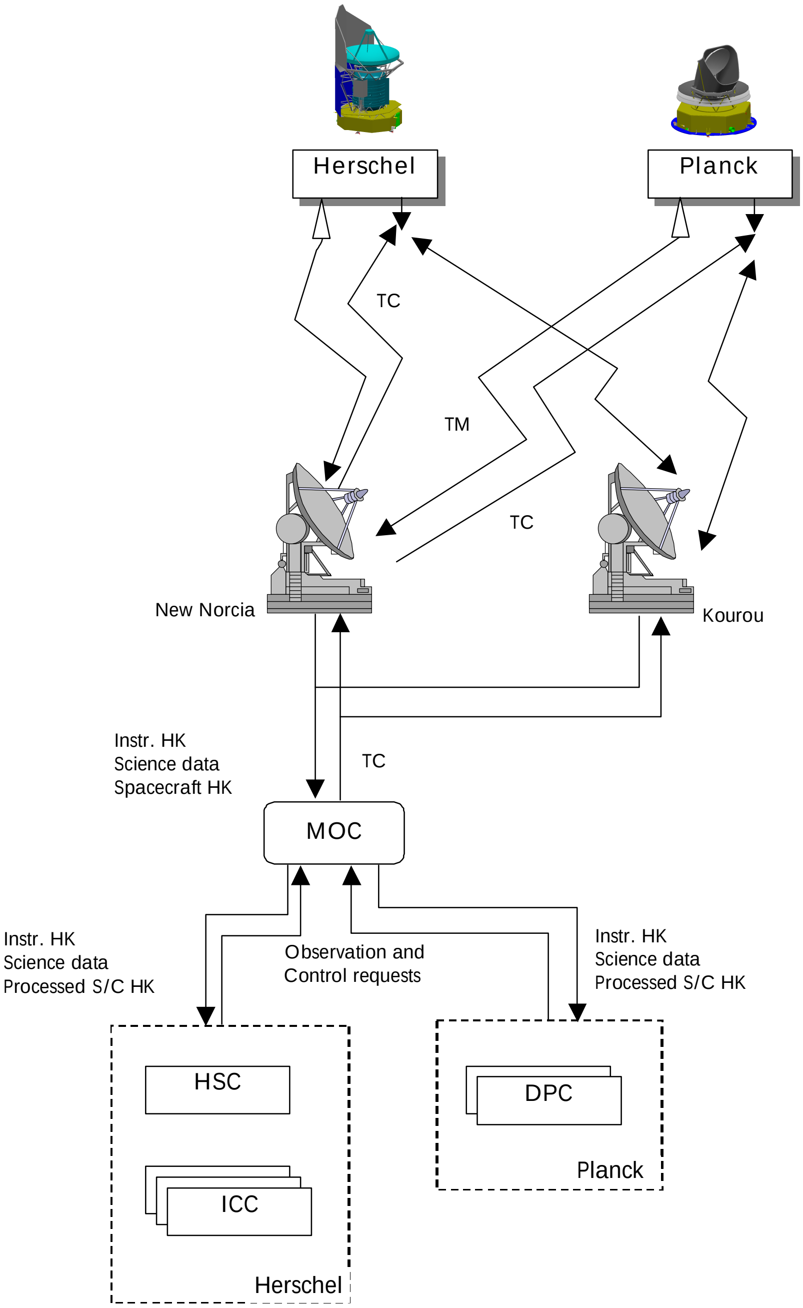


Figure 1-40 Space to Ground link for HERSCHEL and PLANCK satellites

1.5.3. Spacecraft autonomy

The operation of the spacecraft, i.e. the functional interface with Ground, is based on a set of services specified in the Packet Structure ICD. Apart from standard facilities (TM/TC interface, Memory Management, Mass Memory Interface), some features are defined to support the FDIR implementation (On Board Monitoring Function, Event/action) and two facilities are used to support the implementation of the required autonomous spacecraft operation: On Board Scheduling which defines the characteristics and use of the MTL, and On Board Control Procedure (OBCP).

As a matter of fact, the basic concept of operation of the satellites is that all activities will be performed according to the on-board Mission TimeLine (MTL) during nominal operations, even if the spacecraft is in ground visibility, while the context of operation of the satellites is defined by the current Satellite Mode (see § 3.1.3. “Spacecraft system Modes”). Autonomy functions allowing spacecraft reconfiguration in order to maintain scientific activities are active on-board and do not require inputs from ground. Actions from ground are limited to receiving telemetry (real time and stored in the mass memory) and sending commands to update the Mission Timeline. The Timeline is sized to support 48 hours of autonomous operations.

Real time commanding of the spacecraft is also possible. In the meantime fault protection functions and possibly MTL are still active on-board, and ground commands are not required to maintain spacecraft safety. This is in accordance with the requirement that ground reaction shall not be required within less than 3 minutes (OIRD, CTRL-1). Protection mechanisms (definition of priorities based on the source of the telecommands) are implemented to manage possible conflicts between commands originated on board and on ground.

The reader may refer to Section 3.1.2 “Operation Scheduling” where the On board Scheduling service features are detailed.

The other functionality available to support the nominal operation of the spacecraft will be by execution of pre-defined on-board control procedures (OBCP's).

OBCP's can be activated by:

- MTL (Mission Time Line)
- Ground command
- On-board event, automatically (e.g. FDIR)
- Other OBCP’s.

OBCP's are flight procedures, developed and validated on ground, which are uploaded on-board of the HERSCHEL or PLANCK satellite, stored in Mass Memory until they are started, i.e. interpreted.

Both satellites will be able to survive in a safe mode for at least 7 days without the need of ground intervention.