HERSCHEL / PLANCK

SYSTEM
REQUIREMENTS
SPECIFICATION
[SRS]

SCI-PT-RS-05991

Issue 3 / 3 - 27 July 2004

Prepared by ESA Herschel / Planck Project Team
Responsible A. Elfving – S/C Systems Engineering Manager

Approved by ESA Herschel / Planck Project Manager SCI-PT

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Note: The acronyms printed in italic after the chapter/section titles refer to the first 4-letter part of the requirement identification number.

Document Change Record

Date	Issue / Revision	Changes Description / Traceability / Reference
31/08/2000	1 / 0	Initial formal Issue for the ITT of Industrial activities for phases B , C/D , E1 .
13/07/2001	2 / 0	**General update prior to SRR** , including agreed modifications / clarifications based on : - Renaming of FIRST to Herschel - Clarifications given during the tendering period (Ref: IMT-CS/NB/lh/718/2000 – Clarification no 7) - Clarifications with Alcatel prior to Phase B Kick-Off (Ref: HP-ASPI-MN-78 of 19-23/03/2001) - Joint ESA / Alcatel review (Ref: HP-ASPI-LT-58 and 65, HP-ASPI-MN-128 of 13/06/2001) - SCI-PT Pre-CCB of 19/06/2001 (Ref: SCI-PT-09224) - SCI-PT CCB of 03/07/2001 (Ref: SCI-PT-09402) **Modified Requirements :** <u>Chapter 4 :</u> MOGE-035 MISS-010 , MISS-015 , MISS-035 , MOOM-005 , MOOM-055 , MOOM-060 , MOOM-065 , MOOM-075 , MOOM-085 , MOOM-090 , MOOM-115 , MOOM-140 MOOF-030 , MOOF-055 , MOOF-095 MOFM-060 , MOFM-110 , MOFM-115 <u>Chapter 5 :</u> SGEN-050 SPER-005 , SPER-010 , SPER-015 , SPER-025 SPER-026 , SPER-060 , SPER-065 SINT-040 , SINT-045 , SINT-055 , SINT-070 SENV-040 , SENV-045 , SENV-080 , SENV-111 SENV-145 , SENV-210 SCMD-020 , SCMD-045 , SCMD-050 , SCMD-065 SCMD-085 STHE-005 , STHE-012 , STHE-035 , STHE-050 SCVE-040 , SCVE-075 , SCVE-085 , SCVE-090 SCVE-110 , SCVE-115 , SCVE-185 <u>Chapter 6 :</u> SMPC-060 , SMPC-065 , SMPC-180 , SMPC-190 SMPC-195 , SMPC-200 , SMPC-205 SMSA-035 , SMSA-040 SMCD-040 , SMCD-085 , SMCD-090 , SMCD-145 SMCD-200 , SMCD-205 , SMCD-215 , SMCD-220 SMTT-085 , SMTT-090 , SMTT-140 , SMTT-142 SMTT-145 , SMTT-155

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21/12/01	2 / 1	**General update as result of the SRR ref. CCB SCI-PT-MM-10310 and SCI-PT-MM- 10708** **Modified Requirements :** Chapter 3: FMSC-005, FMSC-010 Chapter 4 : MOGE-035, MOGE-040, MOGE-045, 4.2; 1st para, 4.2.1; last para, 4.2.3.2; 1st and 4th para, MISS-055, MISS-065, 4.2.3.3; 1st para, 4.2.4; 1st para, MISS-081, MISS-083, MISS-100, 4.2.5, 4.2.6, MISS-110, MISS-115, MISS-130, MISS-135, MISS-140, MISS-145, 4.3.1.2 MOOM-040, MOOM-045, 4.3.1.3; last para, Table 4.3.1.1 and 4.3.1.2, MOOM-105, MOOM-115, MOOM-120, 4.4, MOOF-010, 4.4.2, 4.4.2.1, 4.4.2.2, MOOF-050, MOOF-065, MOOF-120, MOFM-045, MOFM-050, MOFM-105 Chapter 5: SGEN-015, SGEN-020, SGEN-025, SGEN-055, SGEN-060, SGEN-075, SGEN-100, SGEN-205, SFUN-025, 5.3.1.1, SPER-020, 5.3.1.2, SPER-050, SINT-015, SINT-035, SINT-040, SINT-045, SINT-047, SINT-060, SINT-065, SINT-070, SINT-085, 5.4.6; 2nd, 3rd and 4th para, SINT-150, SINT-155, SENV-070, SENV-080, SENV-095, SENV-100, SENV-140, SENV-155, STHE-012, STHE-015, STHE-020, STHE-035, STHE-040, STHE-050, STHE-055, STHE-098, STHE-100, STHE-115, SCVE-045, SCVE-050, SCVE-145, SCVE-150

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1 INTRODUCTION

ESA's Horizon 2000 Science Programme has planned two important missions for performing astronomical investigations in the infrared and submillimetre wavelength range:

- Herschel (previously named FIRST : Far Infra-Red and Submillimetre Telescope) , an observatory type mission;
- Planck (previously named COBRAS/SAMBA), a survey type mission.

It was decided in early 1997 to implement the two missions as a single project. Subsequently, the SPC recommended implementation of the two missions following the "Carrier" concept (two spacecraft on a single launch). Herschel and Planck will be launched in the first quarter of 2007.

Herschel (previously FIRST) is the fourth "cornerstone" (CS4) mission in the European Space Agency (ESA) long term space science plan "Horizon 2000". Herschel is a multi-user (observatory type) mission, which targets the far-infrared and sub-millimetre part of the spectrum. Herschel will address key scientific topics such as the formation of galaxies and stars by performing e.g. deep broadband extra-galactic surveys, follow-up spectroscopy of especially interesting program objects discovered in the survey, detailed studies of the physics and chemistry of the interstellar medium in galaxies, including star formation, observational astro chemistry of gas and dust and detailed high-resolution spectroscopy of a number of comets.

Planck (formerly called COBRAS-SAMBA) is the third Medium (M3) Mission in the European Space Agency (ESA) long term space science plan "Horizon 2000".

Planck is a survey mission to image over the whole sky the temperature anisotropies of the cosmic microwave background radiation with a high sensitivity in the frequency range between 25 and 1000 GHz.

This document, with its applicable documents, forms the System and Programmatic Requirements and constitutes the baseline requirements from ESA for the Spacecraft Programme for Phases B, C/D , E and F.

This specification defines in several places requirements and also goals. The following definition for a goal shall apply throughout this specification and within the applicable documents:

Definition of Goal:

The design process shall start its work with the objective to meet the specified requirement under the condition that any design concept followed shall not a priori exclude meeting the goal value. Nevertheless meeting the goal value shall not be a design or cost driver.

The evaluation of any design shall provide the actually achieved values to be compared with the specification and the goal, together with the related assumptions or boundary conditions.

There usually exists a number of typical conditions/parameters which are advantageous for reaching the goal performance, but which are not always compliant with the applicable worst case in-orbit conditions and margins. The verification process shall include the verification of the goal performance. No specific or additional test is required to verify the goal. If goals cannot be fulfilled under nominal conditions without margin, the corresponding performance budget shall consider a combination of typical, well defined, conditions under which the goal will be met. If goals cannot be fulfilled under any conditions the best achievable performance shall be defined with its associated conditions and a formal waiver shall be issued to document the actual performance range of the design.

All requirements in this document which require verification are marked with a unique reference and indicated in italic. Also indicated in italic, the applicability of the requirement : H = Herschel , P = Planck , H/P = both .

2 DOCUMENTS

The following documents of the latest issue form part of this specification.

In the event of a conflict between this document and other applicable documents, the conflict shall be brought to the attention of the ESA Herschel / Planck Project Manager.

In the case of a conflict between this specification and reference documents, this specification shall have precedence.

With issue 2/0 of the present System Requirements Specification , FIRST has been renamed Herschel. However, not all documents referenced below (Applicable and Reference) have been re-titled accordingly . This will be done gradually during the update process of the corresponding documents.

2.1 APPLICABLE DOCUMENTS

2.1.1 System Support Specifications

		Reference Chap.
AD1-1	Product Assurance Requirements FIRST/Planck Satellite, Document no. SCI-PT-RS-04683	5.1.4, 5.1.5, 5.1.7, 7
AD1-2	FIRST/Planck AIV Requirements Specification, Document no. SCI-PT-RS-07430	8
AD1-3	Planck Telescope Design specification, Document SCI-PT-RS-07024	5.4.3, 6.3.1, 6.3.4, 6.4

2.1.2 ESA Undertakings

AD2-1	FIRST Telescope Specification, SCI-PT-RS-04671	4.2.5, 5.4.2, 5.6.14, 6.2.5
AD2-2	Planck primary/secondary reflectors and inner baffle specification Document SCI-PT-RS-07422	5.4.3, 5.6.1.4, 6.4
AD2-3	SREM Experiment Interface Document, H/P-ESA-QCA-EID001/01 (Volume 1 to 5)	4.1

2.1.3 Satellite System Interface Specifications

AD3-1	FIRST/Planck Space to Ground Interface Document (RF link), Document SCI-PT-ICD-07418	5.4.4, 6.7.1, 6.8.1, 6.8.3
AD3-2	FIRST/Planck Operations Interface Requirements Document Document SCI-PT-RS-07360	4.2.4, 5.4.4, 6.7.1
AD3-3	Herschel/Planck Packet Structure Interface Control Document SCI-PT-ICD-7527	6.7.1

2.1.4 Instrument Interface Specifications

AD4-1	Instrument Interface Document, Part A (IID-A), Document no. SCI-PT-IIDA-04624	5.1.1, 5.2, 5.3.3, 5.4.1, 5.6.1.6, 6.1.3, 6.3.1
AD4-2	Instrument Interface Document, Part B (IID-B): Heterodyne Instrument, Document no. SCI-PT-IIDB/HIFI-02125	3.1.4, 5.1.1, 5.2, 5.3.3, 5.4.1, 5.6.1.6, 6.1.3
AD4-3	Instrument Interface Document, Part B (IID-B): Photoconductor Instrument, Doc. No. SCI-PT-IIDB/PACS-02126,	3.1.4, 5.1.1, 5.2, 5.3.3, 5.4.1, 5.6.1.6, 6.2.1, 6.2.5
AD4-4	Instrument Interface Document, Part B (IID-B): Bolometer Instrument, Document no. SCI-PT-IIDB/SPIRE-02124,	3.1.4, 5.1.1, 5.2, 5.3.3, 5.4.1, 5.6.1.6, 6.1.3, 6.2.1
AD4-5	Instrument Interface Document, Part B: High Frequency Instrument, Document no. SCI-PT-IIDB/HFI-04141,	3.1.4, 5.1.1, 5.2, 5.3.3, 5.4.1, 5.6.1.6, 6.1.3, 6.3.1
AD4-6	Instrument Interface Document, Part B: Low Frequency Instrument, Document no. SCI-PT-IIDB/LFI-04142	3.1.4, 5.1.1, 5.2, 5.3.3, 5.4.1, 5.6.1.6, 6.1.3, 6.3.1
AD4-7	Product Assurance Requirements for the FIRST/Planck Scientific Instruments, SCI-PT-RS-04410	7.

2.1.5 Mission Support Documents

AD5-1	FIRST L2 Radiation Environment ESA/Estec/wma/he/FIRST/3	5.5.5
AD5-2	FIRST/Planck Carrier Consolidated Report on Mission Analysis (CREMA), Document no FP-MA-RP-0010-TOS/GMA	3.2.3, 4.2.3.2, 5.1.4, 5.5.2, 5.5.4
AD5-3	Solid Particle Environment for Herschel and Planck, EMA/02-027/GD/PLCK	5.5.7

2.1.6 Applicable Standard Documents

2.1.6.1 ARIANE Standards

AD6-1	ARIANE 5 User's Manual Issue 3 / Rev 0 Mar 2000	5.1.4, 5.4.6, 5.5.1, 5.5.4, 5.5.6, 5.6.1.1, 5.6.1.2, 5.7.1.3, 5.8
AD6-2/1	CSG Safety regulations Volume 1 - General rules CSG-RS-10A-CN latest applicable issue	5.4.5
AD6-2/2	CSG safety regulations, Volume 2, part 1 – Specific rules, ground installations CSG-RS-21A-CN, latest applicable issue	5.4.5, 5.4.6
AD6-2/3	CSG safety regulations, Volume 2, part 2 – Specific rules, spacecraft CSG-RS-22A-CN, latest applicable issue	5.4.5, 6.10.4
AD6-20	deleted	
AD6-24	General specification for payload dynamic models, A5-SG-0-01 Issue 4/1	5.7.1

2.1.6.2 ESA Standards

AD6-3	Telemetry Channel Coding Standard, ESA PSS-04-103, Issue 1, Sept 1989	6.7.1
AD6-4	Ranging Standard, ESA PSS-04-104 Issue 2, March 1991	6.8.1
AD6-5	ECSS Radio Frequency and Modulation Standard, ECSS E-50-05, Draft 9.4, April 2002	6.8.1
AD6-6	Packet Telemetry Standard, ESA-PSS-04-106, Issue 1, Jan 1988	6.7.1
AD6-7	Packet Telecommand Standard, ESA-PSS-04-107, Issue 2, Apr 1992	6.7.1
AD6-8/1	Generic Specification for Silicon Solar Cells, ESA-PSS-01-604, Jan 1988	5.5.5.1, 6.6.2
AD6-8/2	Generic Specification for Ga/AS cells, SPA/TS-0006	5.5.5.1, 6.6.2

AD6-9	ESA Power Subsystem Standard Specification, ESA-PSS-02-10, Nov 1992	6.5.2
AD6-12	Data for Selection of Space Materials, ESA-PSS-01-701	5.1.5

2.1.6.3 ECSS Standards

AD6-10	Space Mechanisms Standard Requirements Specification, ECSS-E-30-00 Part 2-3	5.6.2.1, 5.7.2.1
AD6-11	ESA Fracture Control Requirements, ECSS-E30-01A	5.7.1.2, 6.10.4
AD6-13	A thermal Vacuum Test for the Screening of Space Materials, ECSS-Q-70-02 Draft	5.1.5
AD6-14	A Thermal Cycling Test for the Screening of Space Materials and Processes, ECSS-Q-70-04	5.1.5
AD6-15	Material Selection for Controlling Stress Corrosion Cracking, ECSS-Q70-36A	5.1.5
AD6-16	Determination of Susceptibility of Metals to Stress Corrosion Cracking, ECSS-Q-70-37	5.1.5
AD6-17	ESA Software Engineering Standards, ESA-ECSS-E-40	6.12
AD6-19	Time Code format CCSDS 301.0-B-2, issue 2	6.7.2
AD6-25	ESA-ECSS-Q-80 Software Product Assurance	6.12
AD6-26	Lossless data Compression, CCSDS 121.0-B-1, May 1997	6.7

2.1.6.4 Other Standards

AD6-18	MIL-HDBK-5	5.6.1.4

2.2 REFERENCE DOCUMENTS

RD-1	ESA Pointing Error Handbook, ESA-NCR-502, Issue 1, Feb 1993	4.3.2
RD-2	Radiation Design Handbook, ESA-PSS-01-609, Issue 1, May 1993	5.5.6

RD-3	Packet Utilisation Standard (PUS) - ECSS-E-70/41 Draft	6.7
RD-4	Guide to Applying the ESA Software Engineering Standards to Small Project, BSSC (96)2, Issue 1, May 1996	6.1.2.1
RD-5	Telecommand Decoder Specification ESA-PSS-04-151	6.7
RD-6	Straylight Evaluation for Planck PT-05985, 23 June 1989	5.3.3
RD-7	CCSDS Telemetry Channel Coding CCSDS 101.0-B-4	6.7, 6.8.3

Since the 1st January 1998, some studies have been carried and the following reports are available:

2.2.1 FIRST/Planck Carrier configuration evaluation – ESA documents:

RD-8 FIRST/Planck Carrier Technical Report
PT-TN-05410, 30 June 1998

RD-9 Planck Straylight Evaluation of the Carrier Configuration – Technical Report PT TN 05967 – issue 1/0, 14 Oct 1998

2.2.2 Planck Payload Architect Study – ALCATEL/DSS documents:

RD-10 Planck Payload Module Architect Technical Assistance - Summary Report for Phase 2 - PT-07150, F/P-GR-B0000.009, 1 Oct 1999

RD-11 Planck Payload Module Architect Technical Assistance– Phase 2 Summary Report – PT-07144, PL AS RE 019, 30 Sep 1999

RD-12 Planck Payload Module Architect Technical Assistance – Impact of the SVM and Solar Array Temperature Fluctuations on the Temperature Stability of the PLM – PT-07547, PL AS TN 033, 25 Jan 2000

2.2.3 FIRST Instrument Interface Study – ALCATEL/DSS document:

RD-13 FIRST update of instruments Interface Study PT-07673, FIRST GR B0000 009 Rev 1, 6 Apr 2000

2.2.4 FIRST Optimisation Study –ALCATEL/DSS documents:

RD-14 FIRST System Optimisation Study - Final Report – PT-08036, ASPI/2000/FP/0035, 13 Jul 2000

RD-15 FIRST System Optimisation Study – PLM Final Report – PT-08035, FIRST-GR-B0000.012, 13 Jul 2000

2.2.5 FIRST Payload Module – Air Liquide Study

RD-16 Alternative Study for the FIRST Cryostat – Executive Summary PT-07846, DTA CGEN PC CM T 00 535 0, 11 April 2000

2.2.6 Reference Mission Scenario

RD-17 Reference Mission Scenario, SCI-PT/12759

3 COMBINED MISSION Herschel / Planck

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 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.

COMBINING Herschel & Planck

It recently became apparent, since Herschel and Planck use a similar orbit, that it is possible to combine the two missions (“Carrier” concept) by launching them together.

LAUNCH & ORBIT

Launch:

- Different separation sequences and insertion strategies have been envisaged, the final strategy for the separation has to be discussed with Arianespace and confirmed.

On Orbit:

For the Planck spacecraft a small Lissajous around L2 (Sun/spacecraft/Earth angle 10°-20°) is envisaged.

For the Herschel spacecraft a larger Lissajous around L2 using minimum delta-V is envisaged.

The exact nature of the orbit is discussed and delta-V is given in the Herschel / Planck Consolidated report on Mission Analysis (AD5-2).

OPERATIONS

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.

3.1 SCIENTIFIC MISSION

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 $\Delta T/T \sim 10^{-5}$. 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 (Ω_0), the Hubble constant (H_0), and the cosmological parameter (Λ), 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 $\Delta T/T \sim 2x10^{-6}$, 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.

3.1.1 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:

1. 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
2. to map over the whole sky all major Galactic and extragalactic sources of emission at the wavelengths measured by Planck
3. 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 4π 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 polarization 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 which must be minimised.

3.1.2 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 3.1-1 below.

The first three instruments in Table 3.1-1 belong to the Herschel mission, the two remaining instruments to the Planck mission.

Name	Characteristics	Principal Investigator
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.	T. de Graauw (SRON) Groningen
Herschel Photo-conductor Array Camera and Spectrometer **(PACS)**	A direct detection instrument which performs imaging line spectroscopy and photometry in the 60* - 210 μm 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. * See note below	A. Poglitsch (MPE) Garching
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.	M. Griffin (UoW) Cardiff
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.	J-L. Puget (IAS) Orsay
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.	R. Mandolesi (TESRE-CNR) Bologna

Table 3.1-1 Payload Description

Note: The PACS instrument has the facility to go down to 60 μm. However, there is no specific requirement that the Herschel system and its telescope should be compatible with this lower wavelength.

For the Herschel mission the HIFI, PACS, SPIRE instruments each consist of a cold Focal Plane Unit (FPU) and a number of warm electronic boxes. In addition, the HIFI has a Local Oscillator Unit (LOU) which must be coupled optically to the focal plane unit.

For the Planck mission there are three basic payload components:

1) a telescope and a baffling system, providing the angular resolution and rejection of straylight:

   The telescope design consists of an offset system with 1.5 m projected aperture and of one half-conical surface that links the Planck focal plane instruments to the bottom edge of the sub-reflector (the so-called baffle).

2) the Low Frequency Instrument (or LFI) - an array of tuned radio receivers, based on HEMT amplifier technology, and covering the frequency range - 25 - 110 GHz; and

3) the High Frequency Instrument (or HFI) - an array of bolometers covering the frequency range 85 - 1000 GHz.

   The LFI and HFI are both placed in the focal plane formed by the telescope, and share the focal area equally. This arrangement maximises the optical throughput of each instrument, while keeping off-axis aberrations to an acceptable level.

   A hydrogen sorption cooler provides the temperature required by the LFI receivers. It also constitutes the first stage of the cooling system of HFI, which includes a helium J-T loop (providing 4 K), and a combination J-T loop plus $^4He/^3He$ dilution fridge providing the final bolometer temperature of ~0.1 K.

The instruments and their interfaces with the satellite are described in the Instrument Interface Documents (IIDs), part A and part B (AD4-1 through AD4-7).

3.1.3 ESA Undertakings

The Herschel telescope and its necessary GSE are designed, manufactured, tested and delivered to ESA by European industry .

Herschel Telescope	The Herschel telescope consists of: - a primary reflector - a secondary reflector - a reflector support … (bipods, tripods, etc…) - an interface triangle and mechanical fixation device to the primary deflector - a radiation monitor	European industry

The primary and secondary reflectors and the inner baffle of the Planck telescope are designed, manufactured, tested and delivered to ESA by DK-Planck, a consortium of Danish institutes led by the Danish Space Research Institute (DSRI).

Planck Telescope Primary and secondary reflectors	The reflectors consist of: - a primary elliptical reflector - a secondary elliptical reflector - an inner baffle linking the focal plane and the secondary mirror - a radiation monitor	DK-Planck

3.1.4 Scientific Requirements

The general requirements applicable to the scientific instrumentation are given in the IID 's

Specific requirements from individual instruments are beyond the scope of this section and are addressed in the specific sections of the individual IID's Part B.

FMSC-005 H *The Herschel satellite shall accommodate the Herschel instruments and telescope and shall satisfy all performances and interface requirements as specified in the IID's (AD4-1,AD4-2, AD4-3, AD4-4), and AD2-1. In addition, it shall deliver the instruments in an adequate Lissajous orbit around L2.*

FMSC-010 P *The Planck satellite shall accommodate the Planck instruments and telescope (including the primary, secondary reflectors and baffle) and shall satisfy all performances and interface requirements as specified in the IID's (AD4-1,AD4-5, AD4-6) and AD2-2. In addition, it shall deliver the instruments in an adequate Lissajous orbit around L2.*

4 MISSION OPERATIONS

4.1 GENERAL REQUIREMENTS

MOGE-005 H *The Herschel spacecraft shall support the scientific observations of the Herschel instruments*

MOGE-010 P *The Planck spacecraft shall support the scientific observations of the Planck instruments*

MOGE-015 H/P *The spacecraft design shall enable the operational control by the ground segment during all mission phases and modes in both nominal and contingency situations.*

MOGE-020 H/P *The spacecraft shall be able to support continuous communications with the ground during station visibility periods.*

MOGE-025 H/P *During all mission phases the spacecraft shall be able to receive telecommands and transmit housekeeping data in any attitude and orbit position , i.e. omni-directional coverage shall be provided.*

MOGE-030 H/P *The spacecraft design shall support the following telemetry modes:*

- *Real time housekeeping data (spacecraft and payload)*
- *Real time science + real time housekeeping data*
- *Real time housekeeping data + dump of on-board mass memory*
- *Real time housekeeping +real time science + dump of the on-board mass memory*

MOGE-035 H/P *Each spacecraft shall be equipped with a set of Visual Monitoring Camera(s) (VMC). The purpose being Public Relations effort, the performance (resolution, colour image, etc.), location and field of view shall be selected accordingly.*

Note : The VMC's will be used on a non-interference basis with the science / payload operations .

MOGE-040 H/P *Each spacecraft shall be equipped with a Radiation Monitor according to AD2-3. Its intended operation is also described in AD2-3.*

MOGE-045 H/P *Each spacecraft shall be able to operate out of ground contact and follow a programme of operations loaded by the ground during the communication period (DTCP).*

4.2 MISSION DESIGN

Mission analysis results are documented in AD5-2. system requirements derived from these results are reflected in the present document.

4.2.1 Mission Overview

The operational orbit, for both satellites, is a Lissajous orbit around the L_2 Libration point in the Earth/Moon - Sun system. This point lies approximately on the Earth-Sun line at ~ 1.5×10^6 km from the Earth in anti-Sun direction.

The observatory nature of Herschel implies that it will carry out a large number of observing projects with a wide range of observing times, varying from minutes to months. The longest foreseen programme is a deep survey of part of the sky over a period of several months. There is a requirement that some key Herschel observation programmes are carried out early in the mission. The minimum total routine lifetime specified for Herschel is 3 years at L-2.

Planck will carry out two consecutive surveys of at least 95% of the whole sky. The time required to complete a single full sky survey depends on the detailed telescope configuration, and may vary between 6 and 7.5 months. It is a requirement that each single full sky survey be carried out continuously and consecutively, i.e. no spacecraft nominal operation throughout a full sky survey shall require the interruption of science data collection.

4.2.2 The Ground Segment

The interface between both spacecraft and the ground segment for the mission is given in AD3-1 and AD3-2.

The prime ground station is the 35 m station near Perth / New Norcia (in Australia). The Kourou station may be used as emergency station and during the early phases of the mission (commissioning and performance verification phases). During normal operations, Herschel and Planck will be operated from Perth / New Norcia one after the other, each for a period of a maximum of 3 hours per day (the Daily Telecommunications Period DTCP).

The operation scenarios are:

- During the Herschel observation period of at least 21 hours per day the spacecraft will collect scientific data which will be stored in an on-board mass memory for transmission towards the ground station during the subsequent telecommunications phase. Limited scientific observations will also be conducted during the telecommunications periods, subject to restrictions imposed by the telecommunications and other spacecraft maintenance activities.
- For the Planck operation, the spacecraft will collect the scientific data 24 hours per day, which means that the observation phase will continue during the telecommunications period.

The telecommunications period will be used for uplinking the commands for later execution and dumping of the stored data as well as real-time transmission of science and housekeeping data.

The data acquired at the ground station(s) from each spacecraft will be routed through ESA's operational communications network to the Mission Operations Centre (MOC) at ESOC for subsequent storing and distribution to the Herschel Science Centre (FSC) and the Instrument Control Centres (ICCs), or to the Planck Data Processing Centres (DPCs).

Conversely, the FSC, ICCs and DPCs will provide the MOC with observation and instrument scheduling requests, which inputs will be used by the Mission Planning System (MPS) at the MOC to prepare the command sequence to be uplinked to both spacecraft.

During the Initial Orbit Phase, the LEOP ESA Network can be used for telecommand uplink, telemetry downlink and spacecraft tracking.

After the nominal transfer trajectories have been established, the Perth / New Norcia Prime Station, supplemented by the 15-m station at Kourou, French Guyana, will be used during the commissioning and initial orbit phases, when near continuous contact with both spacecraft is necessary. Once the routine Scientific Operations Phase start, the missions will be supported by the prime ground station only. In emergency situations, other stations (Villafranca, Kourou) may be used.

4.2.3 Mission Operation Phases

4.2.3.1 Pre-launch/launch Phases

The pre-launch operations start six to eight weeks prior to launch. Activities in this phase encompass the final simulations and data flow tests, including the Dress Rehearsal and the final Mission Readiness Tests between the ground stations, the Mission Operations Centre (MOC) and the Herschel Science Centre (FSC), Instrument Control Centres (ICCs), and Data Processing Centres (DPCs) in the last days before launch.

In addition, specific spacecraft pre-launch operation, such as filling/topping-up of the cryostat, etc, will take place.

MISS-005 H/P	*Both spacecraft shall be compatible with the facilities at the launch site. However, specific non-standard facility modifications/extension that might have to be implemented (e.g. for helium handling or dry nitrogen flushing) by the launcher authority shall be identified by the Contractor.*

MISS-010 H/P *Deleted .*

MISS-015 H/P *Both spacecraft shall be compatible with a direct ignition of the launcher upper stage, shall be supported by internal power and withstand the mechanical and thermal environment.*

Notes: *1) The baseline injection scenario (from lift-off to separation of the satellites) with an Ariane 5 EC/A launcher has a total duration of 25 minutes , and is composed of :*

- Lower stage powered phase duration : 9 minutes

- Upper stage powered phase duration : 16 minutes .

2) Typical launch trajectory data is given in the Herschel / Planck Consolidated Report on Mission Analysis (AD-5.2).

MISS-020 H/P *During the launch phase, both spacecraft shall be in a minimum power mode using on-board batteries. All instruments are switched off with the exception of the launch lock of the mechanical coolers for the Planck S/C. Command for cryogenic valve actuation, if necessary during launch, could be supplied by the launch vehicle.*

MISS-025 H/P *Both spacecraft shall be compatible with a daily launch window of 45 minutes.*

MISS-030 H/P *Both spacecraft shall be compatible with the combined duration of the yearly launch windows of at least 6 months.*

MISS-035 H/P *Deleted.*

Note: The transfer trajectory will be defined such that no eclipse will occur from separation .

MISS-040 H/P *Both spacecraft shall be compatible with the attitude constraints imposed during the launch phase*

4.2.3.2 Initial Orbit Phase (IOP)

After separation from the launch vehicle, the ESA Network with stations at Kourou, Perth / New Norcia and Villafranca will establish contact with the spacecraft for the uplinking of telecommand messages, the reception of spacecraft housekeeping telemetry, and the performance of range and Doppler measurements. During IOP, constant coverage is ensured by the ground stations except for a daily interruption of maximum 1h 40’. IOP operations will start with initial Sun acquisition and transition from battery to solar power.

All operations defined in the IOP timeline will be undertaken in order to:

- establish the spacecraft health post launch
- configure the spacecraft for subsequent IOP operations

- check-out the spacecraft subsystems
- acquire attitude
- perform the necessary attitude manoeuvres and orbit corrections.

In addition, the standard monitoring and control activities will be performed, which include updating of system budgets, subsystems monitoring, identification and correction of anomalies.

Immediately after spacecraft check-out and attitude acquisition the Herschel telescope heaters (with the cryo cover still closed) and the Planck telescope heaters will be switched on, in order to prevent contamination of the telescope. During IOP, the science instruments will be off with the exception of the launch lock of the mechanical coolers of the Planck S/C.

Following verification of the correctness of the orbit manoeuvre the IOP will end. During the subsequent transfer orbit, spacecraft tracking will continue and additional fine orbit trimming manoeuvres will be executed, if necessary, to reach the correct conditions for entering the operational Lissajous orbit.

MISS-045 H/P	*The spacecraft shall autonomously detect separation from the launch vehicle and reorient itself to achieve Sun-pointing of the solar arrays.*
MISS-050 H/P	*The spacecraft shall autonomously detect correct Sun-acquisition and switch to the solar array power mode.*
MISS-055 H/P	*20 seconds after separation, the spacecraft shall provide telemetry data for spacecraft monitoring and check-out.*
MISS-060 H/P	*The spacecraft shall provide attitude information for attitude reconstitution by the ground.*
MISS-065 H/P	*Both spacecraft shall be compatible with the direction of the Delta-Velocity vector as defined by SGEN-060.*
MISS-070 H/P	*The spacecraft propulsion system shall support all post-launch attitude and orbit manoeuvres required to correct for injection errors.*
MISS-075 H/P	*All planned manoeuvres shall be possible without ground link.*

4.2.3.3 Commissioning Phase

After completion of the IOP when the spacecraft is in its transfer orbit towards L_2, the commissioning phase will start. The telemetry, telecommand and ranging services will, from then on, be provided only by the routine ground station at Perth / New Norcia and Kourou, supplemented as required (emergency) by the station at Villafranca. During part of the transfer orbit high telemetry data rate from Planck might not be possible since the Sun-Spacecraft-Earth angle can be incompatible with the antenna pattern.

The activities in this phase include the complete check-out of spacecraft functions and verification of all subsystems performance, covering the power generation and distribution, data handling and telemetry collection, telecommunications and thermal control. These activities will be carried out by the MOC, and will result in the update of subsystem operating parameters. During this phase the commissioning of the Herschel and Planck payloads may be started according to the relevant (Herschel or Planck) Commissioning Plan once the scientific instruments have achieved the required conditions. When each payload module has reached its nominal operational state the corresponding instruments will be switched on and the subsequent payload functional check-out will be performed by the relevant instrument teams.

At the end of the commissioning phase, the complete functional status of the spacecraft, satellite inertial properties and science instruments will have been determined and the performance verification phases will start. For each spacecraft the commissioning phase is expected to last 1-2 weeks with a maximum of 1 month. The commissioning and all subsequent phases for Herschel and Planck are conducted in parallel.

4.2.3.4 Performance Verification Phase

This phase starts after successful completion of commissioning activities and will cover the routine satellite control, the determination of the Attitude Control and Measurement Subsystem (ACMS) and related system level performances and executing corresponding calibrations, and the determination of performances of the instruments in all modes and their initial calibration. These activities will be performed according to the relevant (Herschel or Planck) Performance Verification Plan. During this phase, the stations at Perth / New Norcia and Kourou will both be used in order to increase the daily ground station coverage.

For each spacecraft the Performance Verification phase is expected to last up to two months.

4.2.3.5 Routine Operations Phase

After the Performance Verification Phase has been completed, the Routine Operations Phase will begin.

During the routine operations phase, the prime station at Perth / New Norcia will allow contact with the spacecraft for the uplink of telecommand messages, ranging and Doppler measurements, reception of science and housekeeping data, and for the execution of the planned observations.

In the routine operations phase, operations will be conducted according to a pre-planned timeline of observations, in which spacecraft and instrument commands are normally uplinked according to a schedule.

For the Herschel mission, the unrestricted scientific observations will take place during a period of at least 21 hours/day, the Observation Period (OP). The OP will in general start with a brief calibration period, still under ground control. Subsequently, the spacecraft will execute autonomously its preloaded observation programme. Scientific and housekeeping data will be stored in the on-board mass memory. At the end of the Observation Period, transmission of the stored data as well as real time housekeeping and science data will start. This phase, the Daily Telecommunications Period (DTCP), will last a maximum of three hours. During the Telecommunication Period, the observation/spacecraft schedule parameters for the next Observation Period are uplinked and verified for correctness and spacecraft housekeeping tasks (e.g. reaction wheel unloading and instrument coolers recycling) may be executed.

Within the limitations imposed by the need to point the Medium Gain Antenna (MGA) towards the earth, Herschel scientific observations may be carried out during the DTCP.

For the Planck mission, once routine operations are initiated, the observing mode will be unique. However, a number of instrumental modes will be pre-programmed to support various levels of uncompressed data downlink; these modes will be used during commissioning and contingency situations as instrument diagnostics.

Routine operations will be tied to the period of visibility afforded by one ground station. During the visibility period, the data of the preceding observation period shall be telemetred to ground within 3 hours, interleaved with the ongoing observations

Additionally, orbit maintenance manoeuvres will be performed for both spacecraft, typically every month, in order to keep the orbit from drifting too far away from the nominal one.

4.2.4 Operational Orbit

The Planck orbit is a “small” Lissajous orbit requiring an insertion manoeuvre, whereas for Herschel a “large” Lissajous orbit without insertion manoeuvre is selected.

The details of the orbit reached by each spacecraft after the injection sequence are given in AD5-2.

MISS-080 H/P	*Both spacecraft shall be compatible with the operational Lissajous orbit around the 2nd Lagrangian Libration point in the Earth/Moon – Sun system.*
MISS-081 H	*The Herschel spacecraft shall be compatible with a maximum Sun/Spacecraft/Earth angle of 40 degrees in its operational orbit.*
MISS-083 H/P	*Both spacecraft shall be compatible with a maximum distance to Sun of 154E6 km.*
MISS-085 H/P	*Both spacecraft propulsion systems shall support all orbit correction/ maintenance manoeuvres.*

Note:	*Typically, orbit maintenance manoeuvres will have to be executed every month.*
MISS-090 P	*To perform orbit maintenance the spacecraft design shall not require dedicated slew manoeuvres but maintain the attitude imposed by the execution of the nominal sky scanning law.*
MISS-095 H/P	*The attitude constraints as defined in Section 4.2.7. shall be satisfied during the ΔV and orbit maintenance manoeuvres.*
MISS-100 H/P	*Both spacecraft propulsion systems shall support the ΔV and orbit maintenance manoeuvres for worst case solar aspect angles of these manoeuvres as defined by SGEN-060.*

These worst case solar aspect angles follow from the mission analysis (AD5-2) and might require the decomposition of an orbit maintenance manoeuvre into several separate manoeuvres resulting in a decreased efficiency.

4.2.5 Ground Station Coverage

Deleted.

4.2.6 Eclipses

In the Lissajous orbits the spacecraft will be well outside the Earth's shadow and no eclipses will occur for the nominal lifetime. An eclipse may be experienced by the spacecraft during the coast arc before the delayed ignition when the spacecraft are still on the launch vehicle.

4.2.7 Attitude Constraints and Restrictions

MISS-105 H/P	*The attitude constraints and restrictions shall be respected at separation until the end of mission.*
MISS-110 H	*The Herschel spacecraft shall be compatible with any of the following combination of sun aspect angles away from the +Z-axis during all observational modes: +/-30 degrees about the Y-axis and +/-1 degrees about the X-axis.*
MISS-115 H	*Deleted.*
MISS-120 P	*The Planck spacecraft shall be compatible with a sun aspect angle of ± 10° from the -X-axis (around the spin axis) during all operation modes.*
MISS-125 P	*The Planck spacecraft shall be designed such as to enable the Planck instruments to image at least 95% of the sky twice over.*
MISS-130 H	*During the DTCP, the MGA (Medium Gain Antenna) shall be pointed towards the Earth as defined by the Mission Timeline.*

Note for MISS-110 and MISS-120: The in-orbit commandable attitude range will be reduced at each end by the actual Attitude Pointing Error (APE).

4.2.7.1 Herschel Restrictions

MISS-135 H *Mission planning will ensure that during scientific operations, the minimum angle between the line of sight (X axis) of the telescope and the Earth direction shall be 23 degrees.*

MISS-140 H *Deleted.*

MISS-145 H *Mission planning will ensure that during scientific operations, the minimum angle between line of sight (X axis) of the telescope and the Moon direction shall be 13 degrees.*

Note: For the design of the Herschel spacecraft, the principal axis of inertia should be as much as possible normal to the telescope sunshade.

4.3 OPERATIONAL MODES

The spacecraft operational modes and related requirements are defined in this section. Mode transitions are managed either by the spacecraft or from the ground as described in RD-17.

MOOM-005 H/P *Deleted .*

4.3.1 Science Observation Modes

4.3.1.1 Herschel Science Observations

MOOM-010 H *During Herschel Science Observations, the spacecraft shall provide the pointing modes defined in Herschel Pointing Modes, Annex 1.*

MOOM-015 H *Deleted.*

The Herschel Field of Regard (FOR) is defined as the collection of all possible instantaneous directions of the optical axis of the telescope such that none of the constraints on spacecraft attitude are violated. The FOR is thus equivalent to the instantaneous sky coverage.

Because the instruments share the focal plane, the Line of Sight (LOS) of each instrument is in general slightly different from the optical axis of the telescope; but it is of course within the telescope Field of View (FOV). For each instrument the FOR will be slightly different. This difference will be neglected in the following.

Because of these different LOS's the three Herschel instruments cannot observe the same (non-extended) target simultaneously. In general each observation will be executed with a single instrument **(prime mode)**. Nevertheless it might be useful to execute observations simultaneously with a second instrument. In this case, taking into account the instrument characteristics, the only sensible configuration is **PACS Prime** and **SPIRE Parallel**. This is reported in the table 4.3.1.1. Because of the secondary importance of these observations, full operational configuration capability of the second instrument is not required but a so-called **parallel mode** would be selected for these secondary observations. In this mode the "parallel" Herschel instrument is operated in a fixed configuration, i.e. no change in power dissipation in the Focal Place Unit is allowed. In this case the parallel instruments has only a limited TM bandwidth allocated to it.

MOOM-020 H *During the Observation Period it shall be possible to point the LOS of the prime instrument to any target within the FOR according to any of the operational pointing modes as described in Annex 1.*

MOOM-025 H *During the Telecommunication Period it should be possible to point the LOS of the prime instrument to any selected target within the FOR whose coordinates are compatible with telecommunication phase Earth-pointing requirements.*

4.3.1.2 Herschel Fine Pointing

MOOM-030 H *During science observations, the pointing requirements corresponding to the selected observation mode shall be met (section 4.4.2).*

MOOM-035 H *It shall be possible to maintain the fine pointing for periods of up to 22 hours, during which momentum unloading shall not occur.*

4.3.1.3 Planck Survey Mode

The optical axis of the Planck telescope (Line Of Sight = LOS) will be 85° from the +X axis in +Z direction (see Figure 5.1.2. and AD-2.2).

The two instruments will observe the sky individually or simultaneously (nominal mode). In the latter case the instruments will share the available TM bandwidth.

MOOM-040 P *The spin axis of the Planck spacecraft shall be nominally parallel to the X-axis and pointing to the Sun as defined in the Planck Scanning Strategy, Annex 2.*

MOOM-045 P *The direction (sense of rotation) of the spin shall be unique throughout the mission as specified in MOOF-050.*

MOOM-050 P *The spacecraft shall be capable of re-pointing the spin axis to ± 10° away from the Sun.*

MOOM-055 P *The Planck spacecraft shall downlink all the data acquired during 24 Hours without interrupting the survey mode.*

Mission planning will ensure during nominal operations that the angle between the Planck spacecraft negative spin axis (- X.axis) and the vector joining the Planck spacecraft to the centre of the Earth will remain smaller or equal to the maximum Sun/Spacecraft/Earth angle.

4.3.1.4 Payload Operational Modes

MOOM-060 H *The Herschel spacecraft must as a minimum support the modes of instrument operation as specified in Table 4.3.1.1.*

MOOM-065 P *The Planck spacecraft must as a minimum support the modes of routine instrument operation as specified in Table 4.3.1.2.*

Note: Other non-routine modes of operation (e.g. diagnostics) will be defined as needed.

MODE	HIFI	PACS	SPIRE
#1	Prime	Standby	Standby
#2	Standby	Prime	Standby
#3	Standby	Standby	Prime
#4	Standby	Prime	Parallel

Table 4.3.1.1. – Herschel Payload Operational Modes

MODE	HFI	LFI
#1	Prime	Prime
#2	Prime	Standby
#3	Standby	Prime

Table 4.3.1.2. - Planck Payload Operational Mode

4.3.1.4.1 Herschel Mission

During slews from one target to another it might be desirable to operate any of the three Herschel instruments in a fixed default configuration the so-called **serendipity mode**. In this mode no change of power dissipation in the Focal Plane is allowed and no guarantee is given w.r.t. slew performance but the instrument can use the full amount of TM allocated to it. No parallel observations are allowed in this mode.

MOOM-070 H	*During satellite slews, the Herschel satellite shall provide all the resources necessary for operation of one science instrument in serendipity mode. Such science observations shall not put any demands on the spacecraft attitude profile.*
MOOM-075 H	*During the DTCP, the Herschel satellite shall provide all the resources required to operate the instruments in the operational modes defined in table 4.3.1.1. Such observations shall be executed at an attitude compliant with the attitude constraints during the DTCP .*

4.3.1.4.2 Planck Mission

MOOM-080 P	*During Planck Science Observations, the spacecraft shall support the scanning law defined in the Planck Scanning Strategy in Annex 2.*
MOOM-085 P	*The Planck spacecraft design shall allow for complete sky coverage (at least 95 % of the full 4 pi sr. celestial sphere) in a spatially continuous way in less than 7.5 months.*
MOOM-090 P	*The time needed for the regular (planned and/or preventive) maintenance operations of the Planck spacecraft in-orbit shall be less than 10 hours per month and shall take place during DTCP , while continuing the instruments observational operations .*
MOOM-095 P	*During the Telecommunication Period DTCP, the Planck satellite shall provide all resources required to operate both instruments in their nominal operational modes.*

4.3.2 Lines of Sight Calibration Mode

This mode will be used to measure the relative angles between the lines of sight of the instruments and the axes of the primary attitude.

4.3.2.1 Herschel Calibration

Extensive initial calibrations shall take place during the Performance Verification phase.

In addition the validity of these initial calibrations will be checked periodically by a single calibration.

MOOM-100 H *The spacecraft shall support a calibration mode, involving the execution of multiple calibrations in order to establish the angles between stellar reference and the instruments lines of sight such that the pointing requirements of the fine pointing mode can be met at all possible spacecraft attitudes satisfying the attitude constraints of Section 4.2.7. and for all possible spacecraft operational conditions.*

MOOM-105 H *The spacecraft shall communicate, on-board and to ground, a request for pointing correction from the prime instrument per single pointing mode as defined in Annex 1 (excluding line scanning).*

MOOM-110 H *After reception of the request for pointing correction from the instrument, the spacecraft shall autonomously readjust its attitude accordingly.*

MOOM-115 H *The correction shall only be allowed within predefined boundaries , <10 arcsec around Y and Z axes.*

MOOM-120 H *Deleted.*

A ground facility will be provided to update, if necessary, the calibration values such that the pointing performances of the fine pointing mode can be improved during the next 24 hours.

4.3.2.2 Planck Calibration

MOOM-125 P *The spacecraft shall provide inertial attitude data such that it will be possible to derive the absolute angle between the LOS of each Planck detector and the actual attitude of the spacecraft with accuracy compatible with the Planck pointing requirements (AME).*

MOOM-130 P *The spacecraft shall support a calibration mode, involving the execution of multiple calibrations in order to establish the angles between a stellar reference and the instruments lines of sight such that the pointing requirements can be met at all possible spacecraft attitudes satisfying the attitude constraints of Section 4.2.7. and for all possible spacecraft operational conditions.*

4.3.3 Survival Mode

The purpose of the survival mode is to maintain a safe attitude for the spacecraft and the instruments after a major on-board failure or a violation of the attitude constraints. While in Survival Mode, the on-board schedule is discontinued.

Note: Major on-board failures are defined as any hazard, which affects the mission objectives, the mission lifetime or the mission safety.

MOOM-135 *The survival mode shall be activated automatically by the S/C after a*

H/P	*major on-board failure or a violation of the attitude constraints of Section 4.2.7.*
MOOM-140 H/P	*The survival mode shall maintain a safe attitude within the constraints allowing a continuous supply of power and maintaining a thermal environment compatible with the spacecraft and essential loads.*
MOOM-145 H/P	*It shall ensure a two way communication link with the ground station when coverage is available for at least housekeeping telemetry data and commanding (i.e. providing suitable link margins with omni-directional coverage).*
MOOM-150 H/P	*It shall maintain spacecraft and instruments in safe conditions and broadcast a safe mode flag to the instruments upon entry to the safe mode.*
MOOM-155 H/P	*It shall be possible to enter the survival mode by ground command. Exit from the survival mode shall only be possible by ground command.*
MOOM-160 H/P	*The spacecraft shall be able to maintain the survival mode without any ground contact for at least seven days.*
MOOM-165 H/P	*The survival mode shall not rely on any volatile memory (Random Access Memory or other) stored data.*
MOOM-170 H/P	*The exact attitude during the survival mode may not be known, but the attitude constraints of Section 4.2.7. shall be satisfied.*
MOOM-175 H/P	*Upon entry in the survival mode, the Mission Time-Line shall be discontinued. The TM format shall be switched to HK mode only.*
MOOM-180 H/P	*If no ground command has been received since more than a ground programmable time and after a minimum time of 60 hours, transponder/antenna toggling shall be initiated.*
MOOM-185 H/P	*In case transponder/antenna toggling is initiated because no ground command has been received, this toggling shall ensure that all combinations of redundancies within the telecommand and telemetry system are sequentially and continuously configured for a minimum time of 10 minutes each.*

4.3.4 Autonomy Mode

During all mission phases, the spacecraft will be capable of operating nominally without ground contact for a period of at least 48 hours without interrupting the planned operations.

The Autonomy Mode is the normal mode of operation during the routine phase. The general autonomy and fault management requirements are given in Section 4.4 of this document and the Herschel / Planck Operation Interface Requirements Document (AD3-2). Due to the short time of communication, the number of commands will be limited.

MOOM-190 H/P *The spacecraft design shall comply with the AD 3-2 requirements.*

Note: The mission will be executed according to a mission timeline, which will be uploaded during the DTCP.

MOOM-195 H/P *The spacecraft shall support on-board storage of the mission timeline for a 48 hours mission time.*

MOOM-200 H/P *The spacecraft shall support autonomous (i.e. without ground contact) execution of the mission timeline.*

MOOM-205 H/P *The spacecraft shall support rescheduling of planned events in the mission timeline as defined in AD3-2.*

MOOM-210 H/P *The time resolution of the mission timeline shall be 1 s.*

MOOM-215 H/P *It shall be possible to exit from the Autonomy Mode by Ground Command.*

MOOM-220 H/P *The spacecraft shall support on-board storage of all mission data generated during 48 hours (e.g. science and HK data, events, reports etc).*

4.4 OPERATIONAL FUNCTIONS

In addition to the operational modes described in Section 4.3, the following operational functions must be provided.

4.4.1 Angular Momentum Management

If Herschel and/or Planck spacecraft design includes wheels the following requirements are applicable.

MOOF-005 H/P *The spacecraft shall be capable of autonomous wheel off-loading.*

MOOF-010 H *Under nominal conditions, wheel off-loading shall take place outside the Observation Period (OP).*

MOOF-015 H/P *Initiation of wheel off-loading shall be possible by ground command as well as trough the MTL (Mission Timeline).*

MOOF-020 H/P *Off-loading, as well as up-loading, of each reaction wheel shall be possible to a ground-commanded value.*

4.4.2 Pointing Requirements

For Herschel the pointing requirements specified below shall be applicable to each Line of Sight (LoS) of the instruments. The LoS of an instrument is defined as the direction on the observed sky of the geometric centre of an FPU entry beam's far field pattern as projected by the telescope. The error in determining the absolute attitude of any line of sight, using a detector dedicated calibration source, shall be assumed to be less than 50% of the AME.

For Planck, the pointing requirements specified below shall be applicable to any detector LoS of the instruments. The LoS of an instrument is defined as the direction on the observed sky of the radiometric centre of a detector's far field pattern as projected by the telescope. Instrument teams will perform LoS calibrations by receiving raw attitude information, and correlate the data with own data. The output will be a bias estimation with a residual error less than 0.15 arcmin. This calibration will be performed weekly, and its contribution to AME is excluded from the values in requirement MOOF-045.

Unless otherwise specified, the pointing error specifications are expressed as half-cone angles of the optical axis and half-sector angle around the optical axis. They are specified at a temporal probability level of 68%, which implies that error will be less than the requirement for 68% of the time.

MOOF-025 H/P — *The pointing budget shall demonstrate compliance of the design with these requirements; it shall be established according to the rules defined in the ESA Pointing Error Handbook (RD-1).*

Two different requirements for the scientific observing modes are to be taken into account: The Herschel mission and the Planck mission.

4.4.2.1 Herschel Pointing Requirements

<u>Herschel Pointing Error Definitions:</u>

- Attitude Measurement Error (AME): AME is the instantaneous angular separation between the actual LoS direction and the estimated LoS direction. This is referred to as 'a posteriori knowledge'.

- Absolute Pointing Error (APE): is the angular separation between the desired LoS direction, and the instantaneous actual LoS direction.

- Relative Pointing Error (RPE): is the angular separation between the instantaneous LoS direction and the short time average LoS direction during some time interval. This is also known as the pointing stability

- Pointing Drift Error (PDE): is the angular separation between the short time average LoS direction during some time interval and a similar average LoS direction at a later time.

- Absolute Rate Error (ARE): is the difference between the actual and the desired angular rate about the eigen axis of the manoeuvre. This applies only for line scanning.

- Spatial Relative Pointing Error (SRPE): is the angular separation between the average actual LoS direction and a desired LoS direction which is defined relative to an initial reference direction.

MOOF-030 H — *During all scientific observation modes requiring periods of stable pointing or scanning, the pointing requirements with the goals as specified in the table below shall be met.*

ERROR	***LOS (arcsec)***	***Around LOS (arcmin)***	***Goals for LOS (arcsec)***	***Goals around LOS (arcmin)***
APE pointing	*≤3.7*	*3.0*	*≤1.5*	*3.0*
APE scanning	*≤ 3.7 + 0.05 w*	*n.a.*	*≤ 1.5 + 0.03 w*	*n.a.*
PDE(24 hours) pointing	*≤1.2*	*3.0*	*n.a.*	*n.a.*
RPE (1 min) pointing	*<0.3*	*1.5*	*≤0.3*	*1.5*
RPE (1 min) scanning	*≤1.2*	*1.5*	*≤0.8*	*1.5*
AME pointing	*≤3.1*	*3.0*	*≤1.2*	*3.0*
AME scanning	*3.1+0.03*w*	*3.0*	*1.2+0.02*w*	*3.0*
AME slew	*≤10*	*3.0*	*≤5*	*3.0*

Notes : *w is the scan rate in arcsecond / second .*
APE scanning mode requirements and goals around LOS are covered by MOOF-085 (ARE : Absolute Rate Error about scan axis)

MOOF-035 H/P — *Deleted.*

MOOF-040 H — *In consecutive pointings within 4 deg. x 4 deg. spherical area, the **SRPE** of all pointings following the initial pointing, as referred to the average (barycentre) pointing direction of the first pointing shall be less than 1 arcsec (68% probability level).*

The initial reference direction is the average direction of the first pointing. The actual direction of the first pointing will lie within a cone of half angle RPE around this reference direction. The pointing reference axes for all consecutive pointings are specified as angular co-ordinates with respect to the initial reference direction.

4.4.2.2 Planck Pointing Requirements

Planck Pointing Terminology:

Jitter strip: The jitter strip is defined as the band between the two planes which just encompasses the path swept out by the LoS, in any full number of rotations on the celestial sphere.

Jitter strip average: The jitter strip average is the average (best least-square fitting) plane of the jitter strip.

Reference circle: The reference circle is defined on the celestial sphere as the desired circle, which LoS nominally should sweep through. Note that the reference does not consider the phase of the LoS pointing.

Scan direction[1]: the instantaneous time derivative of LoS w.r.t. an inertial frame.

Planck Pointing Error Definitions:

Line of Sight Pointing

- Attitude Measurement Error (AME): is the instantaneous angular separation between the actual pointing direction and the estimated pointing direction . This is referred to as ‘a posteriori knowledge’.

- Absolute Pointing Error (APE): is the instantaneous minimum angular separation of the actual LoS direction and the desired reference circle.

- Relative Pointing Error (RPE): is half the maximum angular width of the jitter strip over a specified time period (nominally 55 minutes). RPE is also known as the pointing stability.

- Pointing Drift Error (PDE): is the angular separation between the jitter-strip average during some time interval (nominally over 55 minutes) and a similar average at a later time (nominally 24 hours), but excluding the deterministic part originating from spin axis reorientation manoeuvres.

- Absolute Rate Error (ARE): is the difference between the actual and the desired angular rate about the spin axis.

- Pointing Reproducibility Error (PRE): is the angular separation between the 2 jitter-strip averages (nominally over 55 minutes) obtained by commanding two identical reference circles at 2 different times (nominally separated by 20 days).

Around Line of Sight Pointing
The pointing error around LoS is the angle between the scan direction and the plane containing Y_{focal_plane} and the LoS, Y_{focal_plane} being a parallel vector to Y_{SC}.

- APE around LoS is the instantaneous pointing error around LoS.

1 the scan direction can be understood as: at a given time, one considers the inertial direction determined the LoS. A short time later, this inertial direction has changed. The direction of variation is the scan direction.

- RPE around LoS is the instantaneous difference between pointing error around LoS and its average over 55 minutes.

- PDE around LoS is the angular separation between the short time average pointing error around LoS during some time interval (nominally 55 minutes) and a similar average pointing at a later time (nominally 24 hours), but excluding the deterministic part originating from spin axis reorientation manoeuvres.

- Pointing Reproducibility Error (PRE): is the angular separation between the two short time average pointing errors around LoS during some time interval (nominally 55 minutes) obtained by commanding two identical reference circles at 2 different times (nominally separated by 20 days).

MOOF-045 P *During the sky survey mode, the pointing requirements are specified in the table below:*

ERROR	***LOS (arcmin)***	***Around LOS (arcmin)***	**Goals for LOS (arcmin)**	***Goals around LOS (arcmin)***
APE	*≤37*	*≤37*		
PDE (24 hours)	*≤6.2*	*≤6.2*		
RPE (55 min)*	*≤1.5*	*≤10*		
AME	*≤0.5*	*≤6*	*≤0.2*	
PRE (20 days)	*≤2.5*			

**: No active control actions are expected during the period when RPE is applicable.*

MOOF-050 P *The nominal spin axis motion about the spacecraft +X-axis shall be at constant rate of +1 rpm (+6°/sec) with an Absolute Rate Error of less than 5.4 arcmin/sec.*

MOOF-055 P *Between 2 consecutive re-orientation manoeuvres , the spin rate drift or fluctuation over one hour shall be less than 10^{-4} rpm .*

MOOF-060 P *Deleted.*

4.4.3 Herschel Slew Requirements

Note: The observatory nature of Herschel implies that it will carry out a large number of observing projects with a wide range of observing times varying from seconds to hours.

The following definitions of slew and scan apply to Herschel and Planck:

A slew is a manoeuvre of the spacecraft from one pointing direction to another without specific requirement on the path.

A scan is a manoeuvre of the spacecraft along a specified path with a specified rate along this path.

MOOF-065 H	*Deleted.*
MOOF-070 H	*Slews shall nominally not use the Reaction Control Subsystem (RCS).*
MOOF-075 H	*The maximum slew speed shall be at least 7 degrees/min when the slew angle is large enough to permit full angular velocity.*
MOOF-080 H	*It shall be possible to change by command, scan rate between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.*
MOOF-085 H	*The Absolute Rate Error about the scan axis shall be better than 1% of the demanded rate but not less than 0.1 arcsec/s.*
MOOF-090 H	*For slews smaller than 16 arcmin, during any of the observational pointing modes, the total time between initiation of the slew and the moment when the telescope axis has achieved the pointing requirements, as defined in paragraph 4.3.2.1, on the new target shall be less than:* *Requirement 10+SQRT (2*ϕ) seconds* *goal 5 + SQRT(ϕ) seconds* *ϕ being the slew angle in arcseconds.*
MOOF-095 H	*The system shall be dimensioned for operational slews of at least 90 degrees, executed twice per day. Slews with an amplitude of 90 degrees shall be completed within 15 min, including settling.*

No constraints, other than the attitude constraints listed in Section 4.2.7. apply to the slewing method.

4.4.4 Planck Slew Requirements

MOOF-100 P	*The spacecraft shall be capable of reorienting the jitter strip average* with *an average frequency of one manoeuvre every 45 minutes throughout the nominal lifetime.*
MOOF-105 P	*The spacecraft shall be capable of reorienting the jitter strip average with an average amplitude of 3 arcmin (consistent with the Planck scanning law) and a resolution of 0.1 arcmin in any direction at a maximum rate of once per 30 min.*
MOOF-110 P	*The spacecraft shall be capable of reorienting the jitter strip average for up to 3 arcmin with an accuracy of ≤0.4 arcmin relative to the previous orientation (amplitude and direction; 68% probability level)*
MOOF-115 P	*The duration, including the settling time, of a 3 arcmin amplitude jitter strip average reorientation shall be ≤ 5 minutes (elapsed time during which pointing requirements cannot be met)* The shortest duration between two manoeuvres will be 30 min.

MOOF-120 P	*For large spin axis reorientation not part of the Planck scanning law (up to 20 degrees), the rate of reorientation of the jitter strip average shall be at least 0.5 arcmin/s.*
MOOF-125 P	*To meet Planck APE and PDE requirements the spacecraft design shall not require dedicated reorientation manoeuvres but utilise a maximum of +/-10% tuning of the amplitude of the manoeuvres needed to execute the nominal sky survey.*

4.5 FAULT MANAGEMENT REQUIREMENTS

The main objective of fault management is to protect the satellite and its scientific payload against the effects of faults, thereby maximising the operational lifetime. The following top-level requirements apply:

MOFM-005 H/P	*The design shall prevent the loss of the satellite. Any hazardous situation, which will not cause immediate loss but may develop into a loss of the satellite, shall be prevented by design or shall be protected.*

In addition the following supporting functional requirements shall be met:

MOFM-010 H/P	*Single failures, which pose a threat to mission objectives, mission life or spacecraft safety shall be eliminated. Where this cannot be achieved, a justification for retention shall be proposed for ESA assessment and approval by a Request For Waiver (RFW).*
MOFM-015 H/P	*The spacecraft design shall not include any failure propagation path such that failure from one function/unit causes permanent failure to another function/unit.*
MOFM-020 H/P	*Redundant units shall have a physical separation between them. If redundancy is implemented in the same box, a metallic separation is required.*
MOFM-025 H/P	*Where redundancy is employed, the design shall allow to operate and verify the redundant item/function independently of the nominal use.*
MOFM-030 H/P	*Each redundant path or function shall meet the full performance requirements.*
MOFM-035 H/P	*Autonomous failure detection and recovery shall not be based on a single sensor readout.*
MOFM-040 H/P	*Switch over to redundant units shall be possible without reconfiguration of unrelated units.*
MOFM-045 H/P	*The satellite shall respond to on-board failures by switching, independent from ground control, to redundant functional path. Where this can be accomplished without risk to satellite safety such switching shall enable the continuity of the mission timeline and performance. In*

the event that alternative redundant paths do not exist or that the failure effect is too complex to allow autonomous recovery, the satellite shall enter Survival Mode.

MOFM-050 H/P — *No single failure in the on-board protection system shall cause the spacecraft to go into survival mode.*

Note: This requirement may be waived if the design of the protection system functional chain can be shown to be inherently robust against spurious events or false triggering.

MOFM-055 H/P — *The spacecraft shall suppress uncontrolled recycling of error reaction functions.*

MOFM-060 H/P — *It shall be possible to enable, disable or reverse any on board autonomous function or action by ground command.*

Exceptions (e.g. Power distribution , DC/DC converters over-voltage protections , …) shall be identified and agreed .

MOFM-065 H/P — *The design of fault management systems shall be intrinsically fail-safe.*

MOFM-070 H/P — *All relevant anomalies shall be properly detected and unambiguously reported.*

MOFM-072 H/P — *Spurious anomaly detection (false alarms) shall be avoided.*

MOFM-075 H/P — *A clear and adequate fault reporting shall be provided in the telemetry.*

MOFM-080 H/P — *A clear and adequate fault diagnosis and identification shall be provided on-board.*

MOFM-085 H/P — *An expedite and reliable procedure, under ground control, shall be provided to return to nominal operations after a failure.*

MOFM-090 H/P — *Autonomous action shall be implemented at the appropriate level, i.e. at system level if the impact is system wide, at subsystem level if the impact does not reach further than the subsystem and at unit level if the impact is constrained to that unit.*

MOFM-095 H/P — *The implementation of any autonomous action shall avoid switching back and forth between unhealthy systems.*

MOFM-100 H/P — *An anomaly detection shall be confirmed by using more than one sample of the same measurement.*

MOFM-105 H/P — *The anomaly detection system must ensure that only valid information is used.*

Note: This requirement may be waived if the design of the anomaly detection system functional chain can be shown to be inherently robust against spurious events or false triggering.

MOFM-110 H/P — *Trigger limits shall have adequate and quantified margins .*

MOFM-115 — *It shall be possible to adjust software parameter values for confirmation time and trigger by ground command.*

H/P	*confirmation time and trigger by ground command.*
MOFM-120 H/P	*For any on-board autonomous reconfiguration, telemetry data shall indicate the time and the conditions, at/under which the event occurred.*
MOFM-125 H/P	*Control laws and parameters for autonomous functions shall be capable of being modified by ground command.*
MOFM-130 H/P	*No nominal operation shall require the deactivation of the on-board protection system.*

5 SPACECRAFT SYSTEM

5.1 GENERAL REQUIREMENTS

5.1.1 Definition

The two spacecraft Herschel and Planck will be launched on a single ARIANE 5 ECA-type launcher.

The Herschel / Planck composite is the name given to the assembly of the Herschel satellite and the Planck satellite in the configuration that can be integrated in the ARIANE 5 fairing.

The Herschel satellite will be divided into the following modules :

- The Payload Module (PLM) including the Herschel telescope as provided by the European Space Agency,
- The Service Module (SVM)

The Planck satellite will be divided into the following modules:

The Payload Module (PLM) including the Planck telescope reflectors and the Planck Telescope baffle as provided by the European Space Agency,

- The Service Module (SVM).

SGEN-005 H/P	*Both spacecraft shall optimise as much as possible the commonality between the Herschel and Planck components and interfaces in order to reduce the costs.*

The instruments will be developed by national institutes and are not covered by this document; they are considered as external interfaces as defined in the IID's part B (AD4-2 to AD4-6). The Herschel Payload Module will accommodate the three instruments of Herschel ; the Planck Payload Module will accommodate the two Planck instruments.

SGEN-010 H/P	*Units* *All drawings, specifications and engineering data shall only use the International System of Units (SI units).*

5.1.2 Axis System

The following axis system shall be used for all system, modules and subsystems activities, documentation and plans (Fig. 5.1-1 and Fig. 5.1-2).

5.1.2.1 Herschel Axis System

SGEN-015 H *The Herschel S/C coordinate system (O_{HSC}, X_{HSC}, Y_{HSC}, Z_{HSC}) is defined as follows:*
- the origin O_{HSC} is at the centre of the Herschel/Launcher separation plane.
- the X_{HSC}-axis is normal to the Herschel/Launcher separation plane, positive towards the payload.
- the Z_{HSC}-axis is normal to the X-axis such that nominally Z is pointing positive towards the sun.
- the Y_{HSC}-axis completes the right handed system.

At subsystem level, the origin of the axis system may be translated along the X-axis.

5.1.2.2 Planck Axis System

SGEN-020 P *Deleted.*

SGEN-025 P *The Planck S/C coordinate system (O_{PSC}, X_{PSC}, Y_{PSC}, Z_{PSC}) is defined as follows:*
- the origin O_{PSC} is in the centre of the Planck/Launcher separation plane.
- the X_{PSC}-axis is normal to the Planck/Launcher separation plane, positive towards the payload.
- the Z_{PSC}-axis is normal to the X-axis, in the symmetry plane of the telescope, with the positive direction on the concave side of the telescope.
- the Y_{PSC}:-axis completes the right handed system.

5.1.3 Configuration

As an example only, the system mechanical configurations are given in Figures 5.1-1 and Figure 5.1-2.

The following configuration requirements are applicable:

SGEN-030 H/P *Each spacecraft shall be configured in a modular way, with:*

- *each respective Service Module (SVM), which provides the spacecraft subsystems working in a normal temperature environment,*
- *the Herschel Payload Module (PLM), including the cold focal plane units of the scientific instruments and the cryogenic subsystem as well as some warm payload equipment,*
- *the Herschel Telescope,*
- *the Planck Payload Module consisting of the telescope with the instruments and all necessary equipment for a separate integration.*

Figure 5.1-1 -- The Herschel System Configuration

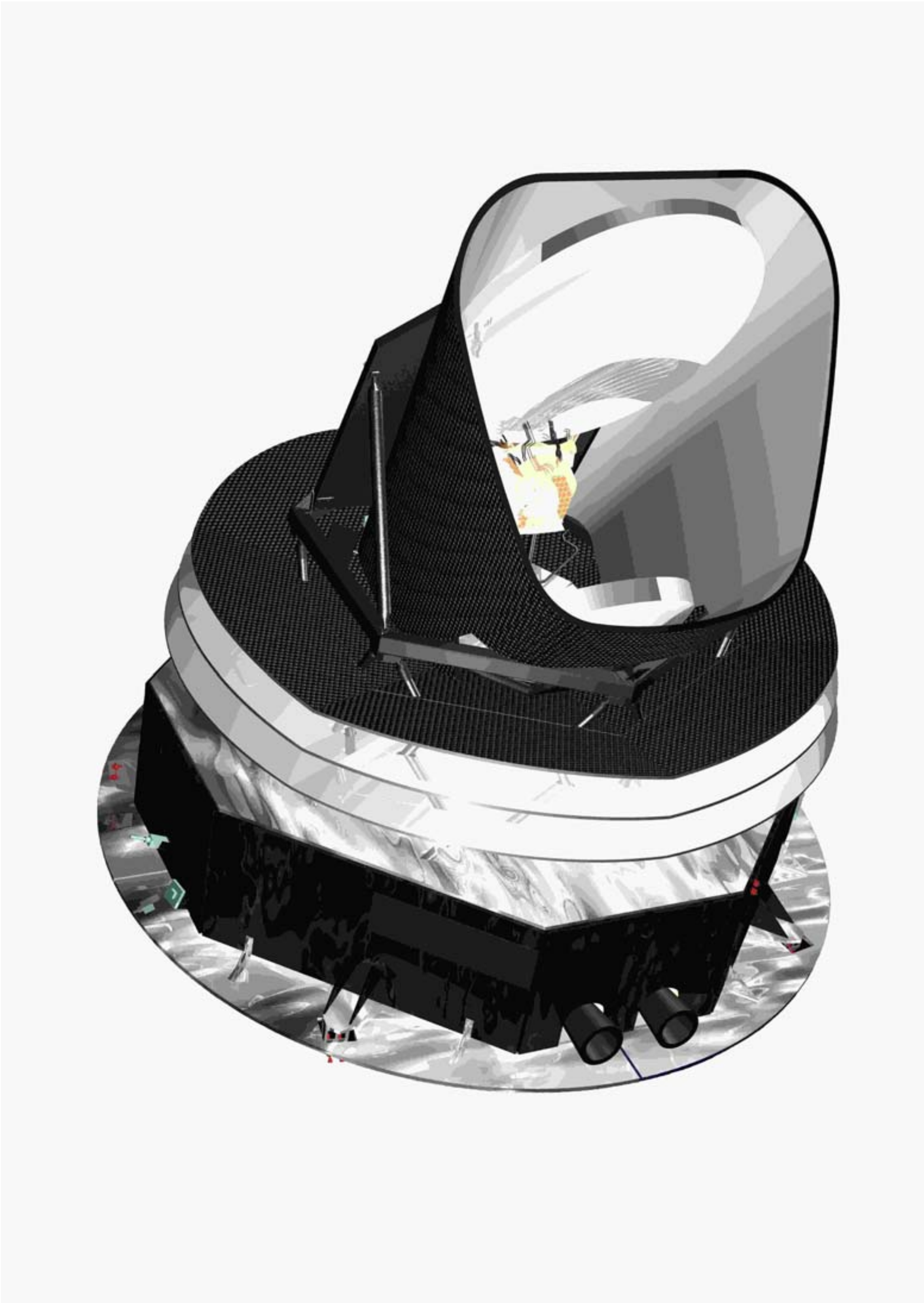


Figure 5.1-2 -- The Planck System Configuration

SGEN-035 H/P *The Herschel and Planck spacecraft design shall allow for maximum autonomy during integration and testing of the Herschel Payload Module, the Herschel Telescope Assembly, the Planck Payload Module and the Service Modules.*

SGEN-040 P *The Planck spacecraft spin axis shall be the principal axis of maximum moment of inertia.*

SGEN-045 P *For the Planck spacecraft, the stabilisation inertia ratio, expressed as lambda = 1+sqrt[(Ix/Iz-1) (Ix/Iy-1)] with Iz<Iy<Ix, taking into account satellite inertia uncertainties shall be higher than 1.05.*

5.1.4 Mass Properties

Mass and Delta-V

SGEN-050 H/P *The total mass of the Herschel / Planck composite at launch , including the scientific instruments and ESA reserve, shall not exceed 5593 kg including applicable development margins.*

Notes : 1) The total composite mass is 6273 kg (S/C + launcher adapters) corresponds to the performance of an Ariane 5 EC/A into an injection orbit to L-2

SGEN-055 H/P *Deleted.*

SGEN-060 H/P *The Delta-V requirements shall be as defined in the table below:*

	Herschel		Planck	
	Delta-V (m/s)	Direction w.r.t. S/C-to-sun (deg)	Delta-V (m/s)	Direction w.r.t. S/C-to-sun (deg)
Perigee velocity correction	10	any	10	any
Removal of LV dispersion	50	any	50	any
Manoeuvre on day 12	3	any	3	any
Mid-course correction	2	any	2	any
Orbit injection “15^0 Planck orbit”	N/A	N/A	215	125
Injection correction	N/A	N/A	2	any
Orbit maintenance	4.5	28.4 or 208.4	2.5	28.4 or 208.4

SGEN-065 H/P *Deleted.*

SGEN-070 H/P *The knowledge accuracy of the satellite mass shall be better than +/- 1% and of the moment of inertia shall be better than +/- 5%.*

Static and Dynamic Balance

SGEN-075 H/P *The flight ready spacecraft shall comply with the static and dynamic balance requirements specified in the ARIANE 5 Users manual (AD6-1).*

5.1.5 Materials, Processes and Parts

SGEN-080 H/P *The parts, materials and processes shall comply with the requirements, the environments and the quality assurance provisions as specified herein and with AD1-1.*

Parts, materials and processes will be selected according to their suitability for the intended application and on the basis of previous experience. The materials will be selected in agreement with AD6-12.

The following specific requirements apply:

SGEN-085 H/P *The selection of mechanical parts shall be justified by analyses, similarity, and if necessary, appropriate tests and their qualification for the required application shall be demonstrated.*

SGEN-090 H/P *Materials which are not used inside pressurised volumes on the spacecraft shall have low outgassing properties as determined by test method according to AD6-13:*

- Total Mass Loss (TML) < 1%

- Collected Volatile Condensable Material (CVCM) < 0.1%

In case of materials used in the vicinity of critical (optical) elements, the more stringent requirement applies:

- TML < 0.10%

- CVCM < 0.01 %

SGEN-095 H/P *Materials shall not be flaking or dusting so that a high degree of cleanliness of the flight hardware can be achieved and maintained. This is also applicable to materials used on GSE.*

SGEN-100 *Materials and combinations of materials bonded to each other shall be resistant to the thermal cycling to which they will be exposed until the*

H/P	*end of the mission. A standard thermal cycling method is defined in AD6-14, but the contractor shall as necessary perform specific thermal cycling tests which are representative of the actual qualification temperatures for the application, for qualification with at least a factor 1.5 on the number of cycles expected until end of the nominal lifetime (minimum 10 cycles).*
SGEN-105 H/P	*Materials shall be resistant to the radiation to which they will be exposed during their operational lifetime. The contractor shall determine what the anticipated radiation environment will be for materials used in various locations and as necessary demonstrate by appropriate testing that the properties shall not degrade below acceptable limits for significant properties.*
SGEN-110 H/P	*Materials, which are in contact with each other, shall be compatible with each other. Compatibility shall be demonstrated by test if insufficient data is available from standard references or previous applications.*
SGEN-115 H/P	*Materials shall be resistant to corrosion or they shall be suitably protected against corrosion.*
SGEN-120 H/P	*Materials shall have high resistance to stress corrosion cracking (SCC) for all structural applications but also for applications (like pretensioned springs or welded constructions which frequently include residual internal and assembly stresses) in which the materials are exposed for extended periods of time to tensile stresses in the terrestrial atmosphere or potentially corrosive environments. The requirement also applies for GSE handling and lifting devices for loads higher than 30 kg.* *Adequate resistance to SCC shall be verified in agreement with AD6-16.*
SGEN-125 H/P	*Metals which are in direct contact with each other shall not form a galvanic couple with a difference of more than 0.5 V Electro-Motive Force (EMF); in corrosive environments it shall not be more than 0.25 V EMF.*
SGEN-130 H/P	*As far as practicable, materials and mechanical parts shall be non-magnetic. In case magnetic material must be used for a particular function, the magnetic characteristics of the part will have to be determined and depending on the effects on system level, magnetic compensation methods might have to be applied.*
SGEN-135 H/P	*Materials that are nutrients for fungus shall not be used when their use can be avoided. Where used and not hermetically sealed, these materials shall be treated with a suitable fungicide agent.*
SGEN-140 H/P	*Materials which may constitute a safety hazard or can cause contamination shall not be used without specific approval by ESA (RFW). Examples of such materials are:* - *B Beryllium-Oxide* - *Cadmium* - *Zinc*

- *Mercury*
- *Radioactive materials*
- *PVC*

5.1.6 Maintenance, Accessibility, Repairability and Testability

SGEN-145 H/P *The design of the spacecraft shall consider the need for accessibility and the methods to be employed for the removal of units, placement of test aids, for equipment requiring adjustment or maintenance with the aim of eliminating or minimising:*

- *the possibility of injury to personnel*
- *the possibility of damage to equipment or facility*
- *the possibility of incorrect assembly*
- *task complexity*
- *use of special tools or equipment*
- *use of non-standard hardware*
- *design complexity*
- *the need for special skills*
- *the activity duration*

SGEN-150 H/P *It shall be possible to access or remove equipment if it requires maintenance control, with minimum disturbance to and interference with spacecraft or payload.*

SGEN-155 H/P *Items to be removed before flight (red tag items) shall be visible after integration with the spacecraft.*

SGEN-160 H/P *Items requiring integration for safety, logistical or life reasons, close to the launch, shall be accessible without removing any equipment from the spacecraft.*

SGEN-165 H/P *Items, which require adjustment, servicing or maintenance before launch, shall be accessible without removing any equipment from the spacecraft.*

SGEN-170 H/P *Each item of the spacecraft shall be directly interchangeable in form, fit and function with another item of the same part number (configuration item number). The performance characteristics and dimensions of like units shall be sufficiently uniform to permit interchange with a minimum of adjustment and re-calibration.*

SGEN-175 H/P *Periodic maintenance requirements during storage and ground life shall be minimised and declared.*

SGEN-180 H/P *The spacecraft and its constituting modules/assemblies and sub-assemblies shall survive all environmental testing without the need for refurbishment.*

5.1.7 Cleanliness and Contamination

SGEN-185 H/P	*The composite design shall be compatible with the cleanliness and contamination requirements given in the Product Assurance document (AD1-1) until the end of the nominal lifetime.*
SGEN-190 H/P	*The spacecraft and its items (like optical bench, telescope …) shall not contaminate the instruments and optical surfaces more than as specified in the following requirements*
SGEN-195 H/P	*deleted.*
SGEN-200 H	*For the Herschel telescope, the optical subsystem transmission losses (as defined in AD2-1) shall be lower than 3.5% (TBC) over the full 80 - 670 µm range at the time of cryostat cover opening in-orbit. Appropriate and timely analyses and measurement verifications shall be undertaken throughout the programme to give maximum confidence that this performance will be achieved.*
SGEN-202 H	*For the Herschel telescope, the optical subsystem transmission losses (as defined in AD2-1) shall be lower than 4.2% (TBC) over the full 80 - 670 µm range at the end of the nominal mission.*
SGEN-205 H/P	*The contamination of all optical surfaces of the Herschel and the Planck telescopes and instruments shall be controlled during all phases of the project (including ground life, pre-launch, launch and orbit life).The contamination shall not exceed the values given in the table below:* *Note : the particulate contribution during launch (ascent phase) shall be assumed to be 2300 ppm*

Planck

	Particulate (ppm)		*Molecular (10-7 g/cm²)*	
	Reflector1/ Reflector2	*FPU*	*Reflector1/ Reflector2*	*FPU*
Level at delivery to Prime	*900*	*300*	*5*	*30*
Total at the End of Nominal Lifetime	*5000*	*5000*	*40*	*60*

Herschel

	Particulate (ppm)			*Molecular (10-7 g/cm²)*		
	LOU	*M1/M2*	*FPU*	*LOU*	*M1/M2*	*FPU*
Level at delivery to Prime	*300*	*300*	*300*	*40*	*2*	*40*
Total at the End of Nominal Lifetime	*1200[1)] (TBC)*	*4500[2)]*	*1200[3)]*	*60[1)] (TBC)*	*40[2)]*	*60[3)]*

1) *Applicable for the 1st mirror inside the LOU*
2) *This value is an average of the requirement for M1 and M2*
3) *Applicable also for the LOU windows on the CVV*

SGEN-210 H/P *The spacecraft shall provide means to prevent contamination of the telescopes and instruments in-orbit during the initial (outgassing) phase and during the thruster firings.*

5.2 FUNCTIONAL REQUIREMENTS

The top-level functional requirements for the spacecraft are given below.

SFUN-005 H/P *Each spacecraft shall collect, store and transmit to the ground station all data (scientific and housekeeping) coming from the scientific instruments.*

SFUN-010 H *The Herschel Payload Module shall:*

- *Provide the necessary interfaces (mechanical, optical and electrical) with the Agency's provided Telescope and other elements of the spacecraft.*
- *Accommodate the focal plane units (FPU) of the instruments, the Local Oscillator Unit (LOU) of HIFI and the Buffer Amplifier Unit (BOLA) of PACS in accordance with the requirements and interface specification of the IID's Part B (AD4-2, AD4-3, AD4-4)*
- *Provide to the instruments FPU's, the required thermal environment, through a cryogenic subsystem*

SFUN-015 P *The Planck Payload Module shall provide the following functions:*

- *Provide the necessary interface (mechanical, optical, thermal and electrical) with the Planck Service Module*

- *Accommodate the offset telescope*
- *Accommodate the HFI and LFI instruments in accordance with the requirements and interface specification of the IID's (AD4-5, AD4-6)*
- *Provide the required thermal/stray light environment*

SFUN-020 H/P — *Each Service Module shall provide the following functions:*

- *Structural support and SVM thermal control*
- *on board storage of TM (SSR)*
- *control and measurement of satellite attitude*
- *satellite orbit control*
- *electrical power generation, conditioning, storage and distribution*
- *radio frequency transmission/reception with the ground*
- *data handling for distribution of ground and on-board commands and sampling/formatting of telemetry data*
- *distribution of all electrical signals through an SVM harness.*

SFUN-025 H — *The Herschel Service Module shall provide the following specific functions in addition to the above mentioned:*

- *support the Extended Herschel Payload Module*
- *interface with the launcher or the Planck spacecraft according to the selected launch configuration*

SFUN-030 P — *The Planck Service Module shall provide the following specific functions in addition to the above mentioned:*

- *support the Planck Payload Module*
- *interface with the launcher*
- *support the Herschel spacecraft according to the selected launch configuration.*

5.3 PERFORMANCE REQUIREMENTS

5.3.1 Lifetime

5.3.1.1 Nominal Lifetime

SPER-005 H — *For the Herschel mission , the Herschel spacecraft shall have a nominal lifetime of 3.5 years from launch till the end of the mission. This duration includes an allocation of 6 months for the transfer to the L-2 Lissajous orbit.*

SPER-010 — *For the Planck mission , the Planck spacecraft shall have a nominal lifetime of at least 21 months from launch till the end of mission*

P	*lifetime of at least 21 months from launch till the end of mission .* *This duration shall allow two full sky surveys (with a coverage of at least 95% of the full sky) at the operational Lissajous orbit around L-2 , and includes an allocation of 6 months for the transfer to the L-2 Lissajous orbit.*
SPER-015 P	*Deleted .*
SPER-020 H/P	*The completely integrated Herschel and Planck spacecraft shall permit storage in a controlled facility before launch, prior to start of transport to the launch site of 24 months. If required, helium refilling(s)/top-up(s) may be envisaged during this period.*

5.3.1.2 Extended Lifetime

SPER-025 H	*The lifetime in orbit (from launch till the end of the mission) of Herschel items which degrade with time or usage shall be designed for 4.5 years , under nominal conditions (no additional margin is required).*
SPER-026 P	*The lifetime in orbit (from launch till the end of the mission) of Planck items which degrade with time or usage shall be designed for 2.5 years , under nominal conditions (no additional margin is required).*
SPER-030 H	*For Herschel , propellant for orbit maintenance, attitude control and momentum management shall be dimensioned for 4.5 years.*
SPER-035 P	*For Planck , propellant for orbit maintenance, attitude control and momentum management shall be dimensioned for 2.5 years.*

5.3.2 Orbit Control

For orbit control, i.e. midcourse corrections after insertion into the transfer trajectory and orbit maintenance manoeuvres are necessary.

The actual magnitude and direction of the required manoeuvres will be determined after periods of tracking and subsequent orbit determination and the manoeuvre parameters will be up-linked to the spacecraft which will execute the manoeuvres by either time-tagged or ground command.

SPER-045 H/P	*The spacecraft must be able to execute the commanded manoeuvres. The magnitude error of the Delta-V manoeuvre shall not exceed 1% for manoeuvres of more than 10 m/s and shall not exceed 5% for smaller manoeuvres (including the effects of attitude accuracy) of the commanded magnitude at 95% confidence level.*

5.3.3 Straylight

For the Herschel mission

The straylight coming into the focal plane can have three distinct origins:

- Sources outside telescope field of view
- Sources inside field of view
- Thermal self emission

The definition of the optical components and properties of the Herschel scientific instruments, as far as relevant for the stray light verification are defined in the IID's parts A and B (AD4-1, AD4-2, AD4-3, AD4-4). The requirements are the following :

a. Sources outside telescope field of view

The far infra-red and sub-millimetre sky is dominated by four extremely bright objects: the Sun, the Earth, the Moon and Jupiter. Off-axis rejection is determined mainly by the quality of the baffling system at small angular distances from these bright sources.

SPER-050 H	*The parasitic light in the focal plane shall be below 1% of the background induced by self emission of the optical system for Sun, Earth, Moon at worst case locations corresponding to the aspect angle limits as specified in Section 4.2.7 for the Herschel observation mission phase.*

Note: The limit angle for Jupiter shall not be a design driver but shall be specified by the Contractor based on the actual design.

b. Sources inside field of view

The diffraction theory shows, that for a telescope of limited size, the energy coming from a monochromatic point source, even if it has a very strong maximum, is distributed across the whole focal plane. Imperfections in the mirror qualities, mainly dirt and small scale irregularities, will amplify this spill-over.

For information, it will be noted that:

Over the entire field of view at an angular distance of 3 arcmin or more from the peak of the Point Spread Function (PSF) the irradiance shall be less than 10^{-4} of the PSF peak irradiance (in addition to the level given by diffraction).

c. Thermal self emission

The optical subsystem of Herschel being at a finite temperature will emit far infra-red and sub-millimetre radiation that will fall onto the detectors, introducing spurious signals which are difficult to eliminate.

SPER-055 H	*The straylight level received at the detector element location of the PLM/Focal Plane Unit Straylight Models by self emission, not including the self-emission of the telescope reflectors alone, shall be less than 10% of the background induced by the self emission of the telescope reflectors.*

This requirement includes the self-emission of the PLM / Focal Plane Unit Straylight Model, which will be delivered by ESA.

For the PLANCK Mission

The contractor is invited to consult Reference Document RD-6 as a guide to the approach to be followed.

The straylight coming into the focal planes can have two distinct origins:

- Sources external to the spacecraft in the far-field of the telescope
- Spacecraft Self emission sources .

The definition of the optical components and properties of the Planck scientific instruments, as far as relevant for the straylight verification are below. The requirements are the following :

a. Sources external to the spacecraft in the far-field of the telescope

External straylight in the millimetre and sub-millimetre wave range is dominated by four extremely bright sources: the Sun, the Earth, the Moon and the Milky Way. Large angle off-axis rejection is determined mainly by the telescope shield's shape and size.

SPER-060 P	*The system rejection at the detectors for Sun, Earth, Moon at worst case locations shall be , at least :* ***30 GHz :*** *-91 dB , -78 dB and -71 dB respectively.* ***100 GHz (HFI) :*** *-91.5 dB (-99 dB), -78.5 dB (-86 dB) and -71.5 dB (-73 db) respectively* ***353 GHz :*** *-92 dB (-108 dB), -79 dB (-95 dB) and -72 dB (-81 dB) respectively.* ***857 GHz :*** *-98 dB (-122 dB), -85 dB (-109 dB) and -78 dB (-95 dB) respectively.*

Notes 1) The requirement for the Milky Way is of order –65 dB from peak but is driven by the telescope in free-standing configuration.

2) The values between brackets shall be taken as goals .

b. Spacecraft self emission Sources

SPER-065 P	*The Amplitude Spectral Density (ASD) at the bolometer (HFI) or cold LNA (LFI) of any signal due to fluctuating thermal emission from a S/C element that couples radiatively into payload detectors , shall be as specified below for each of the five defined individual frequencies , taking into account the power transfer function between the radiating source and the detectors .*

The ASD (in Watts / √Hz) of each frequency component between 0.01 Hz and 100 Hz shall be such that :

Frequency [GHz]	**ASD** [Watt / √Hz]
30	< 3.4 E-18 X
100 (LFI)	< 1.1 E-17 X
100 (HFI)	< 2.1 E-18 X
353	< 1.8 E-18 X
857	< 2.2 E-17 X

Note :
X is equal to one for any frequency component fo of the fluctuation source synchronous with the Planck S/C spinning rate (i.e. multiple of f.spin = 1 / 60 Hz).

Otherwise , X = (B * t.obs * Delta.f) , where Delta.f = fo – k * f.spin and k is chosen to minimise Delta.f .
t.obs = 3600 * FWHM / 2.5 arcmin , and FWHM is the angular resolution of the antenna radiation pattern in arc minutes .

In order to enable calculation of the straylight, the position, orientation and beam characteristics of the five horns in the focal plane at 30 ,100 , 353 and 857 GHz, together with their frequency bandwidth are given in annex 3.

5.3.4 Reliability, Fault Tolerance and Single Point Failures

SPER-070 H/P *A failure of one piece of equipment (unit level) shall not cause failure of or damage to another piece of equipment or subsystem, including the scientific instruments.*

SPER-075 H/P *Protected switching configurations employing separate “arm” and “active” operations shall be implemented whenever an unintended activation can lead to an operational hazard.*

activation can lead to an operational hazard.

SPER-080 H/P	*Protection systems shall be intrinsically fail safe and shall be capable of being enabled and disabled by ground command.*
SPER-085 H/P	*Cross strapping shall be incorporated in between chains of redundant units so that maximum overall reliability is achieved.*
SPER-090 H/P	*Hot redundancy shall be provided for functions, which could result in loss of mission if failing (e.g. receivers).*
SPER-095 H/P	*Provisions shall be made to prevent malfunction or elimination of redundant units by a common cause.*
SPER-100 H/P	*There shall be on-board failure detection capabilities*
SPER-105 H/P	*Event packets containing the details of any reconfiguration and the exact time of occurrence shall be included in the housekeeping telemetry and be stored on-board as necessary for later transmission to the ground. These event packets shall also be available to other on-board applications.*
SPER-110 H/P	*Compliance to the fault tolerance requirements, as given in section 4.5, shall be verified by FMECA or by other suitable methods, which are subject to agreement with ESA.*
SPER-115 H/P	*Single point failures, which cannot be eliminated from the design with reasonable effort (or fault tolerance requirements, which cannot be met) shall be summarised in a Single Point Failure/Critical Items List. They shall be subjected to formal approval by ESA on a case by case basis with a detailed retention rationale.*

5.4 EXTERNAL INTERFACES REQUIREMENTS

This Section gives the requirements for the interfaces between the spacecraft and the other elements, which constitute the Herschel / Planck system, the launcher, the ground segment, the instruments, the Herschel telescope and the Planck reflectors.

5.4.1 Instrument Interfaces

The instruments' interfaces are defined in the IID's Part B (AD4-2, AD4-3, AD4-4, AD4-5 and AD4-6), which are fully applicable.

SINT-005 H	*The Herschel spacecraft shall provide a mass allocation of 465 kg for the baseline payload accommodation as defined in IID Part B (AD4-2, AD4-3 and AD4-4) including margins.*

SINT-010 P *The Planck spacecraft shall provide a mass allocation of 480 kg for the baseline payload accommodation as defined in IID Part B (AD4-5 and AD4-6) including instrument coolers and margins.*

SINT-015 H/P *In addition to the margin specified in paragraph 5.1.4, the structural design of the Herschel and Planck spacecraft including the payload interfaces shall be able to meet its requirements if the mass of any particular payload unit is increased by 20% above the allocated values agreed in the IID's part B, issue 2.0 (AD4-2, AD4-3, AD4-4, AD4-5, AD4-6).*

SINT-020 H *The Herschel spacecraft shall provide a mean power allocation of 550 W to the Herschel payload during nominal scientific operations, including instrument margins.*

SINT-025 P *The Planck spacecraft shall provide a mean power allocation of 1000 W to the Planck payload during nominal scientific operations, including instrument margins.*

SINT-030 H/P *The spacecraft shall provide peak power for the instruments as defined in the IID's Part B (AD4-2, AD4-3, AD4-4, AD4-5, AD4-6).*

SINT-035 H/P *The thermal design of the spacecraft shall be able to meet its requirements for the following increases or decreases in the power dissipation of any particular payload unit with respect to the values agreed in the IID's Part B (AD4-2, AD4-3, AD4-4, AD4-5, AD4-6):*

- *Cold payload units below ambient temperature 20 %*
- *Warm payload units: 10 %*

SINT-040 H *The Herschel spacecraft shall provide the necessary resources for the average acquisition of at least 130 Kbps science telemetry over 24 hours.*

SINT-045 P *The Planck spacecraft shall provide the necessary resources for the average acquisition of at least 130 Kbps science telemetry over 24 hours.*

SINT-047 H/P *The spacecraft shall provide the necessary resources for the burst acquisition of at least 300 Kbps science telemetry from a single instrument for at least 30 minutes.*

The science telemetry rate includes instrument science and instrument periodic and non-periodic housekeeping data and the formatting overhead for the TM packet service.

SINT-050 H *For the Herschel Mission, a "On Target Flag" (OTF) shall be generated when the commanded target has been acquired.*

SINT-055 H *The OTF shall be made available in the TM (required for instrument data processing). The OTF shall indicate the time at which the OTF conditions start and end .*

SINT-060 P	*Deleted.*
SINT-065 P	*For the Planck mission the spacecraft shall deliver the precise instant (± 1.5msec) at which the phase of the spin can be referenced in inertial space.*
SINT-070 P	*The spin reference message shall be made available in the TM (required for instrument data processing).*
SINT-075 H/P	*The time correlation between the attitude information and science data shall be better than 0.5 ms.*

In addition, the instruments will be provided with redundancy for all functions as defined in the IID's Part B (AD4-2, AD4-3, AD4-4, AD4-5, AD4-6).

SINT-080 H/P	*28V bus regulated and MIL-1553B standard shall be the electrical interface types used for the instruments.*
SINT-085 H	*The Optical Bench (OB) supporting the Focal Plane Units of the Herschel instruments inside the Herschel Payload Module (FPLM) shall be in aluminium.*

5.4.2 Herschel Telescope Interface

The Herschel telescope and its ground support equipment are designed, manufactured, tested and delivered by European industry .

The telescope is an axi-symmetric, 3.5 m diameter Cassegrain telescope and consists of:

– a primary reflector
– a secondary reflector
– a secondary reflector support structure
– an interface triangle and mechanical fixation devices to the primary reflector

SINT-090 H	*The spacecraft shall accommodate the Herschel telescope defined in AD2-1 including mechanisms (TBC) and shall provide the resources to ensure that the performance requirements of Herschel and the needs of its instruments are fulfilled.*

5.4.3 Planck Reflectors Interface

The Planck Primary and Secondary Reflectors, the straylight baffle and its ground support equipment are designed, manufactured, tested and delivered by DK/Plank.

SINT-095 P	*The spacecraft shall accommodate the Planck telescope and its reflectors defined in AD1-3 and AD2-2 and shall provide the resources to ensure that the performance requirements of Planck and the needs*

of its instrument needs are fulfilled.

5.4.4 Ground Segment Interface

SINT-100 H/P *The spacecraft design shall be compatible with the ground segment interfaces as defined in the Herschel / Planck Space/Ground Interface (RF link) Documents (AD3-1) and the Herschel / Planck Operation Interface Requirement Document (AD3-2).*

SINT-105 H *The Herschel spacecraft design shall permit the dump of 24 hours stored telemetry with the real time science and housekeeping telemetry and simultaneously upload of the mission timeline in less than 3 hours at the maximum distance from the earth around L2 and with the Perth / New Norcia ground station.*

SINT-110 P *The Planck spacecraft design shall permit the dump of 24 hours stored telemetry with the real time science and housekeeping telemetry and simultaneously upload of the mission timeline in less than 3 hours at the maximum distance from earth around L2 and with the Perth / New Norcia ground station.*

SINT-115 H/P *Kourou ground stations type will be used during commissioning, initial orbit phase and in case of emergency.*

SINT-120 H/P *The spacecraft shall be compatible with a maximum duration of 6 hours of daily contact with the Kourou ground station type.*

<u>Note</u>: *The main reason for this requirement is for recovery of the spacecraft from emergency/survival mode.*

5.4.5 Ground Facilities Interface

SINT-125 H/P *The spacecraft design shall be compatible with the relevant ground test facilities.*

However, specific non-standard facility modifications/extensions might have to be implemented (e.g. for helium handling or nitrogen flushing).

SINT-130 H/P *A justification for such modifications/ extensions shall be submitted to ESA for assessment and approval.*

SINT-135 H/P *Electrical access for adequate system testing must be ensured.*

SINT-140 H/P *The spacecraft design shall be such as to allow for transportation of each complete spacecraft as well as the separate modules by standard commercial means.*

SINT-145 H/P *The design of the satellite and all operations and handling on the site shall be compliant with the safety regulations of the launch site (AD6-2).*

5.4.6 Launcher Interface

The launch vehicle will be Ariane 5 ESV type launch vehicle. The launch vehicle is described in the Ariane 5 User's Manual (AD6-1). The launcher interface document will be prepared during phase B.

Concerning the masses to be taken into account, the Herschel / Planck composite includes:

- The Herschel spacecraft,
- The Planck spacecraft,
- The launcher adapter(s),
- The Sylda-5.

SINT-150 H/P	*The Herschel and Planck spacecraft shall be compatible with a launch on Ariane 5.*
SINT-155 H/P	*The Herschel and Planck spacecraft design and operations shall comply with all performances, requirements, interfaces and operations specified in the Ariane 5 User's Manual (AD6-1).*

The flight adapter(s)* together with the separation mechanism (including clampband) will be provided by ESA (via Arianespace).
The test adapter(s), which need to be representative of the launch vehicle adapter will be provided by ESA (via Arianespace).

The cryogenic operations to be performed on the launch site will be described in the launcher interface document to be produced during Phase B.

SINT-160 H/P	*The telemetry and telecommand standards applied to the satellites shall be compatible with those used on the launch site in order to perform the launch tests and to monitor the satellite during the launch preparation.*
SINT-165 H/P	*The spacecraft Ground Support Equipment shall be compatible with the requirements listed in AD6-2/2.*

5.5 ENVIRONMENT CONDITIONS

The satellite will be exposed to environments pertinent to the ground life, the launch and the orbital phase.

On ground, during launch and in orbit, the satellite will be submitted to mechanical and acoustic loads, to thermal and humidity environments and to electromagnetic environment. In orbit, it will also be exposed to particle radiation.

SENV-005 H/P	*On ground, during integration, handling and transportation, the environment, with the exception of bake-out, shall be such as to be significantly less severe than launch and orbit conditions with the exception of the thermal environment of the Cryostat for Herschel and the Planck sorption cooler radiator.*
SENV-010 H/P	*No induced environment shall lead to a degradation of the spacecraft and the instrument performances*

5.5.1 Mechanical Environment

SENV-015 H/P	*The Herschel / Planck composite shall be designed to withstand all mechanical static and dynamic loads encountered during its entire life, including: manufacturing, assembly, handling, transportation, testing, launch and in-orbit operations.*
SENV-020 H/P	*Manufacturing, handling and transportation loads (except for the MGSE interface points themselves) as well as test loads shall not be design drivers.*
SENV-025 H/P	*The mechanical environment for the launch phase shall be derived from the Launcher Coupled Loads Analysis.*
SENV-030 H/P	*The mechanical dynamic test environment shall meet the requirements of the Ariane 5 User's Manual (AD6-1).*

5.5.2 Thermal Environment

SENV-035 H/P *The spacecraft shall be designed to withstand all thermal environments encountered during its entire life, including:*

a) Integration, transportation and testing, including bake-out
b) Spacecraft preparation at the launch site
c) pre-launch phase with the spacecraft under the fairing.
d) ascent phase including the coast phase
e) in-orbit operations from launcher separation until the end of the mission

SENV–040 H/P	*The constraints applicable to b) above shall be derived from the Ariane 5 User's manual.*
SENV-045 H/P	*The constraints applicable to c) and d) above shall be derived from a specific thermal analysis of the spacecraft integrated with the launcher Analysis (under the responsibility of ARIANESPACE).*
SENV-050 H/P	*The constraints applicable to a) and e) above shall be derived by the contractor.*

SENV-055 H/P *The in-orbit environment shall be derived from the Mission Analysis Document (AD5-2).*

SENV-060 H/P *The environments under a) above shall not be design drivers, except for the bake-out.*

5.5.3 Humidity

SENV-065 H/P *The spacecraft shall be designed to withstand a relative humidity (RH) without performance degradation of 45 % RH to 65 % RH , non-condensing, and for two weeks a relative humidity of 95 % RH , non-condensing.*

5.5.4 Pressure

SENV-070 H/P *The spacecraft shall be designed to withstand any external air pressure between ambient (0.105 MPa) and vacuum (< 10^{-4} Pa).*

SENV-075 H/P *The composite shall be designed to withstand the depressurisation profile as defined in the Ariane 5 User's Manual (AD-6-1).*

5.5.5 Radiation Environment

Although, after the LEOP, the spacecraft will not traverse the Earth's radiation belts, the spacecraft will still be exposed to energetic protons and heavy ions from solar flares and cosmic rays.

The principal anticipated radiation effects are:

- Degradation of electronic components, detectors and materials (dose effect, ionising and non-ionising)
- Interference with detector operation (background)
- Cosmic ray induced upsets
- LET spectra
- “Latch-up”
- Electrostatic charging .

SENV-080 H/P *The contractor shall be responsible for performing radiation analyses as required using the nominal mission scenario and taking into account the data from the Herschel L2 Radiation Environment document (AD5-1). The in-orbit case with a beginning of mission in February 2007 shall be taken into account.*
In particular, the figures related to the Silicon Solar cells, Gallium Arsenide cells, single dose/depth, non-ionising dose/depth and raw particle spectra shall be taken into account.

5.5.5.1 Radiation Dose

SENV-085 *The satellite shall be designed to withstand the doses predicted for a 2*

H/P *times the nominal lifetime of the spacecraft except for the solar array sizing.*

SENV-090 H/P *The components and their shielding shall be compatible with the above requirement such that the radiation dose will not cause failures or produce unacceptable changes in performance.*

SENV-095 H/P *For the design of the solar array and the determination of its degradation during the mission, the total equivalent fluence of 1 MeV electrons shall be taken into account for the extended lifetime.*

SENV-100 H/P *Components shall be qualified (either based on existing or new test data) to withstand the doses predicted according to SENV-085. Radiation testing shall be included in the lot acceptance testing, if the margin is small and if the variation of radiation resistance between lots is large or insufficiently known. An exception to this requirement is the solar cells, which shall be qualified according to applicable documents (AD6-8/1 and AD6-8/2).*

5.5.5.2 Radiation Induced Background

Radiation impinging onto a detector or its associated electronics can produce an increase in noise, which in turn can produce a significant decrease of performance. Such changes can last until well after the radiation dose has stopped (remittances).

SENV-105 H/P *The spacecraft design and component selection shall be such as to minimise these effects, including any necessary means to ensure the most rapid restoration of nominal performance.*

5.5.5.3 Single Event Upset

The spacecraft will be subject to cosmic ray and heavy ion impacts, which can provoke Single Event Upsets (SEU) in devices containing bi-stable elements such as memories, comparators or gate latches.

Important parameters in defining SEU sensitivity are the “Threshold LET” (linear energy transfer) which is the lowest LET (stopping power) required to cause upset, and the limiting cross section which is the saturated value of the upset rate as a function of LET

SENV-110 H/P *The spacecraft design shall withstand the effects of SEU's without interrupting the on-going operation and it shall include proper error detection, transient filters and correction schemes.*

SENV-111 H/P *The prediction of Single Event Upset (SEU) effects and rates shall be based on the Linear Energy Transfer (LET) spectrum given in AD5-1.*

This LET spectrum includes the fluxes of galactic cosmic rays and of solar protons .

SENV-115 H/P	*The rate of uncorrectable errors in spacecraft memories shall be better than 1E-11 (error/bit/day).*
SENV-120 H/P	*Any device used as memory (EDAC, registers …) for which the correct functioning is critical to mission objectives, mission life or spacecraft safety, shall have protection against SEU effects.*
SENV-125 H/P	*All spacecraft processor semiconductor memories and registers shall implement Single Error Correction and Double Error Detection (SECDED) for each smallest addressable unit in memory.*
SENV-130 H/P	*The processor design shall ensure that the processor internal registers are refreshed at a rate sufficient to avoid cumulation of deposited charges leading to errors.*

5.5.5.4 Latch-up

Cosmic rays may cause latch-up in certain technologies, primarily CMOS. Latch-up is permanent and potentially destructive.

SENV-135 H/P	*Protection against latch-up and de-latching shall be provided for devices showing a sensitivity to latch-up.*

5.5.5.5 Electrostatic Charging

Especially during solar flares, hot plasma can charge spacecraft surfaces to several kilovolts negative.

SENV-140 H/P	*Spacecraft design and materials selected shall be such as to ensure that no parts of the spacecraft are charged to high potentials.*
SENV-145 H/P	*All spacecraft surfaces exposed to the plasma environment shall be conductive and grounded to the spacecraft structure.* *Agreed exceptions are : Solar cells on solar arrays, and optical solar reflectors (OSRs) on the Herschel sunshade.*
SENV-150 H/P	*The exposed harness di-electric charging shall be taken into account and appropriate design provisions shall be taken.*

SENV-155 H/P	*The spacecraft design and component selection shall take these effects into account and shall ensure that these effects do not cause a degraded performance or hazardous situations, which could lead to loss of mission.*
	The spacecraft shall withstand without being disturbed, the following levels:
	- *For Conducted Electrostatic Discharge (current injected anywhere in the structure):*
	  - *Energy: 15 mJ*
	  - *Voltage: 15 kV (may be reduced to 4 kV if risk for is*

apparent)

- *For Radiated Electrostatic Discharge (spark gap at 30 cm distance)*
  - *Energy: 15 mJ*
  - *Voltage: 15 kV*

5.5.6 Electromagnetic Compatibility

The EMC requirements applicable to the spacecraft are defined here below and the following EMC areas have to be taken into account:

- EMC with the launcher
- EMC with the space environment
- Internal spacecraft EMC
- EMC with the instruments.

SENV-160 H/P	*The spacecraft shall not be susceptible to self-generated electromagnetic interference and ensure satisfactory payload performance during the mission, as well as non-hazardous operation of the spacecraft in ground test and launch environment. The term EMC shall cover all frequencies (including DC) which fall in either the Payload, Spacecraft or Launcher bandwidth.*
SENV-165 H/P	*The spacecraft electromagnetic emissions and susceptibility shall comply with the payload requirements listed in the IID's Part B outside the DTCP*
SENV-170 H/P	*The composite electromagnetic emissions and susceptibility shall comply with the launcher requirements (AD6-1).*
SENV-175 H/P	*The grounding scheme shall be selected to meet the payload and spacecraft subsystem requirements.* *As baselined, the spacecraft will adopt a distributed single point grounding scheme.* Note: The grounding scheme shall be selected to meet the Payload and Spacecraft Subsystems requirements. This may require a trade-off between the distributed single point grounding scheme (structure ground concept) baselined in IDD part A and other scheme.
SENV-180 H/P	*Good and reliable bonds shall be provided between the various parts of any electronic box, connectors, harness shields, structure including external booms, thermal blankets (foil and MLI) and the spacecraft structure.* Note: The Contractor shall define the limits acceptable for bonding for the items listed above, including the number of required bonding points.
SENV-185 H/P	*The power converter frequency bands shall be selected to minimise potential interference with the bandwidth of payload equipment.*
SENV-190	*A frequency control plan shall be established and maintained as part*

H/P *of the EMC programme.*

SENV-195 H/P *A 6 dB interference margin shall exist between susceptibility and specified environment, except for any pyrotechnic devices where this margin shall be 20 dB.*

The Radiation Design Handbook (RD-2) shall be used as a guideline. The precise performance requirements for the integrated system, subsystems and equipment shall be established with ESA agreement.

SENV-200 H/P *Galvanic isolation shall be provided between primary and secondary power.*

SENV-205 H/P *Signal, power and data lines and their returns shall be separated.*

SENV-210 H/P *The contractor shall support an EMC Review Board consisting of experimenters, Industry and ESA in order to review the Spacecraft/Payload EMC performance and to advise and seek solutions to EMC when needed.*

Note : This is a “ Statement Of Work “ and not a Requirement .

5.5.7 Solid Particle Environment

SENV-215 H/P *The applicable solid particle in-orbit environment is given in AD5-3. The spacecraft shall be designed to minimise the effect of this environment.*

5.6 SYSTEM DETAILED REQUIREMENTS

5.6.1 Mechanical Detailed Requirements

Definitions

- Primary structures :

  The primary structures are the main flight Loads paths and define the major structural frequencies.

- Secondary structures :

  The secondary structures are not responsible for the main load transfer. They are fastened to the primary structure, and transfer unit loads to the primary structure.

- Unit/Equipment structures :

Unit/Equipment structures are those belonging to self standing items such as experiment units and sensors, mechanisms, subsystem components and electronic boxes.

5.6.1.1 Stiffness Requirements

SCMD-005 H/P — *Structure resonance frequencies shall meet the launcher requirements as specified in AD6-1.*

SCMD-010 H/P — *The eigen frequencies of compact equipment and boxes in hard-mounted conditions shall be above 140 Hz.*

5.6.1.2 Strength Requirements

SCMD-015 H/P — *Each satellite shall be able to withstand the mechanical environment as deduced from the coupled analysis with the launcher.*

SCMD-020 H/P — *Under worst case combinations of mechanical and thermal loads and after application of the relevant safety factors (SF) , the margins of safety (MOS) shall be positive .*

SCMD-025 H/P — *The structure shall withstand at element, subassembly, or complete spacecraft level the following:*

- *the ultimate loads without rupture, collapse or permanent deformations that impact the integrity of other parts or the system performance.*
- *the yield loads, where applicable, without permanent deformation or any plastic deformation resulting in performance degradation.*
- *the buckling loads without elastic buckling or collapse taking into account a non perfection of the failing element, e.g. by knock-down factors.*

SCMD-030 H/P — *Under the design loads and where the mass of each unit or component is set at the maximum allocated, the force fluxes at the launcher interface shall meet the launcher requirements as specified in AD6-1.*

SCMD-035 H/P — *The spacecraft structure shall withstand the complete set of tests at qualification level with sufficient margins without the need of any refurbishment for flight.*

5.6.1.3 Safety Factors

SCMD-040 H/P — *Safety Factors (SF) shall account for inaccuracies in predicted allowable and applied stresses due to:*

- *Analysis uncertainties*
- *Manufacturing tolerances*
- *Scatter in material properties*

- *Setting at interface*

SCMD-045 H/P *The following safety factors (SF) are defined for the dimensioning of the equipment to cover uncertainties of load factor evaluation , material data and analysis , as well as to avoid undesirable influences of manufacturing tolerances .*

They shall be applied to the design limit loads , yield against permanent deformation , ultimate against rupture and loss of functionality :

Item	***Yield SF***	***Ultimate SF***	***Buckling SF***
Conventional metallic materials	*1.1*	*1.5*	*2.0*
Unconventional materials	*1.4*	*2.0*	*2.0*
Inserts and joints	*1.5*	*2.0*	*NA*

Table 5.6-1 – Basic Safety Factors

SCMD-050 H/P *Deleted .*

Definition of conventional and non-conventional materials:

Conventional materials:

All materials, also composites, provided sufficient statistical data are available to derive A values as defined in AD6-18 (MIL-HDBK-5F, Section 1.4.11).

Unconventional materials:

Those materials for which sufficient statistical data are not available.

Inserts and joints:

Standard inserts as defined in the Insert Design Handbook PSS-03-1202 may use a safety factor of 1.5 against minimum "A" ultimate capabilities.

5.6.1.4 Loads and Margins of Safety

During flight, the spacecraft will be submitted to static and dynamic loads induced by the launch vehicle.

The following loads are defined:

Limit Loads

Limit loads are the enveloping mechanical and thermal load combinations which have a 99% probability of not being exceeded during the entire life of the structure, including manufacturing, handling, transportation, ground testing without qualification, launch and on-orbit operations. They shall be derived from the various locations on the spacecraft from the quasi-static loads applied at the spacecraft centre of mass (COM) and the loads resulting from the spacecraft vibration.

Design Loads

Design loads are simplified load cases, which shall envelope the limit loads, and the qualification loads of the environmental testing.

Preliminary Design Loads

Preliminary design loads are the design loads to initiate the design phase.

Yield Loads

Yield loads are design loads multiplied by the yield safety factor.

Ultimate Loads

Ultimate loads are design loads multiplied by the ultimate safety factor.

Buckling Loads

Buckling loads are design loads multiplied by the buckling safety factor.

SCMD-055 H/P *The design loads applicable to units shall be greater than or equal to the design loads of the supporting structure.*

SCMD-060 H/P *The interfaces shall be designed against the design loads of the attached items applied at the centre of mass of these items.*

SCMD-065 H/P *The following preliminary design loads shall be used for initial design. They will be superseded in the next phases of the development and when test loads and flight loads based on coupled analysis with the launcher will be available.*

A - For Primary Structures :

Case	Longitudinal	Lateral
1	*9 g*	*1.5 g*
2	*5 g*	*3 g*

B - For the Helium-II Tank and its suspension :

Case	Longitudinal	Lateral
1	*13 g*	*1.8 g*
2	*5 g*	*5 g*

C - For the Propellant Tanks :

Case	Longitudinal	Lateral
1	*15 g*	*10 g*
2	*5 g*	*15 g*

D - For Service Module (SVM) equipment Panels :

Case	Longitudinal	Lateral
1	*15 g*	*10 g*
2	*5 g*	*15 g*

Longitudinal loads can have any sign .
Lateral loads can have any direction and sign .

E - For the secondary structure :

Unit brackets and attachments	*30 g*	*spherical envelope*
Antenna booms , flexible units	*50 g*	*spherical envelope*
Solar Arrays	*15 g*	*spherical envelope*

F - The preliminary design loads of the Herschel telescope are specified in AD2-1 and in AD2-2 for the Planck reflectors .

Margins of Safety (MOS)

SCMD-070 H/P *The margin of safety shall be calculated as follows :*

$$MOS = \frac{\text{Allowable load or stress}}{\text{Applicable load or stress}} - 1.0$$

The applicable loads are defined in paragraph 5.6.1.4.

The Yield Margin of Safety (YMOS) compares the yield strength capability of the structural elements to the yield loads.

The Ultimate Margin of Safety (UMOS) compares the ultimate strength capability of the structural elements to the ultimate loads.

The Buckling Margin of Safety (BMOS) compares the buckling strength capability of the structural elements to the buckling loads.

The strength capability is equal to that load which exactly induces the allowable stresses.

SCMD-075 H/P *The material Design Allowable shall correspond to the A values as defined in the applicable document reference AD6-18, MIL-HDBK-5. The contractor shall perform material testing as necessary to establish* *the Design Allowable. The test program and interpretation of the results are subject to ESA approval.*

5.6.1.5 Mass Margin

SCMD-080 H/P — *The total spacecraft mass shall be minimised wherever reasonable and shall include, at the beginning of the Phase B, a margin on each spacecraft elements depending on the development status of those elements as follows :*

- *Completely new developments* — *20%*
- *new developments derived from existing hardware* — *15%*
- *existing units requiring minor/medium modification or units passed PDR* — *10%*
- *existing units or units passed CDR* — *5%*

The propellant masses shall be determined on the basis of dry mass including the above contingencies and shall itself include the lifetime margins (section 5.3.1).

- *launcher dispersion compensation propellant* — *5%*
- *orbit insertion propellant* — *0%*
- *orbit maintenance propellant* — *50%*
- *angular momentum management/attitude control* — *50%*

SCMD-085 H/P — *The total mass of the Herschel / Planck composite shall include an ESA reserve of 100 kg.*

Note : The above specified margins and reserve shall be identified and visible in the mass budget of the total mass of the Herschel / Planck composite .

5.6.1.6 Alignment and Stability Requirements

The Herschel alignment budgets and alignment and stability requirements within the Herschel Scientific Instrument Focal Plane Units as well as between the HIFI FPU and the LOU are given in the IID's (AD4-2, AD4-3, AD4-4).

The Planck system level alignment concept, alignment budgets and alignment and stability requirements between the Planck Focal Plane Unit, the Planck PLM, the Planck SVM and the Planck Telescope is given in the IID's (AD4-5, AD4-6).

SCMD-088 H — *In addition to the alignment requirements originating from the Herschel LoS pointing requirements of section 4.4.2, the applicable explicit in-orbit alignment requirements for the three instrument focal plane units with respect to the telescope are as follows (at 95% probability level):*

Focus alignment:

Instrument	*Focus alignment along the telescope optical axis*
PACS	*<+/-7.0mm*
SPIRE	*<+/-7.7mm*
HIFI	*<+/-8.5mm*

Pupil mismatch:

Instrument	*Pupil mismatch in the telescope M2 plane*
PACS	*<+/-7.0mm*
SPIRE	*<+/-9.5mm*
HIFI	*<+/-24mm*

SCMD-090 H/P *For each spacecraft an alignment plan and budgets shall be established and maintained by the prime contractor.*

Other specific payload units alignment requirements are also given in the IID's Part B (AD4-2, AD4-3, AD4-4,AD4-5, AD4-6).

The alignment and stability requirements of the SVM and SVM equipment (e.g. startrackers) with respect to the PLM or telescope shall be derived by the contractor from the relevant performance specifications.

Specific alignment and stability requirements at module (PLM, SVM) or assembly level (Herschel Telescope) are given in the relevant Sections.

SCMD-095 H/P *Optical references shall be used for alignment of the focal plane instruments, telescopes and critical components.*

SCMD-100 H/P *The optical references shall be accessible during module and system AIT operations.*

SCMD-105 H/P *The alignment stability of the spacecraft shall be commensurate with all spacecraft performance requirements (pointing, optical) and the following causes of misalignments shall be taken into account:*

- *Setting due to mounting procedures*
- *Setting due to launch distortions*
- *Gravity release*
- *Deformations caused by orbital temperature variation over the complete mission (including initial cooldown)*
- *Ageing*
- *Creep*
- *Composite structure deformations due to moisture release and radiation.*

SCMD-110 H/P *The stability analysis shall be budgeted according to contributions as specified. Each potential cause of misalignment shall be compliant with its allocation.*

5.6.2 Mechanisms Requirements

5.6.2.1 General

All subassemblies featuring parts moving under the action of commandable internal forces shall be considered as mechanisms. They include all hold-down and release mechanisms, hinges, actuators and latches and relevant pyrotechnics which are required for latching, deployment, alignment, positional control, ejection, etc. of spacecraft subsystem equipment. General mechanism requirements and ESA standards applicable to mechanism are given in AD6-10.

Any mechanism associated with the scientific instruments, e.g. covers, vacuum doors, calibration source mechanisms, etc. will be the responsibility of the Principal Investigator supplying the instrument and will not be part of the spacecraft mechanism subsystem.

SCME-005 H/P	*The mechanisms shall comply with the requirements of AD6-10. In case of conflict between requirements in AD6-10 and the requirements in the present document, the latter ones will have precedence.*
SCME-010 H/P	*The mechanism, with its electronics for drive and control shall include monitoring equipment to provide data describing the status of the mechanism and/or electronics.*
SCME-015 H/P	*The monitoring data shall be accessible to the spacecraft telemetry at any time and shall be of the absolute type.*
SCME-020 H/P	*During launch, the deployables must be contained within the limits of the dynamic envelope of the allocated space within the launch vehicle. In this configuration, all deployable and movable assemblies shall be properly restrained to avoid excessive loads or damage by contact or excessive amplification of vibration.*
SCME-025 H/P	*Global and local envelope volumes shall be defined for all moving parts within which they are free to move. It shall be demonstrated at system level and at unit level that these envelopes are sufficient and do not lead to mechanical interference.*

The performance of the mechanism is described by the following:

- The motion will be described by the Kinematical Variables (acceleration, velocity, displacement) and the Dynamic Variables (forces, torques).
- The initial and final state will be described by the Steady State Parameters, i.e. relative position or velocity with respect to a well-defined interface.
- The Kinetical Variables are the results of the interaction of various parameters, e.g. mass, inertia, spring force, friction, adhesion, etc. Those parameters are called the Physical Parameters.

SCME-030 H/P	*The tolerances of the Steady State Parameters shall be specified and demonstrated compatible with the functional needs.*
SCME-035 H/P	*The parameters restricting the design of the Dynamical Variables shall be established and demonstrated compatible with the functional needs at system level.*
SCME-040 H/P	*The mechanisms shall comply with the safety requirements of launcher, launch range and spacecraft.*

5.6.2.2 Performance Requirements

SCME-045 H/P	*The structural parts of the mechanisms shall meet the requirements specified in Section 5.6.1.*
SCME-050 H/P	*Stiffness requirements shall be established and demonstrated compatible with the structural and functional needs at system level for all the envisaged configurations of the mechanism.*
SCME-055 H/P	*In addition to the limit/design loads specified in Section 5.6.1.4 the structural parts of the mechanisms shall withstand the loads induced by its operation.*
SCME-060 H/P	*Hold-down and release mechanisms shall be capable of being operated the number of times required by on-ground and in-orbit operations plus a margin of at least 10 operations.*
SCME-065 H/P	*Mechanisms shall be simple and self-locking and be easily resettable for ground testing in case of latches for post-deployment latching.*
SCME-070 H/P	*Mechanisms shall not be capable of being driven in an anomalous and non-recoverable configuration.*
SCME-075 H/P	*Off-load mechanisms, if used, shall be capable of being operated manually for protection during handling or transportation. Such attachments as required for manual operation may be removable provided that removal does not compromise the built of the equipment.*
SCME-080 H/P	*Mechanisms shall satisfy the thermal requirements of Section 5.6.3.*
SCME-085 H/P	*Motors shall withstand their stalling torques for a period of time of at least 24 hours under the maximum predicted operating voltage without degradation under the hottest qualification environmental temperatures.*
SCME-090 H/P	*Mechanisms shall be capable of being tested representatively on ground and of being operated in an ambient environment. However, if required, flushing with inert gas may be designed to protect parts of the mechanism, which are sensitive to operation in air due to the presence of moisture, particles or other sources of contamination.*
SCME-095 H/P	*Mechanisms shall not require any periodic maintenance for their entire storage period. Activation and maintenance after a period of storage is acceptable to verify the functional performances.*

5.6.2.3 Detailed Requirements

SCME-100 H/P	*Existing parts and components used in mechanisms shall be fully qualified for the intended application. The qualification procedures are subject to ESA approval.*
SCME-105 H/P	*Sliding surfaces shall be avoided. If they cannot be avoided, lubricated hard surface coatings shall be applied to prevent fretting.*
SCME-110 H/P	*Mechanisms shall only employ lubricants that are qualified according to procedures compliant with ESA PA requirements. Dry lubricants are preferred. Use of liquid lubricants shall be fully justified and approved by ESA.*
SCME-115 H/P	*Emergency mechanical end stops shall be designed to prevent a moving part from protruding from the volume envelopes defined in Section 5.6.2.1.*
SCME-120 H/P	*The mechanisms shall comply with the relevant power supply and harness requirements specified in Sections 6.5 and 6.11, respectively.*
SCME-125 H/P	*Windings shall be designed and tested to withstand a high voltage of 500 V DC / 1 min (for operating voltage up to 50 V) and 1500 V DC (for higher operating voltage), applied between each other or between windings and the structure for a period of time of at least two minutes without causing disruptive charges.*
SCME-130 H/P	*Torsional loads shall not be applied to electrical cables, which change their configuration, e.g. wires around a hinge.*

5.6.2.4 Pyrotechnics Requirements

SCME-135 H/P	*The use of pyrotechnics shall be avoided. If no alternative exists, the use of pyrotechnics in the design shall be duly justified by the contractor and approved by ESA.*

If no alternative solution exists, the pyrotechnics shall comply with the following requirements:

SCME-140 H/P	*As a minimum, properties such as strength, shock impulse, redundancy, performance output, sealing and operation at temperature extremes under vacuum must have been demonstrated.*
SCME-145 H/P	*The initiation chain of all Electro-Explosive Devices (EED) shall incorporate inhibits compatible with the launcher safety requirements for hazardous devices.*

5.6.3 THERMAL CONTROL REQUIREMENTS

The following requirements are applicable to the Thermal Control Subsystem (TCS) of the spacecraft :

5.6.3.1 Definitions

STHE-005 H/P *Deleted .*

Conventional and cryogenic temperature ranges

Due to the cryogenics temperatures required for both Planck and Herschel payloads, the equipment temperature range are split into 2 domains:

- the conventional temperature range (T>120K)
- and the cryogenic temperature range (T<=120K).

Use of Temperature Margins for Conventional and Cryogenic Temperature Range

STHE-010 H/P *In the conventional temperature range, the following definition and thermal control requirements shall apply .*

STHE-012 H/P *For the cryogenics temperature range, the definitions are identical, except for the temperature margins between various temperature ranges (Qualification, Acceptance...) which are depending of the temperature levels and the heat budgets .*

The prime contractor shall propose on a case by case basis the relevant margins to be used, depending on the temperature level, and heat budget. The proposed margins shall be subject to ESA approval.

Temperature reference point TRP

The TRP is a point located in/on the unit.

STHE-015 H/P *The TRP shall be selected by the <u>unit thermal designer</u> in order to be the most representative of the unit temperature.*
The TRP shall be instrumented during the Qualification/Acceptance testing of the unit and during the TB/TV test at system level and, as far as operationally required, for the flight.

System Interface Temperature Point STP

Deleted.

STHE-020 *Deleted.*

H/P

Radiative Sink Temperature RST

The RST is a virtual black body radiation temperature used to define the equivalent radiative load on a unit. This includes both the natural environment load (solar, planetary albedo and infrared fluxes) and the radiative exchanges with other items on the spacecraft.

TCS Design Temperature Range

The TCS design temperature range is specified at TRP and STP for the operating and non-operating mode of a unit. This temperature range represents the requirements for the TCS design activities.

TCS Predicted Temperature Range

The TCS predicted temperature range (operating, non-operating, switch-on) is a temperature range obtained from the relevant TCS calculated temperature range after addition of all possible uncertainties. The TCS predicted temperature range is based on nominal worst case considerations excluding failure cases.

STHE-030 H/P *The TCS predicted temperature range shall be enveloped by the relevant TCS design temperature range with a TCS design margin, which shall be justified by the spacecraft Contractor.*

Unit Acceptance Test Temperature Range

The acceptance test temperature range is the extreme temperature range at which a unit shall be tested for a limited period of time.

STHE-035 H/P *Fulfilment of all the functional performances (operational and non-operational) of the unit shall be demonstrated by test for the complete acceptance test temperature range. This test is mandatory for all FM units prior to delivery to the spacecraft.*

Unit Qualification Test Temperature range

The unit qualification test temperature range is the extension of the unit acceptance test temperature range by 5 degree C both ends. The qualification test temperature range is the extreme temperature range at which the unit shall be tested for a limited period of time to qualify its design.

STHE-040 H/P *Fulfilment of all the functional performances (operational and non-operational) of the unit is mandatory for the complete acceptance test range. Partial deviation from the performance requirements may be accepted within the item qualification test margins, provided they do* *not affect the interfaces to the S/C and they are reversible.*

Unit Design Temperature Range

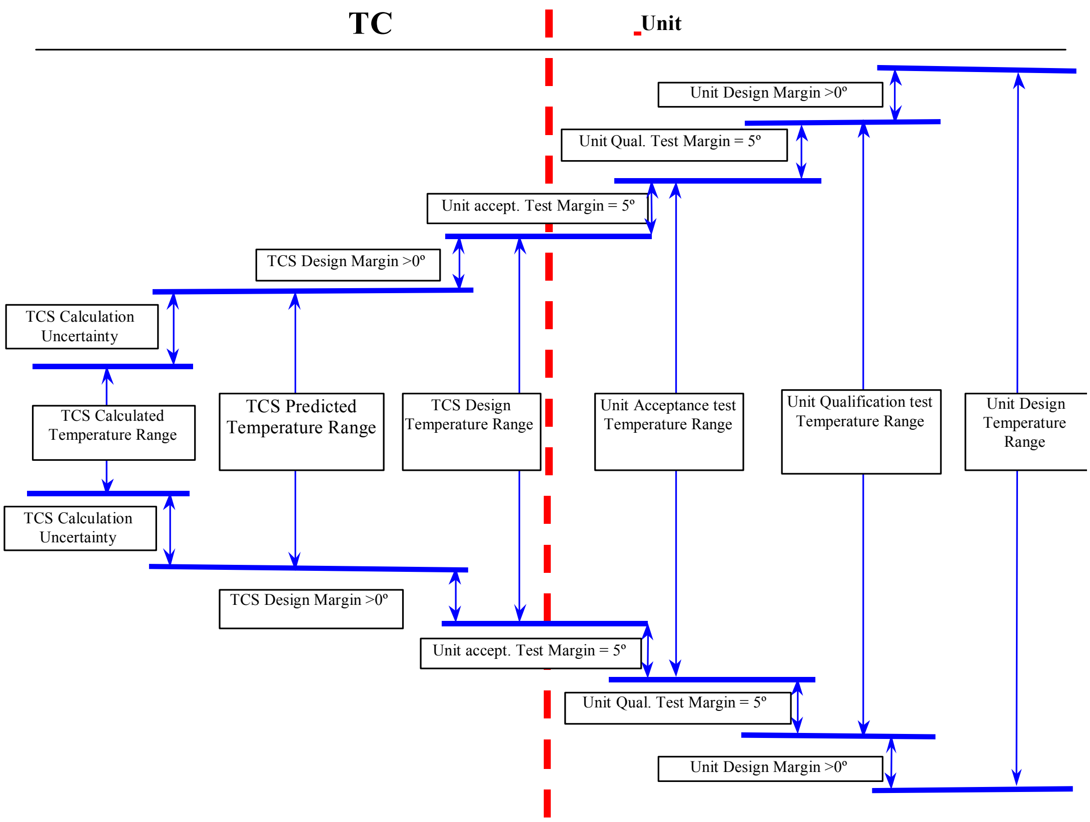
The unit design temperature range represents the requirements for the unit internal thermal design activities.

STHE-045 H/P *The internal thermal design of a unit shall envelope the unit qualification test temperature range at TRP and STP for the operating and non-operating modes of this unit.*

Margin Philosophy

The various definitions defined above and the related margin philosophy are displayed on the following chart for conventional temperature range.

STHE-050 H/P *For Cryogenic temperatures, the unit temperature ranges shall be tailored to the relevant cryogenic range. The proposed ranges shall be subject to ESA approval.*



Margin philosophy for Conventional temperature range.

5.6.3.2 Functional Requirements

STHE-055 H/P	*The TCS shall ensure that the TRP temperatures are kept within their TCS design ranges for all phases of the mission with all energy boundary conditions specified or derived from this specification.*
STHE-060 H/P	*The thermal control subsystem shall use the inherent or designed-in thermal properties of the structure and units, a minimum of additional thermal control components, and the satellite geometry to maintain temperature levels and distributions within the specified limits for allowable satellite orientations.*
STHE-065 H/P	*In-flight equipment temperatures shall be monitored by means of sensors. These sensors shall provide information about spacecraft health and shall serve as a reference for heater control.*

5.6.3.3 Performance Requirements

STHE-070 H	*For the Herschel cryogenic subsystem all thermal requirements as specified in IID's Part B for the Focal Plane Units and any other payload or spacecraft units requiring cryogenic cooling for at least the nominal lifetime until all helium has been consumed shall be met.*
STHE-075 P	*The thermal design shall comply with the requirements of the Planck IID's Part B.*
STHE-080 H/P	*The TCS shall ensure that all equipment temperatures remain within the thermal design limits defined for each unit, during all phases of the mission, including ground testing. If applicable, it shall also ensure the required temperature stability for equipment. It shall maintain the structural parts with the required temperatures and temperature stabilities such that the necessary alignments are met between units involved in the pointing or alignment required performances.*
STHE-085 H/P	*The thermal design shall be compatible with all solar aspect angles and albedo and any radiative inputs, which are foreseen during all mission phases.*
STHE-090 H/P	*The TCS shall ensure survival of spacecraft during eclipses from launch until end of mission with minimum use of heater power.*
STHE-095 H/P	*The thermal design shall take into account the degradation of the surface properties (α, ε) during the mission lifetime.*
STHE-098 H/P	*The margins for unit acceptance with respect to the TCS design temperature range shall be at least 5°C on both sides.*
STHE-100 H/P	*The margins for unit qualification with respect to the TCS design temperature range shall be at least 10°C on both sides.*

5.6.3.4 Design Requirements

Note: As far as possible, spacing of 10 to 20 mm between the spacecraft structures and the MLI foils can be used as double wall shield protection against space dust particles.

STHE-105 H/P *The thermal control subsystem must be as simple as possible. MLI and radiators with thermal coatings control the Sun, Earth and albedo effects and the internal heat distribution and rejection. Internally, thermal coatings and conductive paths will be used to control the temperature of critical units.*

STHE-110 H/P *Heaters shall be used when necessary. All heaters shall be capable of being commanded from ground.*

STHE-115 H/P *The TCS shall be protected against any single point of failure of any item of the chain of the temperature measurements by appropriate redundancy. The TCS shall be design to minimise the temperature fluctuations of the TRP.*

STHE-120 H/P *The thermal control subsystem design shall incorporate sufficient flexibility to accommodate foreseeable changes in layout, power dissipation (amount and location), mission requirements and required temperature ranges.*

STHE-125 H/P *The thermal design shall be such that easy repair and minor changes in design are possible through simple removal and replacement of insulation blankets, foils, heaters and/or by in-place refurbishment of thermal control coatings and surface treatments.*

STHE-130 H/P *The thermal design shall minimise the need for ground operational testing and subsystem level thermal vacuum tests. It shall not impose unacceptable constraints on other spacecraft elements nor on mission operation.*

STHE-135 H/P *The thermal design shall be such that the spacecraft can be developed, integrated and tested at module level, with minimum interaction from the other modules. The modules shall therefore be thermally de-coupled as much as possible.*

STHE-140 H/P *Grouping of heaters circuits shall be implemented whenever feasible in order to minimise the total number of needed ON-OFF commands.*

STHE-145 H/P *Use of material with stable thermo-optical properties is required. Any deviation shall be adequately justified and the ageing law assumptions shall be substantiated*

STHE-150 H/P *The TCS design shall allow easy access to the units and equipments. All parts belonging to the TCS shall stay within their allocated volume envelopes. The MLI design shall ensure a minimum clearance of 20 mm between the MLI and any moving part. If the MLI is attached to a moving part, the clearance shall be of 35 mm at least.*

STHE-155 H/P *The TCS shall be testable on ground. If special equipments are required to evacuate the heat during the spacecraft functional tests under ambient environment, they shall be compatible with the cleanliness requirements. No TCS item shall prevent the spacecraft* *from being operated/tested under an attitude required by the thermal environment test.*

STHE-160 H/P — *Venting of all the cavities including the interspacing of the MLI shall be designed to avoid damaging overpressure during the ascent. The method of venting shall prevent the release of contaminants toward the sensitive components of the payload or of the spacecraft.*

5.7 SYSTEM VERIFICATION REQUIREMENTS

5.7.1 Verification of the Mechanical Design

5.7.1.1 Modelling

SCVE-005 H/P — *A structural Finite Element Model of the spacecraft shall be established by the Contractor.*

SCVE-010 H/P — *Any structural Finite Element Model (FEM) shall be delivered in NASTRAN format.*

SCVE-015 H/P — *The FEM shall be detailed enough to ensure an appropriate derivation/verification of the design loads and of the modal response for all important modes with an effective mass > 5% of the total mass, up to 140 Hz.*

SCVE-020 H/P — *It shall be supported by additional and more detailed models for the analysis and design of specific aspects (strength verification, thermal stress analysis, thermo-elastic analysis, interface stiffness analysis, optical analysis, as required).*

SCVE-025 H/P — *At system level, the FEM shall be reduced to an Interface FEM (IFEM) for the Launcher Coupled Dynamic Analysis (LCDA). The IFEM shall fulfil the requirements established by the Launch Vehicle Authorities, as defined in AD6-24.*

SCVE-030 H/P — *The FEM's shall be correlated against the results of the modal survey tests carried out at component, subassembly and complete spacecraft level. As a result of that, the following criteria shall be satisfied:*

- *for the modes with an effective mass greater than 10% of the total mass*
  - *frequency deviation less than 3%*
  - *error for damping factor less than 20%*
  - *Modal Assurance Criterium (MAC) greater than 0.9*
- *for the modes with an effective mass greater than 5% of the total mass and an eigenfrequency below 100 Hz:*
  - *eigenfrequency deviation less than 5%*
  - *MAC greater than 0.9*

5.7.1.2 Analysis

SCVE-035 H/P *All the design loads applicable to the various parts, subassemblies or complete spacecraft shall be substantiated by analyses of significant events during the complete lifetime. They shall be reassessed after each test at subassembly or system level.*

SCVE-040 H/P *The stiffness analysis shall demonstrate compliance with the requirements as indicated in Section 5.6.1.1. The analytically predicted frequencies shall be higher than the minimum requirement specifications with positive margins .*

SCVE-045 H/P *The stress analysis shall demonstrate MOS, which shall be in agreement with section 5.6.1.2, and cover loads originating from mechanical, thermal and moisture desorption effects combined all together.*

SCVE-050 H/P *In case of a proto-flight approach, the yield and ultimate MOS shall be greater than 0.2.*

SCVE-055 H/P *Strength values for mechanical parts shall not be assumed higher than the values specified for the relevant qualification and acceptance tests.*

SCVE-060 H/P *Fatigue analysis shall be carried out where relevant, and demonstrate a positive reserve after application of 4 times the most constraining life cycles.*

SCVE-065 H/P *Fracture mechanics analysis shall be carried out for the items, which are potentially hazardous for the ground operations and meet the requirements specified in AD6-11.*

5.7.1.3 Testing

SCVE-070 H/P *Verification of the mechanical performance shall be possible by test at element and at subassembly or at system level.*

SCVE-075 H/P *At system level static tests (including the primary structure and high loaded interface structures), the following test factors shall be used with respect to the maximum expected Limit Loads, unless otherwise specified:*

Qualification	*1.25*
Acceptance	*1.0*

SCVE-080 H/P *At system level dynamic tests, the requirements of the ARIANE 5 User's Manual (AD6-1) shall be met as a minimum.*

Note: this specification does not apply for the instruments and their fixations, for which dedicated factors are applicable.

SCVE-085 H/P *Deleted .*

SCVE-090 H/P *A significant number of standard potted inserts with low margin of safety (MOS) shall be tested for workmanship .*

5.7.2 Verification of Mechanisms Design

5.7.2.1 General

SCVE-095 H/P *The mechanism verification shall comply with the requirements of AD6-10 paragraph 4.8. In case of conflict between requirements of AD6-10 and the requirements in the present document, the latter shall have precedence.*

5.7.3 Verification of the Thermal Design

5.7.3.1 Modelling

SCVE-100 H/P *Detailed Thermal Mathematical Models (DTMM) and Detailed Geometrical Mathematical Models (DGMM) of the spacecraft shall be created for analytical predictions representative of all the phases of the mission, including ground tests. Parametrical modelling approach is recommended to ease follow up of design evolution.*

SCVE-105 H/P *The models shall unambiguously identify the flight and the test monitoring points (TRP, STP).*

SCVE-110 H/P *The Detailed Thermal Mathematical Models (DTMM) shall be delivered as a coherent set of ESATAN files compatible with ESATAN version 8.5 or higher , and together with any scripts necessary to run the models and analysis cases . Sub-modelling techniques shall be used down to a level agreed with ESA .*

SCVE-115 H/P *The Detailed Geometrical Mathematical Models (DGMM) shall be delivered as a coherent set of ESARAD files compatible with ESARAD version 4.3.2 or higher , and together with any scripts necessary to run the models and analysis cases . As a minimum, the set of ESARAD files shall include the geometry definition , the kernel and the ESATAN formatting files .*

SCVE-120 H/P *The detailed DTMM and DGMM shall be correlated against the environmental test results. After correlation, the temperature differences between predictions and measurements shall be analysed for all the measurement points*

SCVE-125 *The thermal mathematical model of the test facility shall be compatible*

H/P *with the data measured during the environmental tests.*

SCVE-130 H/P *A Reduced Thermal Mathematical Model (RTMM) of the entire spacecraft shall be derived from the DTMM for system verification. It shall include the launch configuration for the integrated analysis with the launcher.*

The RTMM shall be delivered to ESA.

SCVE-135 H/P *The TMM's shall be able to predict applicable transient behaviour and behaviour under applicable periodic thermal excitations.*

5.7.3.2 Analysis

SCVE-140 H/P *The compliance with the thermal performance requirements shall be demonstrated by analysis for the nominal operational and non-operational cases.*

SCVE-145 H/P *A set of agreed failure cases shall be simulated for which positive TCS design margins shall be demonstrated for any TRP. After correlation of the DTMM with test results, the TCS Design margins may be reduced down to zero for the agreed failure cases.*

SCVE-150 H/P *TCS uncertainties shall be added to the TCS calculated temperature ranges when comparing the TCS predicted temperatures ranges with the TCS design ranges applicable to TRP's, see chart at 5.6.3.1, Definitions. They shall be substantiated by appropriate sensitivity analysis and agreed by ESA.*

SCVE-155 H/P *The differences between the test measurements and the test simulated by the correlated DTMM shall be taken into account for the final flight predictions.*

SCVE-160 H/P *The differences between the results yielded by the RTMM and the DTMM running similar cases (transient and steady state) shall be taken into account for the final flight predictions.*

SCVE-165 H/P *A sensitivity analysis of the DTMM shall be performed*

SCVE-170 H/P *The calculation uncertainties of the DTMM shall be estimated using the sensitivity analysis and an agreed table of uncertainty on input parameters. If required, the uncertainties on relevant parameters shall be reduced using adequate measurements.*

5.7.3.3 Testing

SCVE-175 H/P *The thermal design of the spacecraft shall be validated by a thermal balance test.*

SCVE-180 H/P *The test cases shall cover, as far as practical, the extreme environmental conditions envisaged for the complete mission and the most critical predicted thermal situations.*

“As far as practical” in the requirement above relates to the achievable minimum temperature on ground. If the minimum in-orbit temperature of some units (e.g. the telescope) is below the minimum which can be achieved on ground by conventional means (LN2 shroud), testing at extreme environmental conditions (minimum temperature) is not required. The contractor shall clearly identify and submit to ESA for approval, those cases/units for which above requirement cannot be complied with.

Note: Limit tests of the Planck PLM will be done at operational temperatures.

SCVE-185 H/P	*The spacecraft thermal sensors (e.g. thermistors, thermo-couples) shall be continuously monitored during the test and be used for the assessment of the stabilisation. In addition, they shall be used for the correlation. Additional measurement points shall be provided by test thermal sensors , mainly for complementing the flight measurement plan and monitoring local or general environmental data.*
SCVE-190 H/P	*The environment induced by the test facility shall be continuously monitored during the test with a level of details, as it will be required by the thermal mathematical model for the prediction of the test.*
SCVE-195 H/P	*The Thermal Vacuum test at system level shall be designed to bring all the S/C and Payload units to their worst predicted flight environment without exceeding their qualification range*

5.8 INTERFACE REQUIREMENTS

SCIF-005 H	*All interfaces between Service Module, Herschel Payload Module, and Herschel Telescope shall be kept simple and easily manageable.*
SCIF-010 P	*All interfaces between Service Module and the Planck Payload Module shall be kept simple and easily manageable.*
SCIF-015 H/P	*The mechanical interfaces shall be consistent with the structural, thermal and alignment/alignment stability requirements and shall allow for an easy and repeatable assembly of the modules.*
SCIF-020 H/P	*Herschel and Planck spacecraft shall use a standard Ariane 5 interface as specified in AD6-1.*

6 SPACECRAFT DETAILED REQUIREMENTS

6.1 SPACECRAFT GENERAL REQUIREMENTS

SCGN-005 *H/P*	*The spacecraft structure shall provide the lifting points and transportation interfaces for handling, integration, test and transportation of spacecraft; this applies for all spacecraft integration phases.*
SCGN-010 *H/P*	*All spacecraft actuated valves shall be equipped with a status indicator and their status shall be reported by the telemetry.*

6.2 SVM REQUIREMENTS

The Service Module (SVM) consists of a load carrying primary structure, of a secondary structure and of the units and parts of the subsystems necessary for the mission. The SVM subsystems are:

- The structure, which provides the mechanical interfaces with the launcher (or other separation interface) and supports the SVM units, the Herschel PLM (if applicable) and respectively the Planck Payload Module.
- The mechanisms and pyrotechnics subsystem (if applicable) including all hold-down and release mechanisms, hinges, actuators and latches and relevant pyrotechnics which are required for latching, deployment, alignment, positional control, ejection, etc. of spacecraft subsystem equipment.
- The thermal control subsystem (TCS), which maintains the required thermal environment for proper operations of equipment, taking into account the different environmental conditions
- The sunshield/solar array (SA) which, during sunlit phases, provides the necessary electrical power via a solar cell network and protects the PLM from direct solar radiation.
- The tracking, telemetry and command (TT&C) subsystem, which allows the reception and transmission of RF signals with the ground station and allows the ground ranging and doppler operations.
- The command and data management subsystem (CDMS) which distribute the ground and on-board commands, collects the spacecraft data for on-board distribution and processes the data which shall be transmitted to ground.
- The power control subsystem (PCS) which regulates and distributes the electrical power from the solar array and/or batteries to the users; it includes the batteries.
- The attitude and orbit control and measurement subsystem (ACMS) which determines and controls the satellite attitude; it manages the reaction control subsystem.
- The reaction control subsystem (RCS) which provides the required manoeuvres for orbit injection, orbit maintenance and for momentum management.

- The harness, which distributes all the electrical signals.
- The warm units related to the PLM instruments and the cooler equipment (for Planck).

6.2.1 Functional Requirements

The Service Module (SVM) structure shall provide the following basic functions:

SSVM-005 H	*The Herschel SVM structure shall provide the structural support to carry the Herschel Payload Module (PLM).*
SSVM-010 P	*The Planck SVM structure shall provide the structural support to carry the Planck Payload Module and the Herschel spacecraft if applicable.*

6.2.2 Performance Requirements

SSVM-015 H/P	*Each SVM structure shall be compliant with the overall spacecraft stiffness requirements as specified in Section 5.6.*
SSVM-020 H/P	*Each SVM structure shall be compliant with the strength requirements as specified in Section 5.6. It shall show positive margins of safety for the specified design loads with the specified safety factors.*
SSVM-025 H/P	*All performance requirements shall be met under the applicable environmental conditions encountered on the ground, during launch and on orbit (as defined in section 5.5).*
SSVM-030 H/P	*The SVM structure shall comply with the mechanical design verification requirements as given in Section 5.7.1.*

6.2.3 Detailed Requirements

SSVM-035 H/P	*The primary and secondary structure shall comply with the interface requirements of the payload defined in IID's Part B (AD4-2 through AD4-7).*
SSVM-040 H/P	*The structure design shall be such as to provide simple load paths and simple interfaces.*
SSVM-045 H/P	*The structure design shall provide easy accessibility to connectors and equipment and shall allow for easy integration, removal and maintenance of all secondary structures, subsystems and equipment.*
SSVM-050	*Fastener selection shall be dictated by structural, electrical and*

H/P	*thermal considerations. Fastener types shall be metric. All threaded parts shall be positively locked.*
SSVM-055 H/P	*The lifting points and transportation interfaces shall be arranged such that (except for the lifting points themselves) ground-handling loads will not constitute a critical load case.*
SSVM-060 H/P	*The SVM structure shall not disturb the field of view of optical sensors.*
SSVM-065 H/P	*Thermo-elastic deformation of the SVM structure shall not cause unacceptable misalignment between reference axes and sensors.*
SSVM-070 H/P	*The structure shall be made of materials fulfilling the requirements of Section 5.1.*
SSVM-075 P	*The design of the Planck SVM shall minimise the thermal transients and the periodic thermal variations into the Planck PLM.*

6.3 Herschel PAYLOAD MODULE/CRYOSTAT REQUIREMENTS

The Herschel Payload Module (PLM) of the spacecraft accommodates for the Herschel mission, the focal plane units (FPU's) of the three scientific instruments, viz. (see details in section 3.1.2):

- HIFI (Heterodyne Instrument for Herschel),
- PACS (Photo-conductor Array Camera and Spectrometer),
- SPIRE (Spectral and Photometric Imaging Receiver)

The module provides an adequate thermal environment to these focal plane units and provides the optical interface between the focal plane units and the telescope.

The PLM also provides interfaces with the SVM and the Herschel Telescope.

The PLM consists of:

- The Optical Subsystem, which accommodates the instrument Focal Plane Units in the Focal Plane Assembly (FPA), distributes the light beam to them and provides the baffling. The Optical Subsystem includes the optical bench (OB), providing the mechanical interface to the FPU's.
- A superfluid helium cryostat designed to mechanically support and to maintain the FPU's and optical subsystem within the cryogenic environment as specified in the IID's Part B.
- The PLM / Herschel telescope interface structure for mounting the telescope on top of the cryostat.
- The Herschel PLM thermal control subsystem to maintain all equipment temperatures within their thermal design limits. The helium subsystem, which

provides the cryogenic environment to the FPU's is part of the cryostat and is not considered part of the PLM thermal control subsystem.

- The Herschel PLM electrical subsystem to control and monitor the operation of the PLM. This subsystem also includes the PLM harness, including the science instrument harness as defined from the requirements in the IID’s Part B.
- The Herschel PLM also accommodates the following (warm) payload equipment:
  - the Local Oscillator Unit of the HIFI Instrument
  - The Buffer Amplifier Unit (BOLA) of the SPIRE instrument
  - The waveguides from the Herschel SVM to the PLM LOU

The cryostat consists of:

- Structural and insulation components featuring an outer vessel, a suspension system to minimise heat conduction from outer vessel to the cryogenically cooled elements and the adequate shielding and thermal insulation to minimise the heat radiation from the outer vessel.
- A helium subsystem to provide the adequate cryogenic environment. This passive, single cryogen, cooling system features a main He tank, containing superfluid helium, a passive phase separator and the cryogenic components to operate it. It also features an additional helium tank designed to provide the required autonomy of the cryogenic system on the launcher.
- A cryo cover which closes the cryostat on ground and preserves the sensitive optical components inside the cryostat from contamination during the first days on orbit.
- Internal straylight and thermal baffles and a cavity between cryostat aperture and telescope.

The Herschel PLM extends from the interface with the Herschel PLM support structure (Part of the SVM) to the Telescope Assembly interfaces.

The instrument interfaces requirements are defined in the IID’s Part B (AD4-2, AD4-3, AD4-4) which are fully applicable.

6.3.1 Functional Requirements

SPLM-005 H — *The PLM / cryostat shall accommodate the focal plane units and shall provide the necessary cryogenic cooling to the instruments. It shall be capable of maintaining the values specified in the IID’s Part B (AD4-2, AD4-3, AD4-4) for focal plane unit absolute temperature, temperature stability and temperature gradients during the Commissioning,* *Calibration and Operational phases.*

SPLM-010 H	*The cryostat vacuum vessel shall provide the load path between the SVM/PLM interface structure and the PLM/Telescope and PLM/ Sunshade interface structures and shall provide the mounting interfaces specified above.*
SPLM-015 H	*The PLM shall provide a baffled unvignetted optical path from the entrance of the beam into the PLM to the Focal Plane Units.*
SPLM-020 H	*The PLM shall provide the possibility to close the beam entrance aperture for ground operations and during the initial in-orbit period.*

6.3.2 Operational Requirements

SPLM-025 H	*The shipment of PLM models and of the complete satellite in "cold condition" shall be possible.*
SPLM-030 H	*The determination on a half-yearly basis of the remaining mass of helium contained in the main tank over the nominal lifetime shall be included in the lifetime calculation and shall not shorten the lifetime by more than 1%.*

6.3.3 Performance Requirements

SPLM-035 H	*The cryostat and its internal insulation shall meet the specified nominal lifetime and temperature requirements given in relevant IIDB's. The amount of cryogen shall be sized accordingly and shall include a margin of 15%.*
SPLM-040 H	*During pre-launch, launch and in-orbit the cryostat main bath temperature shall never exceed 2.10K. However, transport capability of the cryostat in the Herschel PLM or the spacecraft container in its superfluid status is not required.*
SPLM-045 H	*The cryogenic system shall be equipped with the adequate piping, bypasses and valves to allow for evacuation, purging, baking out, cooling down, filling, venting and topping up operations.*
SPLM-050 H	*Correct and safe functioning of the cryogenic system including filling and vent lines shall be ensured by an adequate number of valves and safety devoted components such as pressure relief valves and burst discs.*
SPLM-055 H	*It shall be possible to fill the main tank with superfluid helium at 1.6 K to no less than 98% of full capacity.*

SPLM-060 H	*The cryostat shall allow for an on-ground autonomy period of 6 days with the helium tank filled in the above conditions and the helium temperature after 6 days below 2.10 K and instruments being non operational.*
SPLM-065 H	*To obtain the on-ground autonomy, an auxiliary reservoir with He I at atmospheric pressure shall be used. It shall be possible to fill this reservoir through the payload access doors in the Ariane 5 fairing.*
SPLM-070 H	*The helium subsystem shall be adequately instrumented, including temperature sensors and in particular with devices for the measurement of the mass of helium remaining in the tanks on the ground with an accuracy of 2% and with an accuracy of 5% in orbital conditions (for the main HeII tank only).*
SPLM-075 H	*The main tank shall be equipped with heaters to enable depletion within two days during ground operations.*
SPLM-080 H	*Final Cryostat filling operations, including conversion to superfluid helium and topping up of the main tank shall be performed within a period not exceeding 24 hours and ending prior to launch day minus four days (J-4), with the spacecraft installed on the launcher but without the fairing.*
SPLM-085 H	*It shall be possible to perform the actuation of valves during the launcher upper section (L9) boost phase, directly from Ariane 5 initiated commands.*
SPLM-090 H	*In orbit helium exhaust shall be made such that, during the routine scientific observation phase, the resulting torque shall compensate for the solar pressure disturbance in order to minimise the overall increase of angular momentum.*

Temperature requirements

SPLM-095 H	*In operational orbit, the temperature of the helium bath shall remain at the necessary temperature to provide proper cooling to the instruments as defined in the IID's (AD4-1 to AD4-4).*

FPU Accommodation

SPLM-100 H	*The accommodation and alignment of the Focal Plane Units shall meet the requirements as specified in the IID's (AD4-1 to AD4-4).*

Vacuum and tightness requirements

SPLM-105 H	*The cryostat vacuum shall be such as to provide proper and stable cryogenic performances at room temperature.*

6.3.4 Detailed Requirements

SPLM-110 H	*The cryostat shall be equipped with a cryocover, which provides a vacuum-tight closure of the cryostat aperture on-ground and during the initial in-orbit period.*
SPLM-115 H	*The design shall be such as to make leak testing of the complete cryostat possible.*

6.3.5 Optical Requirements

SPLM-120 H	*The aperture shall comply with the telescope optical interface requirements as specified in AD2-1.*
SPLM-125 H	*In particular, the aperture shall be sufficiently large not to cause any vignetting.*
SPLM-130 H	*The beam of the Local Oscillator of the HIFI will enter the cryostat via windows in the CVV and radiation shields. The design of these windows shall be in accordance with the instrument requirements as specified in the HIFI IID part B (AD4-2) and such that the overall heat input through these windows is minimised.*

6.3.6 Cryo Cover Requirements

The cryocover closes the cryostat on ground and preserves the sensitive optical components inside the cryostat from contamination during the first days in orbit.

The following requirements are applicable to the cryocover (cryostat vacuum door) and its opening and latching mechanisms:

SPLM-135 H	*Once in orbit, the cryocover shall be opened by a fully redundant mechanism(s) with adequate margins of safety against worst case torques/forces. Only one in-orbit opening operation is foreseen and such an opening shall be possible with any temperature of the mechanism(s) from ambient down to operational temperature.*
SPLM-140 H	*The cryocover shall, once opened, be protected against unintended closure and bouncing back.*
SPLM-145 H	*The cryocover shall, once opened, not cause vignetting of the telescope beam.*
SPLM-150 H	*The cryocover, when closed, shall be protected against unintended opening.*
SPLM-155 H	*The cryocover in its open position shall be taken into account in straylight and thermal analysis.*

SPLM-160 H	*In order to limit parasitic heat loads through the closed cryocover prior to in-orbit operations, the internal temperature of the door shall be as low as possible by passive shielding and/or ground active cooling.*
SPLM-165 H	*It shall be possible to open and close the cryocover on ground with the cryostat in cold condition by appropriate GSE devices.*
SPLM-170 H	*Deleted.*
SPLM-175 H	*The use of pyrotechnics in the design shall be avoided.*
SPLM-180 H	*During launch and during all ground operations including transport, the cryocover shall be properly restrained to avoid excessive loads or damage by contact or excessive amplification of vibration.*
SPLM-185 H	*All cryocover mechanisms shall comply with the mechanisms and mechanisms verification requirements of Sections 5.6.2 and 5.7.2, respectively.*

6.4 PLANCK PAYLOAD MODULE REQUIREMENTS

The Planck Payload module accommodates for the mission, the focal plane units of the scientific instruments and all related hardware, especially:

- The High Frequency instrument (HFI)
- The Low Frequency Instrument (LFI)
- The Telescope

The Planck module provides an adequate thermal, straylight and RFI environment to the focal plane units and telescope; the Planck Payload module also provides interface with the SVM.

The Planck module consists of:

- An optical bench, which accommodates the primary and secondary reflectors and the inner baffle of the telescope and the Focal Plane Unit, which houses the front, end detectors of HFI/LFI.
- Equipment platform which accommodates the coolers equipment and electronics.
- Rigid connections (for the waveguides) between the Focal Plane Unit and the rigid platform
- Necessary shielding system to meet the thermal and straylight requirements.
- The cooling of the front end is achieved by a cascade of coolers (part of the instruments) and radiatively cooled shields. Each stage provides the necessary pre-cooling for the coolers for the next stages, down to the lowest stage, the dilution stage which gives 0.1K.

6.4.1 Functional Requirements

The Planck Payload Module structure shall provide the following basic functions:

SPLA-005 P	*The Planck Payload Module shall comply and accommodate the Planck instruments [AD4-5, AD4-6], the Planck Telescope [AD1-3] and the shielding necessary to provide the thermal, straylight and RFI environment.*
SPLA-010 P	*The Planck Payload Module structure shall provide the interface to the SVM.*
SPLA-015 P	*Deleted*
SPLA-020 P	*The Planck Payload Module shall never be exposed to the sun.*

6.4.2 Performance Requirements

Temperature requirements

SPLA-025 P	*In operational orbit, the thermal environment of the Planck Payload Module shall be as defined in IID's (AD4-1, AD4-5, AD4-6).*
SPLA-030 P	*The radiative sink temperature (see section 5.6.3) of the innermost shield of the PPLM shall be less than 60 K with a goal of 50 K.*

FPU accommodation

SPLA-035 P	*The accommodation and alignment of the Focal Plane Unit shall meet the requirements as specified in the IIDs (AD4-1, AD4-5, AD4-6).*

6.4.3 Optical Requirements

SPLA-040 P	*The aperture shall comply with the telescope optical interface requirements as specified in AD1-3.*
SPLA-45 P	*The FOV of the instruments shall be unobstructed.*

6.5 POWER CONTROL REQUIREMENTS

During sunlit mission phases, electrical power will be generated by the solar array. During launch, eclipse and peak power demand phases batteries will supply (additional) power. The Power Control Subsystem (PCS) will condition, control and distribute the electrical power to all payload instruments and spacecraft subsystems/units. The solar array is not considered part of the PCS and its requirements are specified in Section 6.6.

The PCS shall meet the following functional and performance requirements for all pre-launch, launch and mission modes through the entire duration of the mission.

6.5.1 Functional Requirements

SMPC-005 H/P	*The PCS shall condition, control and store energy coming from the solar array and the batteries.*
SMPC-010 H/P	*The PCS shall condition, control and distribute all the electrical power required by the scientific instruments and spacecraft subsystems and/or units as defined in AD4-2 to AD4-6.*
SMPC-015 H/P	*In case there is no solar array power or if its power is not sufficient to meet the scientific instruments and/or spacecraft power demand, the required (additional) power shall be provided by the batteries of the PCS.*
SMPC-020 H/P	*The PCS shall maintain proper operating conditions for the batteries and shall manage the charge/discharge cycles of the batteries to fulfil power demands as required.*
SMPC-025 H/P	*The PCS shall provide all resources needed for the operation of the pyro-technical devices (if any) for experiments as well as for spacecraft functions and it shall condition, control and distribute the power to these devices.*
SMPC-030 H/P	*The change of state of all pyrotechnically initiated mechanisms shall be confirmed by an end-effect monitor and reported in the telemetry.*
SMPC-035 H/P	*The subsystem shall provide adequate failure tolerance and protection circuitry to avoid failure propagation and to ensure recovery from any malfunction within the subsystem and/or load failure.*
SMPC-040 H/P	*The subsystem shall provide adequate status monitoring and telecommand interfaces necessary to operate the subsystem and permit evaluation of its performance during ground testing and in-flight operations.*
SMPC-045 H/P	*Sufficient telemetry parameters shall be assigned such that the power available and requested can be established.*
SMPC-050 H/P	*Adequate means and telemetry shall be provided to determine the state of charge of the batteries throughout all mission phases to an accuracy better than 10%*

accuracy better than 10%.

SMPC-055 H/P *The subsystem shall provide sufficient telecommands to:*

- *Meet scientific instrument and spacecraft subsystem switching, reconfiguration and autonomy requirements*
- *Select between redundant equipment*
- *Override the autonomous and protection functions by direct ground command.*

SMPC-060 H/P *Deleted .*

SMPC-065 H/P *The subsystem shall provide dedicated heater outputs for thermally critical units. These outputs shall be connected such that no other unit nor subsystem must be active to energise these lines. The lines shall act as additional redundancies and shall be controlled by independent and dedicated thermostats.*

6.5.2 Performance Requirements

SMPC-070 H/P *The PCS equipment shall be capable of operating continuously under all operational conditions of the mission including contingency situations. No damage or degradation shall result from intermittent or cycled operation.*

SMPC-075 H/P *The subsystem shall restart automatically and autonomously after a complete loss of all main bus when Solar array power reappears.*

SMPC-080 H/P *The PCS shall be able to distribute sufficient power to the scientific instruments and spacecraft subsystems to operate these according to the mission requirements, for all operational modes and during all mission phases.*

SMPC-085 H/P *At power up, restart and upon recovery from any power loss, the spacecraft electrical configuration (including all sub-systems, units and instruments) shall be in a known deterministic and reproducible state.*

This state shall be safe and shall allow a predefined recovery of the spacecraft and of its sub-systems.

The power and the power profile required by the scientific instruments are specified in the IID's Part B.

SMPC-090 H/P *The power conditioning shall be designed such that a regulated 28 V DC Main Bus is provided to all users.*

SMPC-095 H/P *The Main Bus voltage regulation requirement shall be in accordance with the requirements of PSS-02-10 (AD6-9)*

SMPC-100 H/P	*The Main Bus impedance shall be in accordance with AD6-9.*
SMPC-105 H/P	*The power regulation shall be such that the transition and sharing between solar array power mode and battery power mode is performed in a continuous way without main bus voltage variations being outside the specified tolerance range.*
SMPC-110 H/P	*Bus transients due to inter-domain operation shall be in accordance with the requirements of AD6-9.*
SMPC-115 H/P	*Transient voltage excursions due to step load changes shall not interfere with the operation of other subsystems or experiments.*
SMPC-120 H/P	*No single component failure shall cause an over voltage or permit short circuit on the main bus.*
SMPC-125 H/P	*No undesirable operating mode shall occur in the event of failure in other subsystems (including harness) or in one or more experiments.*
SMPC-130 H/P	*Battery selection and design, the number of discharge cycles, the operating temperature and temperature gradient and the battery charge / discharge management shall ensure fulfilment of the satellite power requirements to be compliant with the battery depth of discharge requirements.*

6.5.3 Design Requirements

SMPC-135 H/P	*The design of the subsystem shall be in accordance with the ESA Power Standard PSS-02-10 (AD6-9), shall comply with the system requirements and shall be compatible with the scientific instruments and the other subsystems. All the electrical elements shall comply with the EMC requirements.*
SMPC-140 H/P	*The PCS shall contain all electronics necessary:* - *to provide electrical power from the solar array and/or batteries to all users (SVM and PLM)* - *to charge, discharge and, if needed, recondition all batteries* - *to allow for the capability of automatic and commanded control of the operation of the subsystem* - *for switching and protection of the experiments and spacecraft subsystems*
SMPC-145 H/P	*The subsystem shall be designed such that in all operating modes where the power available from the solar array exceeds the main bus and battery charge demand, the surplus electrical power is left in the solar array. Large circulating currents between the solar array and the spacecraft shall be avoided.*
SMPC-150	*No single point failure shall endanger full mission performance or*

H/P	*cause permanent damage to any essential load.*
SMPC-152 H/P	*An automatic protection shall be provided to ensure that the power subsystem shall be able to recover from any malfunction in any load or from any abnormal spacecraft mode of operation.*
SMPC-155 H/P	*The 28 V main bus shall be distributed through current limiters and switches according to the interface requirements.*
SMPC-160 H/P	*The energy storage system shall consist of batteries. Each battery shall contain thermal sensors, temperature control heating elements and, if needed, cell by-pass diode circuitry.*
SMPC-165 H/P	*The batteries shall be protected against excessive overcharge, undervoltage, overheating and freezing.*
SMPC-170 H/P	*Power pulses required for firing of pyro's (if applicable) and release of deployables shall be supplied by the batteries.*
SMPC-175 H/P	*The batteries and their regulator units shall be functionally one failure tolerant up to the input of the power control/regulation unit, including failures in power transmission elements such as connectors, harness, etc.*

The main bus protection shall meet the following requirements:

SMPC-180 H/P	*Full protection against short circuit or overload shall be provided by limiting the maximum current in any supply line . Protection shall be implemented via electronic protection devices (e.g. LCL , FCL , electronic fuses) . Usage of conventional fuses shall be avoided .*
SMPC-185 H/P	*Essential functions (e.g. synchronisation or auxiliary power supply) shall not rely on centrally generated auxiliary functions. Any power subsystem equipment shall be able to operate independently of any external synchronisation or auxiliary power supply.*
SMPC-190 H/P	*Deleted .*
SMPC-195 H/P	*Deleted .*
SMPC-200 H	*The Herschel power budget shall include an ESA reserve of 100 W , except for the launch phase (from lift-off to separation) during which a reserve of 30 % shall be included .*
SMPC-205 P	*The Planck power budget shall include an ESA reserve of 100 W , except for the launch phase (from lift-off to separation) during which a reserve of 30 % shall be included .*

6.6 SOLAR ARRAY AND SUNSHIELD REQUIREMENTS

The combined sunshield/solar array is mounted on the spacecraft and protects from direct solar radiation.

6.6.1 Functional and Performance Requirements

SMSA-005 H/P	*The solar array (SA) shall provide the necessary power for the spacecraft throughout the nominal lifetime in the worst case conditions for Sun intensity and solar aspect angle in all phases. The worst case for solar aspects angle will be defined, taking into account the attitude constraints and restrictions and phases defined in section 3.2.*
SMSA-010 H/P	*The solar array performance shall be predicted and the performance figures shall include all effects which have an impact on this performance (solar attitude, Sun intensity and variations thereof, cell temperature, radiation, micro-meteorites, etc.) and shall be based on accepted cell degradation figures and actual cell performance measurements.*
SMSA-015 H/P	*A margin of 10% on solar array calculated power at the end of nominal life time shall be taken into account.*

6.6.2 Design Requirements

SMSA-020 H/P	*If silicon cells are used for the electrical network they shall meet the requirements of the ESA specification for silicon solar cells, PSS-01-604 (AD-8/1).* *If GaAS cells are used for the electrical network they shall meet the requirements of the Generic Specification for Gallium Arsenide Solar Cells (AD-8/2).*
SMSA-025 H/P	*All solar array cell strings shall have individual blocking diodes and shunt diodes where required.*
SMSA-030 H/P	*The solar array shall be designed such that it is one string failure tolerant.*
SMSA-035 H/P	*The power transmission elements such as connectors and harness , shall be redundant . The complete connectors themselves shall be redundant , i.e. not only the pins .*
SMSA-040 H/P	*The electrical network shall be composed of identical electrical sections , as far as possible . It shall minimise the resulting magnetic moment and ensure the insulation of solar network with respect to the solar array structure.*
SMSA-045 P	*The solar array design (including all units placed on its surface) shall minimise the generation of periodic temperature changes in the SVM and PLM of Planck induced by the spin modulation of the solar flux.*
SMSA-050	*The edge of the solar array shall be designed to minimise diffraction effects.*

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6.7 COMMAND AND DATA MANAGEMENT REQUIREMENTS

The Packet Telemetry and Telecommand standards will be utilised. The utilisation of the standards will be in line with the Packet Utilisation Standard ECSS-E-70/41 (RD-3).

The telecommand decoder compatible with the Packet Telecommand standard will be in line with the Telecommand Decoder Specification ESA-PSS-04-151 (RD-5).

For Telemetry, convolutional coding concatenated with Reed Solomon coding (I=5) is envisaged. However, an option for Turbo coding is requested. Telemetry concatenated coding and Telemetry Turbo coding are defined respectively in:

- Telemetry Channel Coding ESA PSS-04-103 (AD6-3)
- CCSDS Telemetry Channel Coding, CCSDS 101.0-B-4 (RD-7).

If data compression is envisaged on spacecraft system, the compression is defined in the Lossless Compression CCSDS 121.0.B.1 (AD-6-26).

6.7.1 General

SMCD-005 H/P	*The CDMS shall be compliant with the following ESA Standards:* - *Packet Telemetry Standard, ESA PSS-04-106 (AD6-6)* - *Packet Telecommand Standard, ESA PSS-04-107 (AD6-7)* - *Telemetry Channel Coding ESA PSS-04-107 (AD6-3)*
SMCD-010 H/P	*The CDMS shall be compatible with the Herschel / Planck Operations Interface Requirements Document (AD3-2), the Herschel / Planck Space to Ground Interface Document (AD3-1) and the Herschel / Planck Packet Structure ICD (AD3-3).*
SMCD-015 H/P	*The CDMS shall provide an interface to the Electrical Ground Support Equipment (EGSE). This shall at least include telemetry, telecommand, timing signals and all other signals needed for the system level check-out.*
SMCD-020 H/P	*The CDMS shall be fully redundant including cross strapping to improve reliability. It shall survive any single point failure and no failure shall propagate outside the unit level, or even sub-unit level for complex units.*
SMCD-025 H/P	*The CDMS shall be fully operational after start-up.*

6.7.2 Functional Requirements

SMCD-030 H/P — *The CDMS shall perform the following general functions:*

- *Telemetry acquisition and formatting*
- *Telecommand acquisition, decoding validation and distribution*
- *Data storage*
- *Time distribution and time tagging*
- *Autonomy supervision and management*

SMCD-035 H/P — *The CDMS shall be connected to the instruments via an on-board data bus architecture according to MIL 1553B.*

SMCD-040 H/P — *The CDMS shall exchange TM / TC packets with all on-board units, which can encode / decode TM / TC packets.*

More specific requirements for each of those functions are specified below.

Telemetry

SMCD-045 H/P — *The CDMS shall acquire the scientific and periodic and non-periodic housekeeping data from the scientific instruments.*

SMCD-050 H/P — *The CDMS shall acquire the periodic and non-periodic housekeeping data from the spacecraft subsystems.*

SMCD-055 H/P — *The CDMS shall condition, process, format, packetize and code the data for on-board storage and for telemetry transmission to the ground station and for on-board supervisory functions as required.*

SMCD-060 H/P — *It shall be possible to transmit to ground the various telemetry modes described in 4.1 and simultaneously record the real time housekeeping data or the real time housekeeping data and real time science data.*

Telecommand

SMCD-065 H/P — *The CDMS shall distribute all commands from ground, stored, and/or generated on-board.*

Data Storage

SMCD-070 H/P — *The CDMS shall store all commands, housekeeping and science data generated on-board.*

SMCD-075 H/P — *It shall be possible to dump the non-periodic housekeeping, periodic housekeeping and other data separately.*

SMCD-080 H/P — *The CDMS shall store the mission timeline on-board for 48 hours.*

Timing

SMCD-085 — *The CDMS shall provide synchronisation signals and timing signals*

H/P *as required by the science instruments or spacecraft units.*

SMCD-090 H/P *The CDMS shall maintain on-board a Central Time Reference (CTR) and shall distribute this time to all on-board users . The CDMS Central Time Reference shall be settable by telecommand .*

Autonomy

SMCD-095 H/P *The CDMS shall allow for the implementation of the autonomy requirements as specified in Section 4.*

6.7.3 Performance Requirements

General

SMCD-100 H/P *The CDMS shall perform its own initialisation and monitoring.*

SMCD-105 H/P *The CDMS shall be able to distinguish between permanent faults and transient ones (single event upset, e.g.) and shall be able to reconfigure or adopt a safe mode autonomously as well as by ground command.*

SMCD-110 H/P *The CDMS shall be able to route and store the peak TM and TC traffic without degradation, as required by instruments and on-board users.*

Telemetry

SMCD-115 H/P *Telemetry packets shall be used on the space to ground link. S/C units shall generate unsegmented TM packets.*

Telecommand

SMCD-120 H/P *Telecommand packets with no segmentation shall be used on the ground to space link.*

SMCD-125 H/P *Any invalid telecommand received shall be rejected and the rejection shall be indicated in the telemetry without delay.*

SMCD-130 H/P *The telecommand rate shall be switchable between the high bit rates (4 kbps) and low bit rate compatible with the Kourou station at maximum distance.*

SMCD-135 *H/P* *All commands necessary to recover from the survival mode shall be identified by the contractor.*

SMCD-140 H/P *. Capability shall be provided to send high priority commands (pulse and/or register load commands with only hardware support) to configure essential spacecraft items.*

Note: A high priority command is intended as a single digital signal that is given as command to a unit. A high priority command is used to command essential function under ground control or to override on board actions. The decoding and execution of a high prioritycommand shall therefore require the minimum of on-board resources, and in particular being executed only with simple and highly reliable hardware support. The items referred in the requirement as essential shall be identified after *the spacecraft system design, and shall include on-board commands of high criticality for the spacecraft and/or that are meant to override on board functions. Example of such commands are power distribution reconfiguration, RF network and on-board computer reconfiguration.*

Data Storage

SMCD-145 H/P	*The size of the on-board storage medium shall be sufficient to store the averaged scientific and housekeeping data for a minimum of 2 days . The input data rate of the on-board storage medium shall allow the acquisition of the peak scientific and housekeeping data .*
SMCD-150 H/P	*The storage media shall comply with the following requirements:* - *it shall support partial readout* - *it shall manage free space and automatically mark bad areas* - *it shall make available on request information about free space, files stored and bad areas* - *it shall support simultaneous read and write operations*
SMCD-155 H/P	*The storage media shall have a bit error rate of less than 1 in 10^{13} at end of mission.*
SMCD-160 H/P	*Deleted.*
SMCD-165 H/P	*Each processing unit shall count the single bit corrections by the EDAC and the uncorrectable double errors. These values shall be part of the TM housekeeping information.*
SMCD-170 H/P	*At all times, the CDMS shall record key on board events in a Spacecraft Event Log (SEL) stored in the on-board Data Storage.* *Key events include at least:* *i. H/W and S/W autonomous actions* *ii. H/W and S/W failures* *iii. H/W and S/W reconfigurations* *iv. S/W start-up and shutdown* *v. Procedure start-up and completion* *vi. Recording of the major Mission Timeline (MTL) events* *Recording of the major manual actions (initiated during DTCP), etc*
SMCD-175 H/P	*The Spacecraft Event Log (SEL) shall be partitioned such that the various types of records can be easily separated and handled as separate logs.*
SMCD-180 H/P	*All entries in the SEL shall be time-stamped using the on-board spacecraft time reference.*
SMCD-185	*The CDMS shall allow down-linking of any selected partition of the SEL*

H/P	*SEL.*
SMCD-190 H/P	*It shall be possible to clear the SEL (or any SEL partition) by ground command.*
SCMD-195 H/P	*The input and output data rates of the storage medium and the CDMS shall be compatible with the Telecommunication period for data volumes corresponding to 24 hours of operations.*

Timing

SMCD-200 H/P	*All time reference in telemetry, telecommand and on-board shall be derived from the on-board Central Time Reference (CTR) .*
SMCD-205 H/P	*The accuracy of the CTR (Central on-board Reference Time) shall be at least 1 * 10 E-6 . This includes short term stability over 100 seconds and stability over 30 days , including all parameters influencing the stability (ageing, temperature, accuracy of the time correlation, etc.).*
SMCD-210 H/P	*The time format shall be Consultative Committee for Space Data Systems (CCSDS) Unsegmented Code.*
SMCD-215 H/P	It shall be possible to set and adjust the CTR (Central Time Reference) to TAI (Temps Atomique International , Ref. 1958 January Epoch) as defined in AD6-19 , when needed , and to verify the on-board CTR by telecommand / telemetry .
SMCD-217 H/P	*The accuracy of the time adjustment shall be 500 ms to TAI.*
SMCD-220 H/P	*Each science and housekeeping packets shall contain adequate time information to enable the user to perform the necessary correlation between the data acquisition and the UTC on ground .*
SMCD-225 H/P	*The spacecraft shall deliver the timing information (time in TAI [Temps Atomique International] format) including synchronisation signals and clock to the instruments for datation of their information with an accuracy of 0.1 ms.*

6.8 TELEMETRY, TRACKING & COMMAND S/S REQUIREMENTS

6.8.1 General

SMTT-005 H/P	*The TT&C Subsystem shall be able to receive and demodulate telecommands, modulate and transmit the telemetry, and transpond the ranging signal, simultaneously.*
SMTT-010 H/P	*The TT&C Subsystem shall interface with the ground segment according to the requirements of AD3-1.*

SMTT-015 H/P *The links with the ground shall be established using X-band for both uplink and downlink.*

SMTT-020 H/P *The TT&C Subsystem shall be compatible with the following ESA Standards:*

- *Ranging Standard, ESA PSS-04-104 (AD6-4)*
- *Radio Frequency and Modulation Standard, ESA PSS-04-105 (AD6-5)*

SMTT-025 H/P *The spacecraft shall have no requirements for telecommand and telemetry operation during the launch phase via its RF links.*

6.8.2 Functional Requirements

SMTT-030 H/P *The TT&C Subsystem shall support the following modes for the uplink:*

- *Carrier only*
- *Telecommand*
- *Ranging*
- *Simultaneous Telecommand and Ranging*

SMTT-035 H/P *The TT&C Subsystem shall support the following modes for the downlink:*

- *Carrier only*
- *Telemetry*
- *Ranging*
- *Simultaneous Telemetry and Ranging*

SMTT-040 H/P *The TT&C subsystem shall accept uplink signals and provide a demodulated digital telecommand signal to the CDMS for further processing. This function shall always be enabled without any possibility of switching it off.*

SMTT-045 H/P *The TT&C subsystem shall accept a digital telemetry signal from the CDMS and modulate it onto a downlink carrier. It shall be possible to disable this function.*

SMTT-050 H/P *The TT&C subsystem shall provide a range and/or range rate measurement capability. For ranging, it shall be capable to demodulate ranging tone from the uplink carrier and modulate the downlink carrier with this tone.*

SMTT-055 H/P *Hot redundancy shall be provided for the receive function and cold redundancy for the transmit function.*

SMTT-060 H/P *The receiver outputs shall be cross-coupled with the inputs of the CDMS command decoders.*

SMTT-065 H/P *The configuration shall be such that both receivers can receive and both decoders can decode simultaneously.*

SMTT-070 H/P	*The transmitters shall be able to receive the telemetry stream from both parts of the redundant CDMS.*
SMTT-075 H/P	*The antenna configuration shall ensure sufficient coverage and up-and downlink rate capability for all mission phases.*
SMTT-080 H/P	*When switching between antennas it shall not be necessary to switch off the transmitter.*
SMTT-085 H/P	*Telecommands shall be via the LGA's and the MGA , and the subsystem shall provide the required telecommand capabilities at maximum distance from the Earth and in any S/C attitude .*
SMTT-090 H/P	*Deleted .*
SMTT-095 H/P	*The receiver shall provide a status signal indicating the presence of an uplink signal.*
SMTT-100 H/P	*Limited housekeeping data will be routinely delivered to the LGA's for transmission upon ground request.*
SMTT-105 H/P	*A Medium-Gain Antenna (MGA) shall provide the primary communication for the downlink during the scientific operations phase and during the Commissioning and Performance Verification Phases.*

6.8.3 Performance Requirements

SMTT-110 H/P	*The uplink/downlink signals shall be in the range –7190-7235 MHz for telecommands and 8450-8500 MHz for telemetry. Separate frequencies will be allocated by ESA for Herschel and Planck respectively.*
SMTT-115 H/P	*Deleted.*
SMTT-120 H/P	The link budget calculations and associated margins shall be according to AD3-1 section 4.3.
SMTT-125 H/P	*Deleted.*
SMTT-130 H/P	*Deleted.*
SMTT-135 H/P	*The probability of frame loss on the downlink shall be < 10^{-5}.*
SMTT-140 H/P	*The LGA's shall support an uplink high command rate of 4Kbps using the 35 m station at Perth / New Norcia and a low command data rate of 125 bps using the 15 m station at Kourou , up to a distance from Earth of 1.8×10^6 km for Herschel and of 1.6×10^6 km for Planck.*
SMTT-142	*The MGA shall support an uplink command rate of 4 K.bps for both Perth / New Norcia and Kourou stations , up to a distance from Earth*

H/P	*of 1.8 x 10^6 km for Herschel and of 1.6 x 10^6 km for Planck.*
SMTT-145 H/P	*The LGA's shall support the downlink of real time housekeeping data (spacecraft and payload) telemetry using the 35 m station at Perth / New Norcia , and 500 bps using the 15 m station at Kourou , up to a distance from Earth of 1.8 x 10^6 km for Herschel and of 1.6 x 10^6 km for Planck.*
SMTT-150 H/P	*The omni-directional coverage of the LGA's shall overlap to the extend necessary to ensure that the antenna switching is never time-critical.*
SMTT-155 H/P	*The MGA shall allow for the telemetry downlink with the Perth / New Norcia 35 m station and with the 15 m station at Kourou up to a distance from Earth of 1.8 x 10^6 km for Herschel and of 1.6 x 10^6 km for Planck , during the telecommunication period (DTCP) , at 10° elevation.*

6.8.4 Detailed Requirements

SMTT-160 H/P	*The TT&C subsystem shall not have any single point failure except for the radiating elements of the antennas and their associated cabling. It shall have the capability of recovering from a failure autonomously. In all cases, it shall be possible to override the autonomous recovery action by use of ground commands.*
SMTT-165 H/P	*The subsystem design shall ensure that all its relevant operational parameters are acquired via suitable sensors and provided to the CDMS for incorporation into the HK telemetry.*
SMTT-170 H/P	*The TT&C subsystem shall be designed such as to be launched power "ON"; however, the telemetry function shall be disabled during launch.*
SMTT-175 H/P	*The radio frequency switching between antenna and transponders shall be done without single point failure.*
SMTT-180 H/P	*The subsystem shall meet all EMC requirements.*
SMTT-185 H/P	*The subsystem design shall ensure testability, including hot redundant functions, and failure indication.*
SMTT-190 H/P	*Antenna pattern and performance shall be verified with a test mock-up.*

6.8.5 Ground Compatibility Test

To ensure the full compatibility between the spacecraft and the ground segment, compatibility tests will be carried out. Such compatibility tests shall be accomplished by means of a RF-suitcase. The following requirements are applicable:

SMTT-195 H/P	*The RF-suitcase shall contain flight representative hardware sufficient to test all up- and downlinks for both functional and performance characteristics.*
SMTT-200 H/P	*The RF-suitcase shall enable the verification of all telemetry, telecommand and ranging functions and combinations thereof, as well as spectral analysis.*
SMTT-205 H/P	*The RF-suitcase shall be a self-contained item easy to transport, and shall include flight representative CDMS and RF units as well as the RF switches and cables. The suitcase shall allow to control and monitor all integrated units.*
SMTT-210 H/P	*The RF-suitcase shall be computer controlled to allow the commanding of any function of the units and to display all telemetry data on request. The housekeeping data of the integrated units shall be displayed permanently.*
SMTT-215 H/P	*The command bit stream and clock shall be available to measure the bit error rate (BER).*
SMTT-220 H/P	*The suitcase shall be capable of generating transfer frames in the same layout as during flight, with representative packets*
SMTT-225 H/P	*The suitcase shall be able to support the lower level protocols, e.g. COP-1 for command reception.*
SMTT-230 H/P	*The Contractor shall deliver a RF suitcase description and operation manual so that operations of the suitcase by ESOC technical personnel is possible without the need for Contractor's assistance.*
SMTT-235 H/P	*The RF suitcase shall display the parameters relevant to the commands received (e.g. the number of packets received and the contents of the packets).*

6.9 ATTITUDE CONTROL AND MEASUREMENT REQUIREMENTS

6.9.1 General

The Attitude and orbit Control and Measurement Subsystem (ACMS) provides the hardware and associated on-board software to acquire, control and measures the attitude of the satellite during all mission phases and modes according to the specified system requirements. The attitude and orbit control thrusters, used as actuators, are part of the Reaction Control Subsystem (RCS) for which the requirements are specified in Section 6.10, but their operation is controlled by the ACMS.

The ACMS comprises the following elements:

- attitude sensors for attitude measurement during all mission phases
- actuators to generate control torques for attitude manoeuvres and for compensation of perturbing torques
- electronics and software to manage the attitude measurement and attitude and orbit control functions, to detect and isolate failures and reconfigure if necessary, and to provide the interfaces with the rest of the spacecraft

SMAC-005 H/P	*The ACMS shall be able to provide all the necessary capabilities to satisfy the attitude and orbit control and measurement requirements of all mission phases, operational modes and operational functions.*

6.9.2 Functional Requirements

The following functional requirements are applicable to the Attitude and orbit Control and Measurement Subsystem.

The Ariane 5 upper stage guidance will deliver the spacecraft within predefined limits.

SMAC-010 H/P	*The ACMS shall put the spacecraft within its attitude constraints in less than 5 minutes after separation.*
SMAC-015 H/P	*The ACMS shall allow a first orbit correction manoeuvre to be performed within 6 hours after separation in order to compensate for the launcher upper stage injection errors and the perigee velocity variation and to reach the nominal transfer orbit.*
SMAC-020 H/P	*The ACMS shall allow for additional orbit correction manoeuvres (trim manoeuvres) at any time during the transfer phase to L_2.*
SMAC-025 H/P	*Once in the operational orbit, the ACMS shall allow for orbit maintenance manoeuvres to be executed at monthly (TBC) intervals.*
SMAC-030 H/P	*The subsystem shall acquire and control the attitude necessary for the correct execution of the various orbit insertion, correction and maintenance manoeuvres.*
SMAC-035 H/P	*The ACMS shall provide a stable attitude before and after the deployment of flexible elements (if applicable).*
SMAC-040 H/P	*During all phases of the mission the ACMS shall be capable of acquiring and maintaining any attitude as required by the sequence of mission operations.*

sequence of mission operations.

SMAC-045 H/P	*During the commissioning and calibration phases , as well as during the operational phase, the ACMS shall provide the capability to calibrate sensors according to the requirements in Section 4.3.2.*
SMAC-050 H/P	*The ACMS shall provide the science observation modes as required during the operational phase according to Sections 4.2.*
SMAC-055 H	*The ACMS shall provide slewing and scanning capability of the spacecraft as required for scientific or spacecraft operations in accordance with the requirements of Section 4.*
SMAC-060 H	*The subsystem shall provide angular momentum management according to the requirements of Section 4.3.1.*
SMAC-065 H/P	*The ACMS shall avoid unsafe attitudes, which might endanger the mission or degrade scientific instrument performance. It shall be able to detect a violation, or an attitude mode, which will result in a violation, of the attitude constraints defined in Section 4.2.7.*
SMAC-070 H/P	*The ACMS shall support the survival mode according to the requirements of Section 4.2. to protect the spacecraft and payload in case of hazardous deviations from the safe attitude conditions.*
SMAC-075 H/P	*It shall provide the capability for detecting and isolating any anomaly resulting in the loss of nominal pointing.*
SMAC-080 H/P	*The autonomy capability shall be present during all mission phases and modes and it shall be possible to deactivate/activate this capability by ground command.*
SMAC-085 H/P	*The ACMS shall provide the capability of autonomous attitude manoeuvres, including science observations, slews, tracking, wheel off-loading, etc., according to a pre-defined sequence as required by the mission operations.*
SMAC-090 H/P	*The number of necessary commands to execute the predefined sequences shall be minimised.*
SMAC-095 H/P	*The ACMS shall deliver and receive the signals necessary for the Herschel and Planck instruments.*
SMAC-100 H/P	*The ACMS shall transmit via telemetry unambiguous status information of all command and programme controlled variables and modes and of all parameters required for subsystem monitoring and performance evaluation.*

6.9.3 Performance requirements

SMAC-105 The ACMS pointing accuracy requirements shall comply with the

H/P	*overall spacecraft pointing requirements as specified in Section 4.3.2.*
SMAC-110 H/P	*The attitude pointing and control shall be stable in the presence of perturbation torques, spacecraft flexible modes or liquid slosh during all mission phases and operational modes.*
SMAC-115 H/P	*Under worst case conditions with respect to spacecraft mass properties and perturbation torques, wheel off-loading shall not be necessary more than once per day.*
SMAC-120 H/P	*The execution of the ACMS survival mode shall, once started, not be interruptible by an external command: recovery from this mode shall only be possible after a stable Sun-pointing attitude has been reacquired.*
SMAC-122 H/P	*The ACMS design shall ensure adequate margins for stability and flexure rejection, as a minimum the following margins shall apply:* *gain margin: 6 dB* *phase margin: 30 degrees* *flexure rejection margin: 6 dB for flexible modes which are gain stabilised*

6.9.4 Detailed requirements

SMAC-125 H/P	*The ACMS shall be fully operational at start up 20 seconds after separation.*
SMAC-130 H/P	*Orbit control shall be open-loop under ground or stored time-tagged commands.*
SMAC-135 H/P	*All attitude and orbit control and measurement functions shall be redundant.*

6.10 REACTION CONTROL REQUIREMENTS

6.10.1 General

SMRC-005 H/P	*The Reaction Control Subsystem (RCS) shall provide the necessary forces and torques in order to achieve spacecraft linear and angular momentum changes necessary for orbit transfer/insertion/ maintenance and attitude control, respectively, during all phases of the mission.*

The reaction control system comprises the propellant storage tanks, pipework, necessary valves and pressure transducers and the thrusters. The thrusters are commanded by the ACMS and shall permit execution of the tasks listed below.

6.10.2 Functional Requirements

SMRC-010 H/P *The thrusters shall provide the forces to establish all post-launch spacecraft velocity increments for:*

- *initial launcher injection error and perigee velocity correction*
- *follow-on orbit correction/trim manoeuvres*
- *operational orbit injection (if applicable)*
- *orbit maintenance of the operational orbit*

SMRC-015 H/P *The thrusters shall provide the necessary torques for as minimum:*

- *angular momentum unloading during relevant mission phases and modes.*

SMRC-020 H/P *The RCS shall supply sufficient telemetry data to provide unambiguous status information of all command and programme controlled variables and modes and of all parameters required for subsystem monitoring and performance evaluation.*

6.10.3 Performance Requirements

SMRC-025 H/P *The total tank volume shall allow for a propellant growth of 20 %, subject to tank availability.*

SMRC-030 H/P *The residual forces during manoeuvres which require pure torques shall be minimised.*

6.10.4 Detailed Requirements

SMRC-035 H/P *The RCS shall include sets of thrusters, one nominal and one redundant (not necessarily on different branches), each set shall be capable of performing a full mission profile.*

SMRC-040 H/P *The design of the RCS shall be such that a single component/part failure cannot cause the failure of functions which are vital for mission success.*

SMRC-045 H/P *Deleted.*

SMRC-050 H/P *Deleted.*

SMRC-055 H/P *The layout of the RCS and the arrangement of the tanks shall ensure a symmetrical depletion of the propellant in all tanks* *during all thruster firings in-flight in order to minimise the lateral shift of the spacecraft COM.*

SMRC-060 H/P	*The thruster configuration shall be optimised with respect to overall manoeuvre performance so that propellant consumption for attitude and orbit control is minimised.*
SMRC-065 H/P	*The location and direction of the thrusters shall be such as to avoid, or at least minimise, contamination and plume impingement effects.*
SMRC-070 H/P	*The characteristics of the thrusters and their accommodation on the spacecraft shall not cause any deleterious effects on either the spacecraft or the science instruments during operation.*
SMRC-075 H/P	*Fill and drain valve locations shall be chosen to facilitate loading and unloading of propellants, pressurants and purging fluids.*
SMRC-080 H/P	*Test port locations shall be compatible with all requirements for testing. Interfaces shall be provided through the spacecraft skin connector for providing critical value states (pressure, temperature, etc.) independent of spacecraft power.*
SMRC-085 H/P	*The location of the pyrovalves shall allow for an easy access for initiator and booster installation during the launch preparation.*
SMRC-090 H/P	*Adequate means for determination of the remaining propellant quantities shall be provided. It shall be possible to achieve an accuracy:* - *better than 5% of the remaining propellant, or* - *at least equal to the amount of propellant required for three months of operational life*
SMRC-095 H/P	*The RCS shall comply with the safety and cleanliness/contamination requirements of launcher, launch range and spacecraft.*
SMRC-100 H/P	*The design shall not require welding inside the SVM to complete the RCS assembly.*
SMRC-105 H/P	*The tanks shall comply with the requirements of AD6-11 and AD6-2/3.*
SMRC-110 H/P	*Components (e.g. valves, regulators) using sliding surfaces for their actuation and operation as well as components with bellows inside the fluid containing part are not allowed. For those which cannot be avoided with reasonable effort, a rationale for retention shall be prepared which shall be subject to approval by ESA.*
SMRC-115 H/P	*All materials used in contact with propellants/simulant propellants shall be mutually compatible. All materials selected shall, in particular w.r.t. the mission duration, neither degrade and injure functionality of components nor degrade propellants.*
SMRC-120	*Pyrovalves shall have provisions, which prevents the actuator gas*

H/P	*from flowing in the propellant or gas feed line passages and shall comply with requirements in section 5.6.2.4.*
SMRC-125 H/P	*Heating capability shall be provided to prevent the freezing of the propellants.*
SMRC-130 H/P	*Heating capability shall be provided to prevent condensation of propellants in the pressurant gas control assembly / circuitry upstream of the non-return valves , if applicable (Propellant type)*
SMRC-135 H/P	*The design of the thruster control valves shall be such as to avoid a valve-open failure case.*
SMRC-140 H/P	*For testing purposes, the propellant tanks shall be filled with representative liquids having similar densities.*

6.11 HARNESS REQUIREMENTS

The SVM harness provides all electrical connections between all electrical equipment in the service module. It includes harnesses for power supplies, signals and pyrotechnic pulses. It includes also harnesses for connections with the PLM, the umbilicals and test connectors.

Note: The requirements listed here below shall be used as guidelines for the design of the PLM cryoharness.

6.11.1 Functional Requirements

SMHA-005 H/P	*The harness shall provide adequate distribution and separation of all power supply lines, analogue and digital data lines, command and actuation pulse and stimuli lines between all units of the SVM subsystems and those lines to the PLM, Planck module and Telescope interfaces, the test connectors, the safe/arm brackets and connectors and the umbilical connectors.*

6.11.2 Performance Requirements

SMHA-010 H/P	*The harness shall transmit all electrical currents in a manner compatible with the requirements of the source and destination unit/interface.*
SMHA-015 H/P	*The power harness DC equivalent resistance from the main regulation point to the input of the load (line and return) shall not exceed the value required by the power standard ESA PSS-02-10 (AD6-9).*
SMHA-020 H/P	*The inductance of the power distribution harness for frequencies up to 100 kHz shall not exceed the value required by the power standard (AD6-9).*

(AD6-9).

SMHA-025 H/P	*The isolation requirements between leads, which are not connected together and between shield and centre conductor and shield to shield shall be at least 10 Mohm under 500 V DC at both polarities.*
SMHA-030 H/P	*The loop resistance shall be optimised to insure the best compromise between the drop voltage acceptable to units and the harness mass.*
SMHA-035 H/P	*Deleted .*
SMHA-040 H/P	*The mechanical construction of the harness shall assure the reliable operation of the spacecraft under all environmental conditions. The stress, which occurs during manufacturing, integration, test, transport, launch preparation, launch and in-orbit operation shall cause no changes in the harness, which might affect the correct functioning of the system.* *No piece of harness shall be used as a mechanical support.*

6.11.3 Detailed Requirements

SMHA-045 H/P	*Physical separation along common lines of the categories listed below (power, signals and lines for the mechanisms, if applicable) shall be retained between these categories up to and inclusive of the module interface connectors. Exceptions can be only the routing of harnesses down to connectors in the satellite separation plane.* - *Category 1: all supply lines from power sources to users* - *Category 2: digital signals* - *Category 3: lines for the mechanisms/pyrotechnics* - *Category 4: sensitive analogue signals.*
SMHA-050 H/P	*All equipment shall use a separate connector dedicated to its functional interface, according to the categories listed above.*
SMHA-055 H/P	*Wiring of redundant systems, subsystems or units of subsystems shall be routed through separate connectors and wire bundles.*
SMHA-060 H/P	*Redundant wire bundles shall be routed differently wherever possible.*
SMHA-065 H/P	*Cross strapping of redundant paths and circuits shall not be carried out in the harness.*
SMHA-070 H/P	*The pyrotechnic harness shall satisfy the applicable safety requirements.*
SMHA-075 H/P	*The pyrotechnic harness shall consist of twisted pairs of wires with an overall shield being continuous and connected to the conductive connector shells at all interfaces and grounded to the structure at all intermediate attachment points.*
SMHA-080	*Connections to the initiators shall be capable of being mechanically*

H/P	*broken during ground handling by safe/arm connectors accessible from the outside of the spacecraft.*
SMHA-085 H/P	*The shields of cables shall not be used as return lines.*
SMHA-090 H/P	*All hot/return lines shall be twisted together.*
SMHA-095 H/P	*All harness and all box and bracket mounted connectors supplying power shall have socket contacts.*
SMHA-100 H/P	*Where it is necessary to have a shield connection through a connector, separate pins shall be used.*
SMHA-105 H/P	*The initial design shall ensure that sufficient (including spare) pins are available for all foreseeable subsystem and experiment functions.*
SMHA-110 H/P	*All individual wire-to-pin interfaces shall be covered with transparent heat shrink sleeves.*
SMHA-115 H/P	*The possibility of incorrect mating of connectors shall be excluded by design.*
SMHA-120 H/P	*The harness connectors shall be easily accessible, attachable and removable from the corresponding unit connectors; removal of units or disconnection of adjacent connectors shall not be necessary.*
SMHA-125 H/P	*The harness shall be fixed onto the structure in order to avoid any damage during launch phase. As a general rule it will be fixed:* - *at equipment level: the harness connectors shall be fitted onto the equipment connectors by appropriate locking systems* - *at the structure level* - *at interface level: the connectors shall be fixed on metallic brackets themselves fixed onto the structure.*
SMHA-130 H/P	*Fixation of sensitive signal lines shall be such as to avoid micro-phonic noise.*
SMHA-135 H/P	*The harness restraining systems on the structure shall not bring about any stress at connector level.*
SMHA-140 H/P	*The harness linking equipment mounted in or on the payload module, with the service module shall be such that the heat transferred by conduction is optimised for electrical and thermal performances.*
SMHA-145 H/P	*Permanent connections installed for purposes of test at integrated satellite level shall be routed to skin connectors of the modules concerned (module interface connectors are no longer accessible at that level).*
SMHA-150 H/P	*Skin connectors shall also be provided to make-or-break power circuits.*
SMHA-155	*All these skin connectors shall be closed by caps, bridging connectors,*

H/P *and thermal insulation for flight.*

6.11.4 EMC Design Requirements

SMHA-165 H/P *The harness shall comply with the EMC Requirements mentioned in section 5.6.4.*

The design principles shall be defined by EMC system analysis. Further specific design principles to be implemented are:

SMHA-170 H/P *Twisted power lines shall be pre-manufactured by the supplier to achieve the best magnetic compensation.*

SMHA-175 H/P *Other lines shall be twisted as far as practicable with their corresponding return path, or shall run adjacent to the reference grounds to minimise magnetic loops.*

SMHA-180 H/P *Harness shielding, as far as required, shall preferably be made by means of overall shielding, where the signals in the bundles do not interfere with one another.*

SMHA-185 H/P *The shields shall be connected to the equipment housings via connector pins or to the connector case, if no other special arrangement is derived from the EMC analysis of the interface design.*

6.12 SOFTWARE REQUIREMENTS

6.12.1 General

Several functions of the on-board subsystems will be implemented by on-board software (S/W). This on-board software shall include the in-flight software as well as the ground test software, resident on-board during the AIV activities. The on-board software requirements are defined in this Chapter.

SMSW-005 H/P *All S/W production and test shall follow the ESA Software Standard, ESA ECSS-E-40 (AD6-17) and ESA ECSS Q-80 (AD6-25).*

SMSW-010 H/P *The on-board S/W shall be developed using a high level language, except where explicitly exempted.*

SMSW-015 H/P *The use of a non high level language (e.g. assembler) code in the S/W shall be shown to be absolutely necessary to achieve the required performance, to the satisfaction of ESA before it is implemented.*

SMSW-020 H/P	*All on board software shall be re-programmable on ground and in orbit.*
SMSW-025 H/P	*All on-board S/W running in subsystems shall be developed using the same development environment, except where explicitly exempted.*

The standard development environment comprises standard processor type, standard development language and standard software development tools.

SMSW-030 H/P	*All S/W produced shall be verified by an independent Software Verification Team different from the software supplier.*
SMSW-035 H/P	*All reviews shall be formal and be supported by ESA and higher level contractors.*
SMSW-040 H/P	*The spacecraft shall support post-launch modifications of all on-board software.*
SMSW-045 H/P	*The on-board S/W shall be structured such that modifications to any individual code module have minimum impact on other modules.*
SMSW-050 H/P	*The software maintenance environment shall provide the means to generate and prepare software patches or full images for uplink to the spacecraft.*
SMSW-055 H/P	*The software maintenance environment shall be integrated within the Software Validation Facility.*
SMSW-060 H/P	*The on-board software shall be implemented with a layered structure separating hardware, software, input/output, basic services and general mission services.*
SMSW-065 H/P	*The on-board software shall maintain an up-to-dated status of tasks, functions and procedures in a non-volatile memory.*

New software or software patches to be up-linked to the spacecraft will need to be formally tested and verified prior to their release and use.

6.12.2 Performance Requirements

SMSW-070 H/P	*Starting or stopping processes shall not affect the execution or performance of other running processes.*
SMSW-075 H/P	*The S/W shall protect itself against infinite loops, computational errors and possible lock-ups resulting from an undetected hardware failure.*

On-board Memory

SMSW-080 H/P *Fixed areas of on-board memory shall be dedicated to:*

- *Code*
- *Fixed constants*
- *Variable parameters*

SMSW-085 H/P *All memory shall support direct patching, including areas where memory management is used.*

SMSW-090 H/P *The S/W shall normally run in RAM loaded from no volatile memory.*

The objective shall be to launch with the memory empty of any patches to the on-board software.

SMSW-095 H/P *On board memory shall contain at least 50 % free (unused) memory at Architectural Acceptance Review and 30 % at Software Acceptance Review after coding and testing has been completed; it shall be possible to use this free area for code and/or data.*

SMSW-100 H/P *The spacecraft shall support the dumping to ground of any element of the on-board memory, initiated by telecommand.*

The dump request will specify the name of the memory to be dumped, the start address and length of the dump; multiple selections shall be allowed in one command. Even if several packets are required to convey the dump data to ground, only a single telecommand will be required.

Fault Detection

SMSW-105 H/P *The data handling shall be provided with the capabilities for its fault detection, fault isolation and switching to its redundant items.*

On-board monitoring requirements

SMSW-110 H/P *On-board monitoring shall be the activity continuously ensuring that the on-board units under supervision are in an acceptable safe state. This shall be achieved by regularly checking the state of individual parameters in the housekeeping information.*

SMSW-115 H/P *S/W engineering parameters shall be available in housekeeping telemetry to enable the ground to fully diagnose the status of the S/W.*

Processors

SMSW-120 H/P *The software code used to boot up a processor shall be optimised and characterised in terms of reliability and time to initialise (cold / warm cases)* *warm cases).*

SMSW-125 H/P	*The processor shall boot to a stage that provides the basic critical functions (HK telemetry, TC execution and critical autonomous functions).*
SMSW-130 H/P	*CPU shall contain at least 50 % free (unused) peak load at Architectural Acceptance Review and 30 % at Software Acceptance Review after coding and testing has been completed.*

6.12.3 Verification Requirements

SMSW-135 H/P	*When software units are changed following formal verification, the on-board software shall undergo full regression testing and independent verification.*
SMSW-140 H/P	*Test tools in the development testing of the S/W shall support the same telemetry and telecommand data base as used in system level testing.*
SMSW-145 H/P	*All software codes shall be statically analysed by a standard tool.*
SMSW-150 H/P	*All software codes shall be dynamically analysed by a standard tool.*
SMSW-155 H/P	*A Software Validation Facility (SVF) shall support the software verification at the following levels during development and maintenance phases:* - *unit level; i.e. procedure or function level* - *integration level; i.e. module level* - *subsystem level; i.e. S/W subsystem level*
SMSW-160 H/P	*The SVF shall allow S/W verification to be performed before and after the S/W is integrated at subsystem level.*
SMSW-165 H/P	*The SVF shall support full testing of the software at source code and machine level.*
SMSW-170 H/P	*The SVF shall allow software testing without instrumentation of the target code.*
SMSW-175 H/P	*All software licences for any software used to develop and test the on-board software shall be maintainable at the same version and issue over the full life of the mission at a freeze point in the schedule and be deliverable to the Agency with the corresponding support documentation. The freeze point shall be established in agreement with ESA.*
SMSW-180	*All Herschel / Planck on-board software shall be delivered to ESA in source form including all building scripts necessary to*

H/P	*in source form, including all building scripts necessary to regenerate the on-board image. All supporting documentation shall also be delivered to ESA*
SMSW-185 H/P	*All on-board software resident in ASIC, FPGA or other specified circuits (including firmware and development language) shall be delivered to ESA in source form including all supporting test harness and documentation.*

7 PRODUCT ASSURANCE REQUIREMENTS

The system product assurance is covered by the Product Assurance Requirements Specification (AD1-1) and in document AD4-7 concerning the instruments.

8 ASSEMBLY, INTEGRATION and VERIFICATION REQUIREMENTS

The Assembly, Integration and Verification (AIV) Requirements are specified in the System AIV Requirements Specification (AD1-2).

9 ACRONYMS and ABBREVIATIONS

ABCL	As Built Configuration List
AC	Alternating Current
ACC	Attitude Control Computer
ACM	Attitude Control and Measurement
ACMS	Attitude Control and Measurement Subsystem
ACS	Auto-Correlation Spectrometer
AD	Applicable Document
ADC	Analog Digital Converter
ADD	Architectural Design Document
A/D	Analog to Digital converter
ADP	Acceptance Data Package
ADR	Architectural Design Review
AGN	Active Galactic Nuclei
AIT	Assembly, Integration and Test
AIV	Assembly, Integration and Verification
AM	Alignment Model
AMA	Absolute Measurement Accuracy
AME	Attitude Measurement Error
AO	Announcement of Opportunity
AOCS	Attitude and Orbit Control System
AOS	Acousto-Optical Spectrometer
APD	Absolute Pointing Drift
APE	Absolute Pointing Error
AR	Acceptance Review
ARE	Absolute Rate Error
AR5	Ariane 5
ASF	Additional Safety Factor
ASIC	Application Specific Integrated Circuit
ASW	Address and Synchronisation Word
ATC	Active Thermal Control
AU	Astronomical Unit
AVM	Avionic Model
BAF	Batiment d'Assemblage Final
BAU	Buffer Amplifier Unit
BCR	Battery Charge Regulator
BDR	Battery Discharge Regulator
BER	Bit Error Rate
BEU	Back End Unit
BIB	Blocked Impurity Band
BIT	Build In Test
BMOS	Buckling Margin Of Safety
BOL	Beginning of Life

BOLA	Bolometer Amplifier (PACS)
bps	bits per second
BRU	Battery Regulator Unit
BSF	Basic Safety Factor
BW	Bandwidth
CaC	Cost at Completion
CC	Configuration Control
CCB	Configuration Control Board
CCD	Charged Coupled Device
CCSDS	Consultative Committee for Space Data Systems
CDD	Configuration Data Document
CDMS	Command and Data Management Subsystem
CDMU	Central Data Management Unit
CEU	Cryo Electronics Unit
CFC	Carbon Fibre Compound
CFRP	Carbon Fibre Reinforced Plastic
CMD	Command
COM	Centre of Mass
COP-1	Command Operation Procedure number 1
CQM	Cryogenic Qualification Model
CREMA	Consolidated Report on Mission Analysis
CSG	Centre Spatial Guyanais
CTU	Central Terminal Unit
CVCM	Collected Volatile Condensable Material
CVV	Cryostat Vacuum Vessel
DACS	Digital AutoCorrelator Spectrometer
DBU	Data Bus Unit
DC	Direct Current
DK	Denmark
DLCM	Direct Liquid Content Measurement
DM	Dynamic Model
DMA	Direct Memory Access
DML	Declared Material List
DMPL	Declared Mechanical Part List
DNEL	Disconnect Non Essential Loads
DPC	Data Processing Centre
DoD	Depth of Discharge
DOF	Degree Of Freedom
DPOP	Daily Prime Operational Phase equivalent to Observation Phase
DRB	Delivery Review Board
DS	Digital Serial
DSN	Deep Space Network
DTCP	Daily Telecommunications Phase equivalent to Telecommunication Phase
DTMM	Detailed Thermal Mathematical Model

ECR	Engineering Change Notice
EDAC	Error Detection And Correction
EDS	Electrostatic Discharge
EED	Electro-Explosive Device
EEE	Electrical, Electronic, Electro-mechanical
EEPROM	Electrically Erasable Programmable Read Only Memory
EGSE	Electrical Ground Support Equipment
EIRP	Equivalent Isotropic Radiated Power
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMF	Electro-Motive Force
EMI	Electromagnetic Interference
EOL	End of Life
EOM	End of Mission
EOP	Early Orbit Phase
ESA	European Space Agency
ESD	Electro Static Discharge
ESOC	European Space operations Centre
ESTEC	European Space Research and Technology Centre
ESV	An ARIANE 5 launcher version

FAR	Flight Acceptance Review
FD	Flight Dynamics
FEC	Front Error Correction
FEM	Finite Element Model
FINDAS	FIRST Integrated Network and Data Archive System
FIR	Far InfraRed
FIRST	Far-InfraRed and Sub-millimetre Telescope
FM	Flight Model
FMECA	Failure Modes Effects and Criticality Analysis
FMS	Failure Management System
FOP	Flight Operations Plan
FOR	Field of Regard
FOS	Factor of Safety
FOV	Field of View
FP	Fabry-Perot
FPA	Focal Plane Assembly
FPGA	Field Programmable Gate Array
FPLM	FIRST Payload Module
FPU	Focal Plane Unit
FRR	Flight Readiness Review
FS	Flight Spare
FSC	FIRST Science Centre
FSS	Fine Sun Sensor
FSVM	FIRST Service Module

G/S	Ground Station
G/T	Gain to Temperature Ratio
GFC	Glass Fibre Compound
GFRP	Glass Fibre Reinforced Plastic
GMM	Geometrical Mathematical Model
GSE	Ground Support Equipment
GTO	Geostationary Transfer Orbit
H/W	Hardware
HEO	Highly Eccentric Orbit
HeII	Helium II
HFI	High Frequency Instrument (Planck)
HGA	High-Gain Antenna
HIFI	Heterodyne Instrument (FIRST)
HK	Housekeeping
I/F	Interface
ICC	Instrument Control Centre
ICD	Interface Control Document
ID	Interface Document
IF	Intermediate Frequency
IFAR	Instrument Flight Acceptance Review
IFEM	Interface Finite Element Model
IID	Instrument Interface Document
IOP	Initial Orbit Phase
IRU	Inertial Reference Unit
ISO	Infrared Space Observatory
ITT	Invitation to Tender
JFET	Junction Field Effect Transistors
J-T	Joule-Thomson
KAL	Keep Alive Line
LCDA	Launcher Coupled Dynamic Analysis
LCL	Latching Current Limiter
LEOP	Launch and Early Orbit Phase
LET	Linear Energy Transfer
LGA	Low-Gain Antenna
LO	Local Oscillator (HIFI)
LOS	Line of Sight
LOU	Local Oscillator Unit
LSB	Least Significant Bit
LV	Launch Vehicle
LVDE	Low Vibration Drive Electronics
LW	Launch Window

MAC	Modal Assurance Criterium
MCC	Mission Control Centre
MEOP	Maximum Expected Operating Pressure
MGSE	Mechanical Ground Support Equipment
MLI	Multi-Layer Insulation
MOC	Mission Operations Centre
MOI	Moment of Inertia
MOS	Margin Of Safety
MPPT	Maximum Power Point Tracking
MTL	Mission Timeline
N/A	Not Applicable
NASA	National Aeronautic and Space Administration
NASTRAN	NASA Structural Analysis Tool
NCR	Non Conformance Report
NRT	Near Real Time
OB	Optical Bench
OBDH	On-Board Data Handling
OBT	On-Board Time
ODS	Orbital Disconnect Support
OFD	Operations Facilities Document
OGSE	Optical Ground Support Equipment
OIRD	Operations Interface Requirements Document
OSR	Optical Solar Reflector
OTF	On Target Flag
P/L	Payload
PA	Product Assurance
PACS	Photoconductor Array Camera Spectrometer (FIRST)
PCM	Pulse Code Modulation
PCS	Power Control Subsystem
PCU	Power Control Unit
PDD	Payload Definition Document
PDE	Pointing Drift Error
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PFM	Proto Flight Model
PI	Principal Investigator
PLL	Phase-Lock Loop
PLM	Payload Module
PMD	Propellant Management Device
PPLM	Planck Payload Module
PROM	Programmable Read Only Memory
PSF	Point Spread Function
PSK	Phase Shift Keying
PSVM	Planck Service Module

PT	Product Tree
PUS	Packet Utilisation Standard
PWM	Pulse Width Modulation
QSO	Quasi-Stellar Object
RAM	Random Access Memory
RCS	Reaction Control Subsystem
RD	Reference Document
RE	Radiated Emission
RF	Radio Frequency
RFI	Radio Frequency Interference
RFW	Request for Waiver
RH	Relative Humidity
RHCP	Right Hand Circular Polarization
RML	Recoverable Mass Loss
ROM	Rough Order of Magnitude
RPE	Relative Pointing Error
RS	Radiated Susceptibility
RSS	Root Sum Square
RTA	Real Time Assessment (software)
RTMM	Reduced Thermal Mathematical Model
RTU	Remote Terminal Unit
SA	Solar Array
SAA	Solar Aspect Angle
SAS	Sun Acquisition Sensor
SCC	Stress Corrosion Cracking
S/C	Spacecraft
SCOS	Space Control and Operations Centre
SIN	Straylight Induced Noise
S/N	Signal to Noise Ratio
S/S	Subsystem
S/W	Software
SCET	Spacecraft Elapsed Time
SCL	Spacecraft Control Language
SDE	Software Development Environment
SDS	System Definition Study
SECDED	Single Error Correction and Double Error Detection
SEL	Spacecraft Event Log
SEU	Single Event Upset
SF	Safety Factor
SIS	Superconductor-Insulator-Superconductor
SIV	Software Independent Validation
SM	Structural Model
SOC	Science Operations Centre
SOW	Statement Of Work

SPC	Science Programme Committee
SPIRE	Spectral Photometer Imaging Receiver (FIRST)
SPL	Split Phase Level
SRPE	Spatial Relative Pointing Error
SSAC	Space Science Advisory Committee
SSM	Second Surface Mirror
SSR	Solid State Recorder
SSMM	Solid State Mass Memory
SST	Stainless Steel
STM	Structural/Thermal Model
STMM	Simplified Thermal Mathematical Model
STR	Start Tracker
SVF	Software Validation Facility
SVM	Service Module
TA	Telescope Assembly
TAI	Temps Atomique International
TB	Thermal Balance
TBC	To Be Confirmed
TBD	To Be Defined
TC	Telecommand
TCS	Thermal Control Subsystem
TF	Test Factor
TM	Telemetry
TML	Total Mass Loss
TMM	Thermal Mathematical Model
TOP	Transfer Orbit Phase
TRP	Technological Research Programme
TT&C	Tracking, Telemetry and Command
TV	Thermal Vacuum
UMOS	Ultimate Margin of Safety
UF	Ultimate Factor of Safety
VMC	Visual Monitoring Camera
WBS	Work Breakdown Structure
WFE	Wave Front Error
WP	Work Package
WPD	Work Package Description
YMOS	Yield Margin of Safety
YF	Yield Factor of Safety

10 LIST of REQUIREMENTS ABBREVIATIONS

The table below contains an alphabetically sorted list of the requirement abbreviations used in this document, and the chapters/sections in which they are used. Please note that the Table shows the highest-level chapter/section number for the abbreviation. For example, the abbreviation MISS - Mission Design, is shown to appear in Section 4.2. This means that the same abbreviation is also used in the lower level sections such as 4.2.x and 4.2.x.y.

Requirement Abbreviation	Chapter/ Section	Chapter/Section Title
FMSC	3.1.4	Scientific Mission – Scientific Requirements
MISS	4.2	Mission Design
MOFM	4.5	Mission Operations - Fault Management
MOGE	4.1	Mission Operations - General Requirements
MOOF	4.4	Mission Operations - Operational Functions
MOOM	4.3	Mission Operations - Operational Modes
SENV	5.5	Spacecraft System – Environment Conditions
SINT	5.4	Spacecraft System - External Interface Requirements
SFUN	5.2	Spacecraft System - Functional Requirements
SGEN	5.1	Spacecraft System - General Requirements
SCIF	5.8	Spacecraft System - Interface Requirements
SCMD	5.6.1	Spacecraft System - Mechanical Design
SCME	5.6.2	Spacecraft System – Mechanisms Requirements
SPER	5.3	Spacecraft System – Performance Requirements
STHE	5.6.3	Spacecraft System - Thermal Design Requirements
SCVE	5.7	Spacecraft System - Verification Requirements
SPLA	6.4	Planck Payload Module Requirements
SMAC	6.9	Service Module - Attitude Control and Measurement
SMCD	6.7	Service Module - Command and Data Management
SMHA	6.11	Service Module – Harness
SMPC	6.5	Service Module - Power Control Subsystem
SMRC	6.10	Service Module - Reaction Control Subsystem
SMSA	6.6	Service Module - Solar Array and Sun Shield
SMSW	6.12	Service Module – Software
SMTT	6.8	Service Module - TT&C Subsystem
SPLM	6.3	Herschel Payload Module Requirements
SSGN	6.1	Spacecraft System General
SSVM	6.2	Service Module Requirements
TELE	6.4	Planck Telescope Requirements

HERSCHEL / Planck Project

Herschel Pointing Modes

(Annex I to SRS)

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1 INTRODUCTION

Herschel / Planck is an ESA mission that combines the Herschel (previously called FIRST) and the Planck missions within one single programme.

The Herschel telescope (previously FIRST : Far Infrared and Sub-millimetre Telescope) is dedicated to perform astronomical observations in the far-infrared and sub-millimetre wavelength range. Herschel , the fourth European Space Agency (ESA) cornerstone mission is a multi-user observatory type mission. The detectors of the Herschel instruments have to be cooled to cryogenic temperatures in the range of 0.3 to 2K in order to reach the necessary sensitivity for the observation of a variety of weak radiation sources.

This document defines requirements for Herschel pointing modes to support Scientific Observations, in particular to make maps of extended objects, or to make high sensitivity measurements. This document is annex to the Herschel / Planck Satellite System Requirements Specification (SRS) SCI-PT-RS-05991.

2 RASTER POINTING

2.1 Normal raster pointing

Raster pointing is a series of fine pointing observations of equal duration (*t*), separated by slews, in order that the pointing of the telescope axis moves in a raster pattern as defined in Fig. 1. In this figure the following notations are used:

M is the number of pointings per line.

N is the number of lines.

d_1 is the spherical angular distance between successive steps.

d_2 is the spherical angular distance between successive lines.

In addition the inertial attitude of the pattern is defined by the quaternion Q_{rast} of the 1st raster point and an angle φ defining the rotation of the pattern axes with respect to local instrument axes.

The raster parameters, φ, M, N, d_1 and d_2 are within the following range and resolution:

φ: 0 – 180 degrees resolution: 0.1 degrees

M: 2 - 32

N: 1 - 32

d_1: 2 arcsec - 8 arcmin; resolution: 0.5 arcsec

d_2: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

Note that d_2 being zero, means that it shall be possible to scan N times the points of a single line.

The duration of stable pointing at any position, *t*, will be between 10 seconds and 30 minutes.

2.2 Raster pointing with OFF-position

Raster pointing with OFF-position is a special form of raster pointing where, after a specified number of raster points (ON positions), the spacecraft slews to a predefined point (the OFF position), after which it resumes its raster pointing where it left the raster before going to the OFF position. The number of raster pointings (K) before going to the OFF position is determined by the timing characteristics of the raster pointing such that the time between each subsequent OFF position is less than some characteristic stability time of the instrument. This form of raster pointing is shown in Fig. 2.

For the ON positions, the raster is defined by the parameters Q_{rast}, φ, M, N, d_1 and d_2, with for each position an equal observation time *t*. The definition of these parameters is given above for normal raster pointing and its range and resolution are specified below.

The OFF position is defined by the parameter Q_{off}, specifying the quaternions of the OFF position in inertial coordinates.

K is the number of consecutive ON positions before going to the OFF position, and t_{off} is the time of stable pointing in the OFF position.

The pattern is followed line by line and where after each K ON positions the spacecraft moves to the OFF position. After each OFF position, the raster pointing shall be resumed for the next K ON positions, etc. (Fig. 2).

The raster parameters, φ, M, N, K, d_1 and d_2 are within the following range and resolution:

φ: 0 – 180 degrees resolution: 0.1 degrees

M: 2 - 32

N: 1 - 32

K: 2 - M x N

d_1: 2 arcsec - 8 arcmin; resolution: 0.5 arcsec

d_2: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

The maximum value of K being equal to the total number of ON positions implies normal raster pointing with only a single OFF position pointing at completion of the raster.

Like for normal raster pointing, d_2 being zero means that it shall be possible to scan N times the points of a single line.

The duration of stable pointing at any position, t, will be between 10s and 30 minutes.

The spherical coordinates of the OFF position with respect to the centre of the map shall be within the following range:

d_{1off}: $\pm$(0 arcmin - 2 degrees); d_{2off}: $\pm$(0 arcmin - 2 degrees)

The duration t_{off}, of stable pointing in the OFF position is within the range 10 s to 30 min.

3 LINE SCANNING

3.1 Normal line scanning

This is a scanning mode along short parallel lines, such that the telescope axis moves as shown in Fig.3 with parameters as defined below:

N is the number of lines.

D_1 is the angular extent of the lines.

d_2 is the angular distance between successive lines.

The inertial attitude of the pattern is defined by the quaternions Q_{scan} of the beginning of the 1st scan line and an angle φ defining the rotation of the scan lines with respect to local instrument axes.

The pattern shall be followed line by line in the way shown by the arrows in Fig. 3.

The scan parameters, φ, N, D_1 and d_2 are within the following range and resolution:

φ: 0 – 180 degrees resolution: 0.1 degrees

N: 1 - 32

D_1: 20 arcsec - 20 deg; resolution: 5 arcsec

d_2: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

Note that the minimum of d_2 being zero, means that it shall be possible to scan N times the same line

The scan rate, r, shall be changeable by ground command and will be between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.

3.2 Line scanning with OFF-position

Line scanning with OFF-position is a special form of line scanning where, after a specified number of lines, the spacecraft slews to a predefined point (the OFF position), after which it resumes its line scanning where it left the pattern before going to the OFF position. The number of lines (K) before going to the OFF position is determined by the timing characteristics of the operation such that the time between each subsequent OFF position is less than some characteristic stability time of the instrument. This form of line scanning is shown in Fig. 4.

The line scan pattern is defined by the parameters Q_{scan}, φ, N, D_1 and d_2 as given above.

The OFF position is defined by the parameter Q_{off}, specifying the quaternions of the OFF position in inertial coordinates.

K is the number of consecutive lines before going to the OFF position, and t_{off} is the time of stable pointing in the OFF position.

The pattern shall be followed line by line in the way shown by the arrows in Fig. 4 and where after each K lines the spacecraft moves to the OFF position. After each OFF position, the line scanning shall be resumed for the next K lines, etc.

The scan parameters, φ, N, D_1 and d_2 are command within the following range and resolution:

φ: 0 – 180 degrees resolution: 0.1 degrees

N: 1 - 32

K: 1 - N

D_1: 20 arcsec - 2 deg; resolution: 5 arcsec

d_2: 2 arcsec - 8 arcmin or 0; resolution: 0.5 arcsec

The maximum value of K being equal to the total number of lines implies normal line scanning with only a single OFF position pointing at completion of the line pattern.

The scan rate, r, is between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.

The spherical coordinates of the OFF position with respect to the centre of the map shall be within the following range:

d_{1off}: $\pm$(0 arcmin - 2 degree);

d_{2off}: $\pm$(0 arcmin - 2 degree)

The duration t_{off}, of stable pointing in the OFF position is within the range 10 s to 30 min.

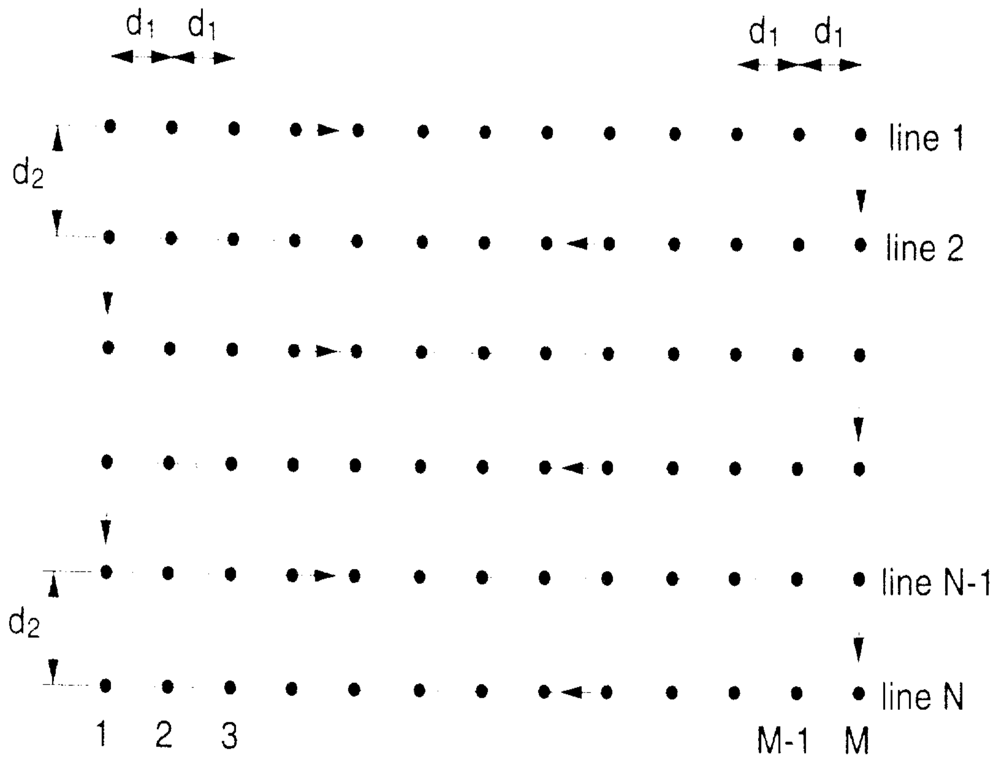

Figure 1 NORMAL RASTER POINTING

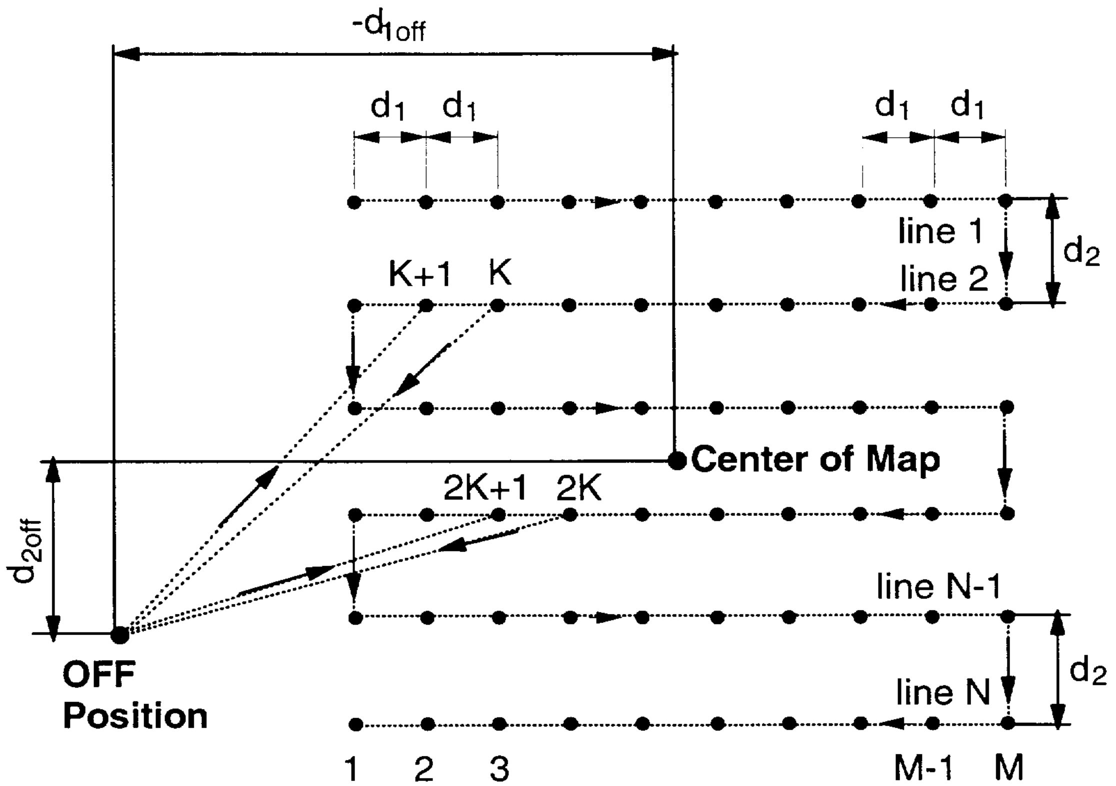

Figure 2 RASTER POINTING WITH OFF-POSITION

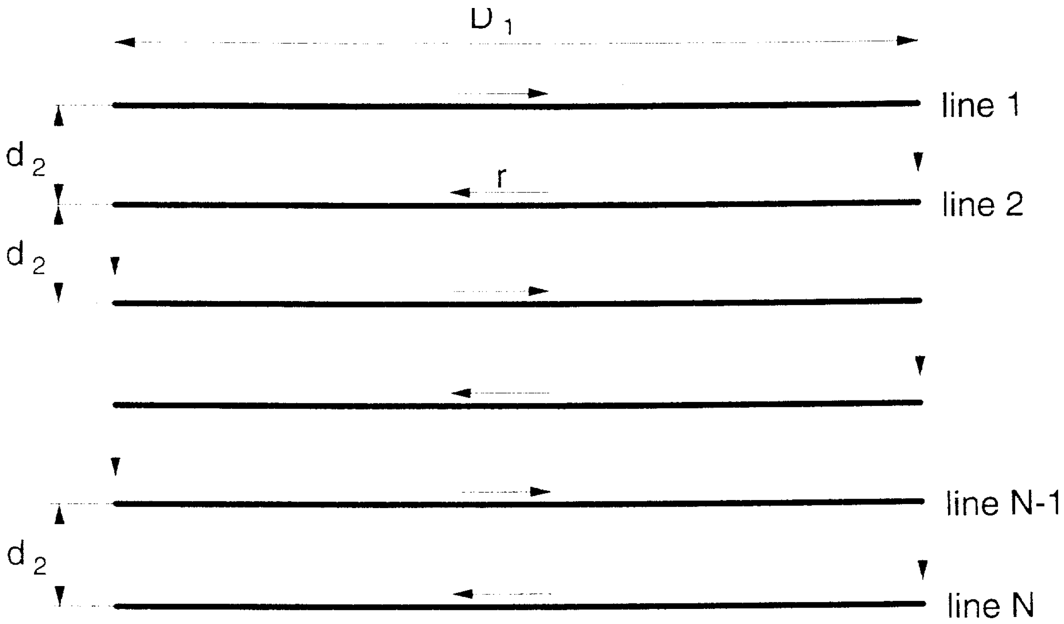

Figure 3 NORMAL LINE SCANNING

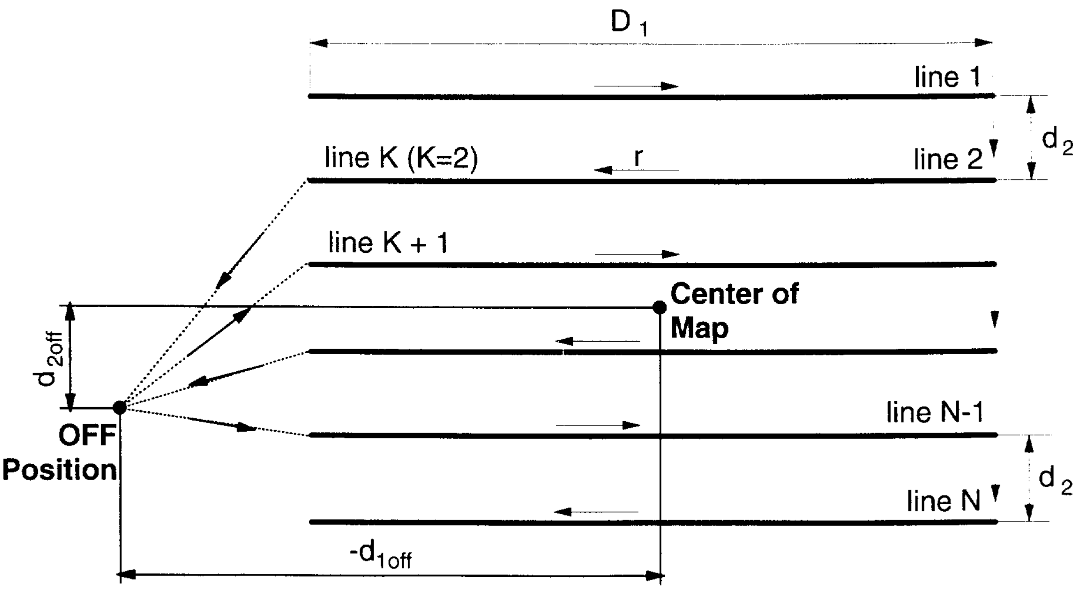

FIGURE 4 LINE SCANNING WITH OFF-POSITION

4 TRACKING OF SOLAR SYSTEM OBJECTS

The satellite shall be able to follow, by ground commanded tables of coefficients of Chebyshev polynoms, objects such as planets, comets, etc. having a maximum speed relative to the tracking star of 10 arcsec/min.

The trajectory of such solar system object will be described by Chebyshev polynomials of at least 3rd order.

The attitude defining the raster (Q_{rast}) (for raster, position switching or nodding) and line scan patterns (Q_{scan}) shall also be possible reference to a solar system object, i.e. the whole pattern moves with the solar system object.

5 POSITION SWITCHING

Position switching is an observing mode in which the instrument line of sight is periodically changed between a target source and a position off the source.

Periodically the telescope pointing direction is changed between a target source and some position off the source.

This is a special case of normal raster pointing with the following raster parameters:

φ:	0 – 180 degrees	resolution:	0.1 degrees
M:	2		
N:	1 - n		
d_1:	2 arcsec – 2 deg;	resolution:	0.5 arcsec
d_2:	0		

The integration times in the "on" and "off" positions are within the range of 10 s to 20 min (depending on the throw).

6 NODDING

Nodding is an observing mode in which the target source is moved from one instrument chop position to the other chop position. In this case the pointing direction will change in the direction of the instrument chopper throw.

Periodically the telescope pointing direction is changed such that the source is moved from one instrument chop position to the other position.

This is a special case of normal raster pointing with the following raster parameters:

φ: 0

M: 2

N: 1 - n

d_1: 2 arcsec – 16 arcmin; resolution: 0.5 arcsec

d_2: 0

The integration times in both positions are equal and are within the range of 10 s to 20 min (depending on the throw).

Herschel / Planck Project

Planck Scanning Strategy

(Annex II to SRS)

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1 INTRODUCTION

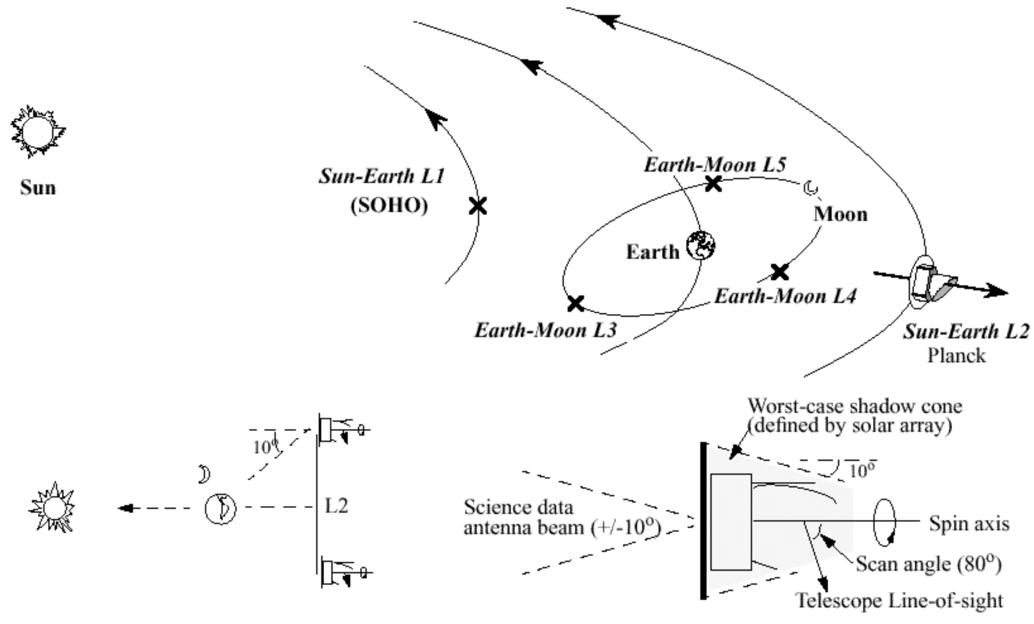
Planck will image the temperature of anisotropies of the Cosmic Microwave Background (CMB) over the whole sky with a sensitivity of $\Delta T/T$ – 2 x 10^{-6} and an angular resolution of – 10 arc-minutes. This objective requires a cryogenic temperature of – 0.1K for bolometers, – 20K for HEMT (High Electron Mobility Transistors) amplifiers, and a cold low emissivity telescope. Planck is the third Medium Size mission (M3) in ESA's long-term scientific plan Horizon 2000.

This document describes the Planck pointing strategy to support the execution of the Planck sky surveys. This document is called up as an applicable document in the Herschel / Planck System Requirements Specification (SRS) SCI-PT-RS-05991.

2 SCANNING STRATEGY

At operational orbit, the Planck telescope defines a sparsely sampled field of view (FOV) approximately 8° in diameter around a reference line-of-sight, which is inclined by 85° from the spin axis. As the satellite rotates, the FOV will trace a circle of diameter 170° on the sky. These circles are referred to as “rings”.

The relevant elements of the orbit and payload configuration are shown schematically in Figure 1. The objective of Planck is to survey the whole sky twice over. By one survey of the sky is meant the coverage by the FOV of at least 95% of the full celestial sphere. The duration of a continuous sky survey depends on the specific value of the scan angle (i.e. the angle between the line-of-sight of the telescope and the spin axis). If this angle is 85°, and observations are uninterrupted, the duration of a sky survey is ~7.5 months (TBC).



Note : In above picture , the Planck Scan angle is indeed 85° (and not 80°).

Figure 1: Relevant elements of the Planck orbit around L2. The maximum Sun-S/C-Earth angle is 10°. The payload must remain in a 10° solar shadow cone defined by the solar array. The Earth must remain within a 10° half-cone angle from the spin axis direction in order to permit telemetry downlink with full bandwidth. The telescope line-of –sight is inclined at 85° from the spin axis, so that the field of view describes a 170° circle on the sky.

In order to carry out its surveys and maintain the payload in the solar shadow, the spin axis of Planck must be displaced on the average by 1° per day in the direction defined by the orbital motion of the Earth around the Sun. This is achieved by spin axis depointing manoeuvres at regular intervals. As the spin axis is displaced, the observed ring also moves and gradually covers a large part of the sky. The set of depointing manoeuvres (defined by amplitude, direction, and time of execution) is referred to as the "scanning law".

The simplest possible scanning law consists of regular manoeuvres to maintain the spin axis aligned with the Sun-S/C direction, e.g. an hourly manoeuvre of amplitude 2.5 arcminutes along the ecliptic plane. This scanning law, which is referred to as the "nominal scanning law", results in less than full coverage of the sky, as two polar caps will remain unobserved for each detector within the FOV (the unobserved areas will be different for each detector depending on its location within the FOV). The diameter of the unobserved polar caps ranges between 10^{o} and 30^{o}. The sky coverage achieved by Planck may be increased by tilting the spin axis away from the ecliptic plane (within the limits allowed by the solar shadow cone and the telemetry antenna), thus allowing detectors to observe the ecliptic poles.

It is important for Planck to be able to remove systematic effects (e.g. instrumental drifts) which contaminate the observations. To achieve this it is necessary to maintain a high level of redundancy, i.e. that a given location of the sky be observed many times (both with short and with long time scale periodicity), with different detectors and with different satellite attitudes. In this respect it may be useful to implement a scanning law which results in each ring crossing many other rings at a range of locations along it. Given the payload configuration, these crossings are clustered at high ecliptic latitudes. However, by tilting the spin axis with respect to the ecliptic plane, the distribution of crossings may be spread over a larger range of ecliptic latitudes.

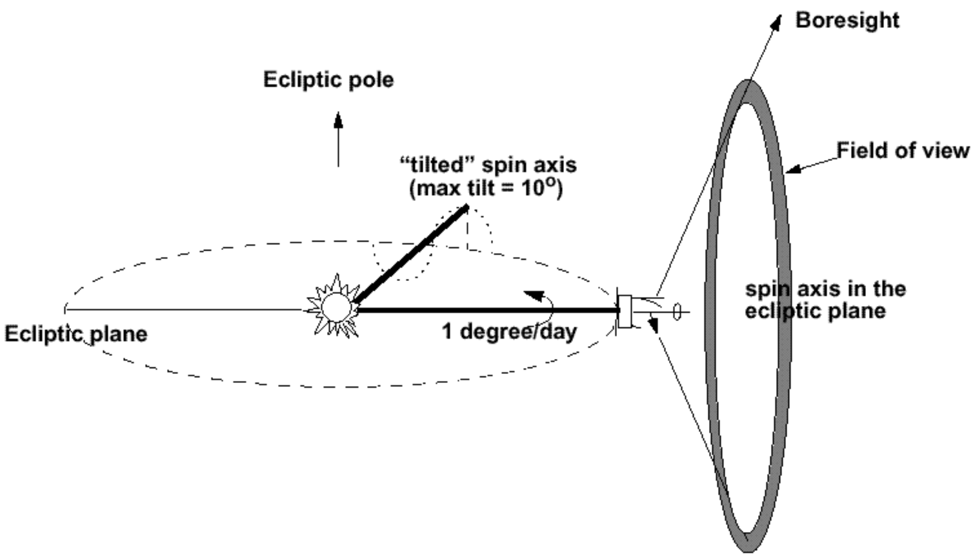


Figure 2: A sketch of the way in which Planck scans the sky. The dashed line indicates the direction of motion of the spin axis for the "nominal scanning law" i.e. along the ecliptic axis, whereas the dotted line shows a possible modification of this law, which increases the sky coverage and the redundancy of the survey.

Therefore, both to increase its sky coverage, and to increase the redundancy over a wider range of ecliptic latitudes, it is likely that the scanning law implemented by Planck will deviate significantly from the nominal one. The specific scanning law to be used will be established by means of detailed simulations during the development of the mission, and may also be modified by tests carried out in flight during the Performance Verification phase. It is also possible that the scanning law used during the second sky survey differs significantly from that used in the first survey. In any case, the scanning law will consist mainly of small modifications of the nominal law, such that the direction of the manoeuvre is out of the ecliptic plane but has a component perpendicular to it. The existence of an out of the ecliptic motion implies that the amplitude of each manoeuvre will be larger than that of the nominal law, and the duration between manoeuvres will be shorter than the nominal one. The motion of the spin axis in the direction perpendicular to the ecliptic plane will accumulate slowly up to a maximum, which will not exceed the limits imposed by the solar shadow and the telemetry antenna. A possible scanning law is sketched in Figure 2.

Herschel / Planck Project

Detectors Characteristics for Planck Straylight Requirements

(Annex III to SRS)

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1 Parameters Defining the Horns

This annex provides the characteristics of the realistic corrugated Horns that shall be used for the evaluation of the Planck straylight analysis.

horn-identifier	x (mm)	y (mm)	z (mm)	phi (deg)	theta (deg)	psi (deg)
HFI 857	0	0	0	0	0	0
HFI 353	-2.74E+01	-5.99E+01	1.50E+02	165.70	30.57093	-1.92
LFI 100	-8.97E+01	8.07E+01	1.18E+02	-156.24	23.90021	1.84
LFI 30	-1.25E+02	1.23E+02	9.08E+01	-141.78	22.32231	2.15

Table 1 the positions of the horns in the global coordinate system

Horn-identifier	taper (db @22 deg)	aperture D (mm)	Beamwidth (deg)
HFI 857	-36	8.2	3.5
HFI 353	-36	8.2	8.4
LFI 100	-30	19.5	11.4
LFI 30	-30	51	15.5

Table 2 Electromagnetic parameters defining the horns