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DOCUMENT

Reference Mission Scenario

Herschel / Planck Project

Prepared by	P. Estaria (SCI-PT)/ D.Patterson (OPS-OF)/ M.Schmidt (OPS-OGH)
Approved by	

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D I S T R I B U T I O N

name	organisation
P. Couzin	ALCATEL
F. Chatte	ALCATEL
P. Rideau	ALCATEL
J. Dodsworth	ESOC
M. Schmidt	ESOC
T. Paβvogel	SCI-PT
L. Aloy	D/TOS
A. Elfving	SCI-PT
S. Thuerey	SCI-PT
F. de Bruin	SCI-PT
I. Rasmussen	SCI-PT
G. Crone	SCI-PT
A. Heske	SCI-PT
J. Marti-Canales	SCI-PT
C. Scharmberg	SCI-PT
O. Piersanti	SCI-PT
G. Pilbratt	SCI-RSSD
J. Riedinger	SCI-RSSD
A. Heras	SCI-RSSD
J. Tauber	SCI-RSSD
K. Galloway	SCI-RSSD
M. McKinnell	SCI-RSSD

C H A N G E   L O G

date	issue	revision	pages	reason for change
15.05.02	1	0		All pages - New Document
20.12.02	2	0		Major rewrite – internal ESA distribution -
21.03.03	2	1		Minor additions / minor updates
02.06.04	3	0		Integration of Instrument Mission Scenarios and updates based on new versions of the MPS, Sub-schedule Usage and Packet Store documents
04.06.04				List of Applicable Documents and Reference Documents updated as per H-P-ASP-MN-4289 v2
07.06.04				Changes according to various e-mail after review within the Science Ground Segment Engineering Groups
06.08.04	3	1		Modifications as agreed during telecon (ALS/ASP/ESOC) on on 16th July (see MoM H-P-ASP-MN-5172)

R E V I S I O N   S T A T U S

Revision Status			Pages affected
Issue/Rev	Date	Approval	
1.0	15.05.02		All (New document) for internal review within ESA
2.0	20.12.02		Major rewrite: Response to PDR RID 8054 and corresponding action AI 8054/1. Comments from A. Elfving (marked up copy – November 2002-) included. Comments from J. Tauber (E-mail 04.11.02) included. Comments from ALCATEL (E-mail 12.11.02 from P. Couzin) *partially* implemented. New distribution list. Purpose and scope of scenario clarified. Ground station network updated. TM and TC data rates updated. Satellite modes and mode transitions updated. FDIR Level 4 cases updated. MTL management updated. HFI-LFI TM bandwidth sharing introduced. LEOP mission scenario updated. Commissioning and PV phase scenario updated: (i) separation spacecraft and instruments; (ii) text improved. DTCP timeline of events updated. Summary of (Herschel) and (Planck) instruments and sorption cooler operating modes added. SOHO-like failure case scenario added. Clarifications on Planck operations: (i) instrument operating parameters updating; (ii) scanning law updating; (iii) degraded mode of instrument operations; (iii) sky coverage constraints; (iv) provision of Planck pointing data by MOC.
2.1	21.03.03		RD11 to RD17 added to the list of RDs. SREM place-holder added (Appendix 7). VMC operations added (Appendix 8) Specific Herschel scenarios added. Herschel instrument operating constraints added. ESOC's comments (C. Watson) implemented.
3.0	02.06.04		See change bars.

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			RD18 to RD26 added to the list of RDs. Details of several ADs and RDs updated. AD6, AD7, AD8 and AD9 deleted as per H-P-ASP-MN-4289 v2 AD10 (CREMA) moved to RD27 as per H-P-ASP-MN-4289 v2 Incorporation of the Instrument Reference Mission Scenarios. Sections 5,6,7 & 8 and App.10. New section 5 for the Instrument constraints and assumptions. Updates to s.3.2 based on new Packet Store Usage document. Updates to s.3.1 based on new Sub-schedules Usage document. Also s.7.1.1 Updates based on new Mission Planning documents. s.7.1 & 8.1 Table for data rates (chapter 2.2) : removed 150 kbps for Downlink to NNO on LGA
3.1	06.08.04		Modifications as agreed during telecon (ALS/ASP/ESOC) on on 16th July (see MoM H-P-ASP-MN-5172): -p 25 TBD removed for number of OBCP slots being 16 ; comments added : OBCP's have lowest TC priority -p18 “time out on ground TC reception” is level 2 failure, not level 4. - p 41;chapter 6.1: separation delays updated with latest availabel figures - Footnote 5 : clarification on operational usage of subschedule in order to resume instrument operations

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1 INTRODUCTION

It had been previously agreed that in order to establish a general framework for the definition of the facilities required to support the Herschel/Planck mission it was necessary to produce, during phase B, a **reference mission scenario.**
This has not proven possible. Many of the elements which are required in order to produce a realistic scenario are still not defined to a level of detail sufficient to produce realistic numbers. In particular there is still much uncertainty in the way the scientific instruments will be operated although, in all cases, the basic operating modes are already defined. The type of commands (elementary commands, high level functions, on-board procedures), the number of commands required to carry out a specific operation, as well as the command rate still need to be defined. Elaboration of the reference scenario is therefore seen as an iterative process, the scenario being refined and made more 'real' as detailed knowledge improves. The first iteration will aim at 'dimensioning' the overall system in such a way that confidence can be gained at an early stage that the end-to-end system will cope with the real mission profile even when important parameters, e.g. instrument sensitivity, instrument scheduling constraints, etc. will change.

This Technical Note is an attempt to provide a general framework for such a scenario. It is based on data currently available from Industry, ESA and the PI-teams. It takes into account the current status of the instruments and the satellite design.

1.1 Purpose

The reference scenario's purpose is to:

- Provide a basis for the sizing of the Mission TimeLine (MTL) and other on board resources (e.g. On-Board Control Procedures -OBCP's-, mass memory, etc.).
- Provide a basis for the sizing of the ground facilities required to support both Herschel and Planck.
- Provide a basis for the definition of Herschel and Planck Ground Segment Tests (in particular the End-to-End Tests) and to the Simulations' programme.
- Provide a basis for the elaboration of spacecraft and instrument Flight Operations Procedures (both 'nominal' procedures and Contingency Recovery Procedures [CRP's])
- Provide a reference against which specific tests should be conducted to demonstrate the system performance under realistic operational conditions.
- Provide a model for the assessment of the satellite commanding characteristics.

- Provide a model for data collection, storage and downlink
- Provide a reference against which the functionality and performance of the On-Board Software (OBSW) can be assessed throughout the software development cycle
- Provide a tool to identify performance bottlenecks and driving requirements

1.2 Scope

This document covers both Herschel and Planck.

Because the two mission models are quite different, i.e. an "open observatory" for Herschel and a "survey" PI-type mission for Planck, the overall scenario includes two scenarios: (i) The Herschel reference mission scenario; (ii) The Planck reference mision scenario.

Since the Herschel operations are more complex than the Planck operations and the corresponding requirements on on board resources more demanding the emphasis is put on Herschel in the current version.

It is expected that the reference mission scenario remains a living document which will be regularly updated. It will become a Reference Document to the System Requirements Specification (AD1).
The reference mission scenario will, therefore, not contain specific, numbered requirements which must be formally traced. It is, clearly, not intended to replace the SRS.

The spacecraft (and ground segment) designs must, obviously, be compliant with the absolute worst cases stated in the SRS. The (Herschel and Planck) reference scenarios should, however, provide a means to avoid designing against totally unrealistic mission models.

Each (Herschel and Planck) scenario will contain a number of lower-level specific scenarios covering the most likely operational situations. The level of detail for each scenario will increase as definition progresses. The individual scenarios will fall into three distinct categories:

- nominal case scenarios (covering a limited number of representative operational situations)
- failure case scenarios (e.g. the SOHO failure cases – 2 cases- included)
- 'extreme' case scenarios (TBC) whose purpose will be to 'push' the system to its limits in specific areas, e.g. TM burst mode handling, event handling, command handling, etc.

As the programme progresses scenarios will be added (or removed) from the Herschel and Planck overall scenarios.

In principle each nominal case scenario will be a "pseudo coded" typical timeline which indicates:

- the on-board operations as defined by the MTL
- the ground operations as commanded by the MOC

over the unit time duration, i.e. 48 hours. Failure (and extreme case) scenarios may or may not involve the MTL. The nominal scenarios will contain the "mission-related" information which is ESA's responsibility. Industry may have to derive the associated, detailed, spacecraft operations.

It is also expected that ALCATEL, as responsible for the overall system engineering and validation, will define, as required, and in agreement with ESA, some of the failure and 'extreme' case scenarios.

In the case of Herschel, in a typical scenario, the timeline will contain a series of "observations", allocated, as appropriate, to various sub-schedules. For each observation the following mission-related information is expected:

- (initial) pointing information (e.g. RA and Dec)
- pointing mode (e.g. fine pointing, raster, line scanning, nodding, etc.)
- instrument mode (and/or AOT)
- observation duration
- etc.

To exercise the overall system robustness over time, as a minimum, a 'soak' test of 48 hours duration will be included for both Herschel and Planck.

For both Herschel and Planck the **nominal** case scenarios will address the **routine** phase of operation i.e. when the instrument are switched on and producing scientific data corresponding to a "normal" mix of operations.

From these scenarios individual 'test cases' shall be derived. These test cases shall be, to the maximum extent possible, exercised at various stages of the AIV activities. These tests must therefore be planned in advance and fully integrated into the corresponding AIV test sequences taking the overall test planning and programmatic constraints into account.

Special modes of operations e.g. **survival** mode (satellite in Autonomous Fail Safe –AFS-) are not considered in detail since they are not driving in terms of resources required.

Similarly the transfer phase to L2, during which the commissioning of spacecraft and instruments as well as part of the Performance Verification (PV) phase are performed is not covered in detail. Extended ground station coverage (minimum 10 hours per day) is available and both New Norcia and Kourou are used. Most of the operations are done manually at a slow pace. They put minimum demands on the overall system resources (satellite and ground)

1.3 Applicable Documents

AD1: System Requirements Specification (SRS)
AD2: Operations Interface Requirements Document (OIRD)
AD3: Packet Structure ICD (PS-ICD), Issue 4.0, 07-November-2003
AD4: Space-to-Ground ICD (SG-ICD)
AD5: System Operations & FDIR Requirements (Alcatel), Issue 4.3, 27-November-2003
AD6: deleted
AD7: deleted
AD8: deleted
AD9: deleted
AD10: deleted

1.4 Reference Documents

RD1: Herschel Operations Scenario Document:
RD2: Planck Operations Scenario Document:
RD3: (Herschel) HIFI IID-B Issue 3.1, 13-January-2004
RD4: (Herschel) Operating modes of the PACS Instrument, 30-September-2003
RD5: (Herschel) Operating modes of the SPIRE Instrument, Issue 3.0, 4-January-2002
RD6: (Planck) HFI IID-B Issue 3.0, 03 October 2003 (no ops manual available)
RD7: (Planck) LFI IID-B Issue 2.1, 01 July 2002 (no ops manual available)
RD8: Ground Segment Review Plan
RD9: On Board Master Schedule size for Herschel (TN)
RD10: Autonomy, OBCP concepts and Requirements (TN)
RD11: On the use of the Herschel / Planck Mission Time Line (TN), SCI-PT-16783
RD12: Satellite States at Launch (TN)
RD13: Herschel Instruments Scheduling Schemes (TN)
RD14: Herschel Instrument Operating Constraints (TBW)
RD15: SREM ICD Issue 1, Revision 4
RD16: SREM User Manual Issue 1, Revision-
RD17: (Rosetta) SREM S/W Users Requirements Document v005
RD18: Intended Operational Usage of Sub-Schedules, PT-CMOC-OPS-TN-6605-OPS-OGH
RD19: Herschel Mission Planning Concept, PT-HMOC-OPS-TN-6601-OPS-OGH
RD20: Planck Mission Planning Concept, PT-HMOC-OPS-TN-6602-OPS-OGH
RD21: Scanning Strategy Reference Document Issue 0.4, 06 November 2003
RD22: Planck 18/20 K Hydrogen Sorption Cooler Operations Document Issue 0.1, 24 October 2003
RD23: Planck Survey Performance and Planning Tool URD Issue 0.4, 06 February 2004
RD24: Planck GS Low Level ICD Issue 0 Draft A, Planck/PSO/2003-007 27 April 2004
RD25: Herschel POS-ICD, HERSCHEL-HSC-ICD-0377, Issue 0.2, 05 April 2004
RD26: Packet Store Usage on Herschel/Planck, PT-CMOC-OPS-TN-6603-OPS-OGH
RD27 Consolidated Report on Mission Analysis (CReMA)

2 MAJOR MISSION FEATURES (HERSCHEL & PLANCK)

In order to put the mission scenario into context the major mission characteristics are briefly summarised below. The description applies to both Herschel and Planck (commonality feature).
Details can be found in AD3 and AD5.

2.1 Ground Station Network

The ground station network allocated to the support of the required TM, TC and Tracking links will be as follows:

Station	LEOP	Transfer L2	Commissioning	PV	Science
Kourou 15m	Yes	Yes	Yes	Partly	No
Villafranca 15m	Yes	No	No	No	No
New Norcia 35 m	Yes	Yes	Yes	Yes	Yes

In case of emergency the Villafranca station (VILSPA 2) may be requested during any phase of the mission.

2.2 Telemetry and Telecommand data rates

The following TM and TC rates will be supported From New Norcia and Kourou using the spacecraft Low Gain Antenna (LGA) or Medium Gain Antenna (MGA).The LGAs provide hemispherical coverage in such a way that Telecommanding and Downlink of TM are possible in any spacecraft attitude.

Uplink	**X-Band**		
	LGA	**LGA**	**MGA**
Kourou 15 m	125 bps	4 kbps[1]	4 kbps
New Norcia 35 m	4 kbps		4 kbps
Downlink	**X-Band**		
	LGA	**LGA**	**MGA**
Kourou 15 m	500 bps	5 kbps[2]	150 kbps
New Norcia 35 m	5 kbps		1.5 Mbps

[1] Up to 350. 000 kms

[2] Up to 750.000 kms

These rates will be achieved without the need to implement turbo-coding and for a Planck "orbit size" of up to15 deg. [3]

The various data sources on-board will be allocated Virtual Channel (VC) numbers to identify them to the ground processing facilities as follows:

VC0 Real Time essential spacecraft HK and critical instruments HK
VC1 Real Time Science data
VC2 Stored Spacecraft HK and instrument HK (periodic and non-periodic)
VC3 Stored Science data
VC4 Real Time routine spacecraft HK and routine instruments HK (periodic and non-periodic)
VC5 Not required
VC6 Not required
VC7 Idle frames (A full frame where the data field is filled with random data)

It will be possible to downlink any combination of VC's independent of the selected bit rate.

If a VC frame is not completely filled with real data, the VC frame shall be filled up with one (or more) idle packets and sent before VC7 begins to send idle frame..

The priority scheme for downlink of VCs will be: VC0 > VC4 > VC2 > VC1 > VC3 > VC7

2.3 Spacecraft Mode Definitions

In defining the spacecraft modes identified below the emphasis has been put on the operational context and the corresponding on-board services. The **S/C Nominal** mode covers all science operations and "nominal" maintenance operations such as spacecraft and instrument commissioning and performance verification, orbit injection and maintenance, etc. The other four modes are support modes to ensure proper (pre-) conditioning, transition or recovery. The **Launch** mode is an "inactive" state where both the CDMU and ACC software are waiting for detection of the separation, however S/C HK packets (e.g. thermistor readings, PCDU and CCU status, ACC status etc.) are generated by the CDMU and the ACC and stored in SSMM. The **S/C Earth Acquisition** mode and the **S/C Survival** mode are not used under any nominal conditions but are available for recovery actions as a result of CDMS level 3 and 4 alarms respectively. Upon transition to S/C Earth Acquisition, the spacecraft shall slew to a ground programmed attitude stored on-board. For Herschel the slew to reach this attitude will use a "dog-leg" to bring Earth within the MGA coverage. For Planck the programmed attitude will be restricted by the

[3] Communication with Kourou at medium-speed rate (150 kbps) and 16 dBi requested MGA gain requires re-pointing of the MGA when the Earth Aspect Angle (EAA) is above around 10 degrees. This will occur during the operational orbit at L2, as well as during certain periods of the transfer phase to L2. Even for Planck this is not considered to be a problem since medium speed rate does not correspond to nominal scientific operations.

sun aspect angle and may not ensure MGA coverage from Kourou under all extreme orbit positions. The **S/C Sun Acquisition** mode is part of the nominal transition after separation from the launcher, however later in the mission this mode is not used under any nominal conditions but is available for recovery actions as result of ACMS alarms.

Mode \ Service	Default Tx	Default Rx	Default TM generation	MTL	ACMS	Instruments
Launch	Off	LGA1 - 0.125 (MGA - 0.125)	VC0: Essential S/C HK VC4: Other S/C HK	Off	SBM	Off
S/C Sun Acquisition	LGA1 – 0.5/5	LGA1 - 0.125 (MGA - 0.125)	VC0: Essential S/C+P/L HK**/* VC4: Other S/C+P/L HK	CDMS only	SAM or SM	Off or Stand-by
S/C Nominal	MGA - 150	MGA – 4 (LGA1- 0.125)	VC0: Essential S/C+P/L HK VC4: Other S/C+P/L HK VC1: Real time science data	Full	NOM/OCM	Any state
S/C Earth Acquisition	MGA - 150	MGA – 4 (LGA1- 0.125)	VC0: Essential S/C+P/L HK VC4: Other S/C+P/L HK	Suspended	NOM	Off or Stand-by
S/C Survival	LGA1 – 0.5	LGA1 - 0.125 (LGA2- 0.125)	VC0: Essential S/C HK** VC4: Other S/C HK**	Suspended	SAM or SM	Off

"Service" represents an on-board function, which is required to have a certain capability depending on the spacecraft mode. Power and Thermal control are not identified as services in the current table as it is expected that these functions shall be identical for all spacecraft modes. The need for replacement heater in case major dissipating elements are switched-off, e.g. SCS, should be a mode independent function of the TCS.

"Default" represents what is "coded" in the on-board software and how the system shall behave upon a transition into this mode. Alternative configurations, e.g. different transmitter or receiver settings, can be achieved by commands, either direct from ground or via MTL.

"Default Tx" represents the default configuration of the transmitter (by default the transmitter shall be ON at mode entry) and associated antenna

- LGA1 – 0.5 means 500 bps via LGA1 (Kourou and New Norcia compatible in any attitude)
- LGA1 – 0.5/5 means default 500 bps via LGA1 but configured to 5 kbps at separation since this is compatible with New Norcia in any attitude and compatible with Kourou and Vilspa up to a distance of 770000 km after launch in any attitude
- MGA – 150 means 150 kbps via MGA (Kourou and New Norcia compatible in Earth pointing configurations)

"Default Rx" represents the default configuration of the prime (and redundant) receiver and associated antenna

- LGA1 – 0.125 means 125 bps via LGA1 on primary receiver (Kourou and New Norcia compatible in any attitude)

- (LGA2 – 0.125) means 125 bps via LGA2 on redundant receiver (Kourou and New Norcia compatible in any attitude)
- MGA – 4 means 4 kbps via MGA (Kourou and New Norcia compatible in Earth pointing configurations)

"Default TM generation" represented the house keeping telemetry which shall be generated by default

- Essential S/C HK means a set of TM packets that sufficiently report on the S/C status in its configuration for the relevant spacecraft mode to ensure ground assessment of S/C health and status.
- Other S/C HK means all other S/C HK data to enrich the understanding of the actual performance of the S/C.
- Essential P/L HK means a set of TM packets, which sufficiently report on the instrument status for the relevant instrument mode to ensure ground assessment of instrument health and status. In particular for Planck this shall include the essential HK from the fully operational cooling chain. It has been agreed with the instrument providers that this shall not exceed 1 kbps split equally between SPIRE, PACS and HIFI on Herschel and LFI, HFI and Sorption Cooler on Planck.
- Other P/L HK means all other instrument HK to enrich the understanding of the actual performance of the instruments (and coolers).

* The VC0 content shall not exceed 5 kbps. With the ACMS in SAM or SM mode it is expected that the Essential S/C HK will not exceed 4 kbps.

** The VC0 content shall not exceed 0.5 kbps. A possibility is to sub-sample the Essential HK data by 1/11..

"MTL" represents if the MTL is active or not and if yes which "sub-schedules" are active

- CDMS only means that only the functions and devices handled by the CDMU are acted upon by the MTL
- Full means that all sub-schedules including instruments can be active
- Suspended means that upon mode entry no commands are issued from the MTL

"ACMS" represents the ACMS mode(s) applicable for the spacecraft mode:

- SBM means Stand-By Mode and is solely used while waiting for launcher separation
- SAM means ACMS Sun Acquisition using nominal hardware
- SM means ACMS Survival Mode using independent hardware
- NOM means Nominal Mode, for Planck this includes also the HCM (Angular Momentum Control Mode)
- OCM means Orbit Control Mode used to perform delta-V corrections

"Instruments" represents the configuration of the instruments

- Off means everything is off, even the cooling chain of Planck. However in launch mode the 4K launch lock is active.

- Stand-by means that the instrument(s) are in stand-by and for Planck the cooling chain is fully operational. Upon a transition into the spacecraft mode, the instruments that were already ON (or in stand-by) in the previous mode shall be maintained in stand-by.
- Any state means that the instruments may be either off, in stand-by or fully operational according to the MTL

2.4 Spacecraft Mode Transitions

The following spacecraft mode transitions can be identified and shall be controlled by the CDMS:

Transition To / From	Launch	S/C Sun Acquisition	S/C Nominal	S/C Earth Acquisition	S/C Survival
Launch	S	A[2]	X	X	X
S/C Sun Acquisition	X	S	C[1]	X	A[1]
S/C Nominal	X	A[3]	S	A[4]	A[1]
S/C Earth Acquisition	X	A[3]	C	S	A[1]
S/C Survival	X	C[2]	X	X	S

A[1]: Transition upon (OR):
- reception of a CDMS level 4 alarm (“SIR”)
- restart after a PCDU “Bus Under Voltage” reset (power ON/OFF of CDMU and ACC)
- command (TC)

A[2]: Transition upon (OR):
- detection of separation switches open
- command (TC)

A[3]: Transition upon (OR):
- reception of an "AIR" message (issued by ACC after detection of an ACMS level 4 alarm)
- reception of a "transition to SAM" message from the ACC (issued by ACC after detection of some ACMS level 2 or 3 alarms)
- command (TC)

A[4]: Transition upon (OR):
- detection of a CDMS level 3a or 3b alarm (“CIR”)
- command (TC)

C: Transition by Command (TC) only
C[1]: Transition allowed only if ACMS is in SAMC[2]: Transition shall include ACMS transition into SAM
X: Transition not allowed
S: Mode self transition, will restore default configuration. Should be available by Command (TC).

2.5 Failure Detection Isolation and Recovery (FDIR)

In order to allow the spacecraft to recover from anomalies of various levels of severity an overall system FDIR has been defined for the spacecraft. The system FDIR is a shared responsibility of the CDMS and the ACMS. For both subsystems surveillance is based on a combination of hardware-related and software-related detection and reconfiguration. The major features of the spacecraft FDIR are summarised below:

- Failures detected at the “lower” levels shall be prevented (isolation) to propagate to the higher levels i.e. recovery shall always be attempted at the lowest level possible (component, module, unit).
- Failure recovery is carried out by switching from a failed configuration to a known back up configuration.
- The failure context is stored on board in order to support subsequent ground investigations.
- Any failure detection, isolation and recovery mechanism can be individually disabled by ground command.
- The main objective of the FDIR is to carry on with the (scientific) mission whenever the satellite integrity is not compromised. Spacecraft and instrument safety remain the overriding concern.
- Two FDIR modes are defined in order to support this philosophy:
    - Autonomous Fail Safe **(AFS)** where the priority is to ensure safe status of spacecraft and instruments.
    - Autonomous Fail Operational **(AFO)** where the emphasis is on continuation of the science mission after a failure as long as an healthy alternative functional path exists (redundancy).

AFO thus aims at minimising science outage. It maintains the continuity of the mission timeline. It implies more complex reconfiguration strategies. Satellite safety remains the top level requirement.

In order to implement a clean hierarchical reconfiguration strategy 5 FDIR levels are specified (Level 0 to Level 4). The levels are characterised by: (i) failure criticality; (ii) recovery sequence; (iii) function involved in the detection (H/W or S/W functions)

The 5 levels are briefly listed below (by increasing degree of severity):

Level 0:
A level 0 failure is associated to a single failure in one equipment unit (e.g. gyro, Star Tracker, EDAC single bit error, etc.) which can automatically be recovered by the unit itself without impact on the system.

Level 1:
Two sub-levels are defined:

- Level 1a: unit-level failure, e.g. ACMS sensor failure, ACMS actuator failure, PCDU failure, TTC transponder failure, etc. detected by the ACMS or CDMS computer. Surveillance of the unit is performed by the corresponding ACMS S/W or CDMS S/W via simple health check and the recovery action is initiated by the same S/W. These failures are single application related.
- Level 1b: failure at communication level, i.e. failure on the 1553 bus such as bus coupler failure, bus protocol errors, I/O timeout, etc. These failures are considered multi application related.

Level 2:
Failure related to a spacecraft vital function e.g. ACMS, RCS failure with inability to maintain proper pointing, failure of the thermal control system, timeout on ground TC reception, etc. The objective is to detect these failures which could not be identified at level 1 and to process them before they turn into a higher level system failure with serious impacts on the mission. Level 2 failure detection and recovery is carried out, depending on the failure, by the CDMS or ACMS S/W.

Level 3:
Internal (CDMU or ACC) processor failure that the processor cannot recover by itself. Typical examples are: EDAC double error, Protected Memory (PM) bus error detected by H/W, Memory protection violation detected by H/W, failure detected by a H/W watchdog, CPU instruction error detected by S/W. Detection is by either H/W or S/W while the recovery is performed by H/W via the ACC or CDMU Reconfiguration Modules.
The first occurrence of these alarms correspond to Level 3a failures, the second occurrence to Level 3b failures. Level 3a failures lead to a reset of the corresponding processor or unit, Level 3b failures lead to a switch to the redundant processor or unit. For the ACMS, this latter case is to be treated as a Level 4 failure mode.

Level 4:
All failures that cannot be detected and recovered by the lower levels (0 to 3). The failure induces global system malfunction. The OBSW is not involved in Level 4 failure detection and recovery.
Detection is carried out by specific system alarms hardwired to the CDMU and ACC Reconfiguration Modules (CDMU_RM and ACC_RM)

Typical examples of level 4 (system alarms) failures.

- Loss of sun pointing (SP), spacecraft angular rate too high.
- Battery depth of discharge (DOD) too deep.
- ~~Time out on ground TC reception (TBD)~~

Level 4 detection and recovery lead to entry into AFS. Level 4 detection and recovery within the ACMS lead to entry into the S/C Sun Acquisition mode with the ACMS in Survival mode. Level 4 detection and recovery within the CDMS lead into the S/C Survival mode with the ACMS in Sun Acquisition mode.

The table below summarises the various failure levels.

Failure Level	Failed Unit or Function	Detection principle
0	Any	By unit itself
1a	Equipment failure	By OBSW. Simple health check
1b	Communication failure	By OBSW. Communication protocol and bus coupler monitoring
2	Main function failure. Performance anomaly	By OBSW. Function performance monitoring
3a	CDMU or ACC failure. **First occurrence**	Processor H/W alarm or S/W watchdog
3b	CDMU or ACC failure **Second occurrence**	As above
4	Global satellite malfunction	H/W system alarms

There is an agreement with the PI-groups that the Herschel and Planck instruments will adopt the same general FDIR philosophy. There is no requirement to use the same level breakdown than for the spacecraft but the instruments are expected to identify 2 FDIR modes as seen from the spacecraft (equivalent to AFO and AFS). Internal instrument FDIR is under the responsibility of the instrument (considered as Level 0 failure for the spacecraft). Instrument failures identified by the spacecraft e.g. via on-board monitoring, or reported to the spacecraft by the instruments e.g. via events are considered Level 1 by the spacecraft. No reconfiguration is attempted (instrument switched OFF or put into "standby") for the AFS mode. Instrument reconfiguration takes place via OBCPs (implementation according to a specific sequence to be defined by the instruments) for the AFO mode.

3 AUTONOMY

Herschel and Planck will be operated for most of their lifetime without ground support. This autonomous mode of operations has a fundamental impact on the spacecraft design and the mission scenario. In addition to the FDIR feature, the concept of a Mission Timeline (MTL), the existence of on-board data storage, the Solid State Mass Memory (SSMM), and implementation of On-Board Control Procedures (OBCPs) are the means to support autonomy. They are described below. AD3 (PS-ICD) provides the "services" required to support these features[4].

3.1 The Mission Timeline (MTL)

The "On-board Scheduling" Service (Service Type 11 in AD3) provides the capability to execute a sequence of time-tagged Telecommands from the MTL. Normally almost all commanding activities in the routine phase will be executed via the MTL, independent of whether the spacecraft is in visibility of the ground or not. The detailed structure of the MTL is not yet defined. It is expected however that the MTL will not be a long list of elementary Telecommands to spacecraft and instruments but will contain essentially instructions to activate spacecraft and instrument high level functions or macro-commands, start execution of OBCPs, and execute elementary spacecraft or instrument TCs.

The MTL is managed by the CDMU. The corresponding commands are passed after processing, at the requested execution time, to end-users identified by their Application Identifier (APID). The accuracy of the MTL execution is 1 sec. Commands loaded in the MTL with the same execution time will be executed in the order they are recorded in the MTL.

The MTL supports the concept of sub-schedules (RD11 & RD18). Sub-schedules will play a central role in the Herschel (and Planck) commanding concept. They will allow the definition of self-contained sets of "operational units" which should make possible the re-synchronisation of operations when, for some reason, the MTL will have been suspended in order to correct a problem. Sub-schedules can be enabled or disabled, or otherwise controlled, without affecting the rest of the MTL.[5]

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[4] Although not strictly dedicated to the direct support of the autonomy, PS-ICD services # 8 (function management), # 12 (on-board monitoring), and # 19 (event/action) can be used in connection with the MTL, SSMM and OBCPs to support autonomy. Most of these services are available to the instruments. These are covered in detail in AD3.

[5] Sub-schedules are introduced in order to be able to resume the MTL after a failure recovery in AFO. The current (executing) sub-schedules are stopped for any level 3 & 4 failure at spacecraft level or upon request from one of the instruments. It is further assumed that once an OBCPs is started a change of status in the originating sub-schedule or overall MTL service shall not affect it. In the general case, the instrument status when the sub-schedule is stopped is not predictable. This implies that the instruments must take into account that they can be held in any of their modes. It is not safe to restart an interrupted sub-schedule. The instruments must, therefore, upon interruption of a sub-schedule carry out the necessary steps to ensure that they are in a "safe" state, ready to resume operations at the next possible opportunity. ~~This may imply some support from the CDMS~~ . Since the MTL cannot be time-shifted any interrupted sub-schedule is lost. The MTL is resumed at the start of the first sub-schedule which follows the recovery action. For further information on sub-schedule handling refer to [RD18]

It must be pointed out that, when ground contact is possible, "maintenance" operations on the MTL loaded on board shall be possible i..e. it should be possible via ground commands to enable/disable MTL commands, insert/delete TCs in the MTL, obtain MTL contents reports, etc. (via PS-ICD "service"11).

Additionally, Service 11 provides the means of inserting and deleting TCs in the MTL and to report its content (full report or summary only). While insertion is on a single command basis, deletion allows to delete a set of commands addressed to a given APID or commands fulfilling a specific (TBD) "filtering criterion", or to delete all the commands in the MTL between times t1 and t2.

It is possible to suspend/resume MTL execution by ground command.

ESOC have carried out an estimate of the size of the MTL for Herschel. The main conclusion is that taking into account an uplink overhead of about 40%, a maximum TC uplink rate of 4kbps and an allocation of maximum one hour to uplink a 48-hour MTL[6], the maximum MTL size should not exceed 1.360 Mbytes.

The MTL will not continue after a reboot or switchover of CDMU. In case of an ACC reboot or switch-over (ACMS failure level 3 or 4) the sub-schedules for the ACMS and instruments will be stopped

Although the MTL should be the major source of commands addressed to the various spacecraft sub-systems and instruments (in particular during the autonomy period), there are at least 5 possible sources of commands[7]:

- Ground (during DTCP or outside DTCP in case of emergency)
- MTL
- Actions as result of on-board events (service 19) –FDIR-
- On-Board Software
- OBCP

The management of these different sources has to be carefully considered, particularly for conflict resolution and priority assignment. FDIR has clearly the highest priority, but there shall never be a situation where the ground is "locked out" from commanding. It might be necessary for the ground in

[6] There will normally still be at least enough commands for 24 hours of activities on-board at the beginning of the DTCP. During the DTCP the ground will uplink commands for the subsequent 24 hours period. This is in order to have 48 hours of autonomous operations. Loading a 48-hour MTL would be necessary in case a DTCP is missed. In such a case a full 48-hour schedule would have to be uplinked at the next DTCP.

[7] Commands (regardless of their source) are of two types: (i) HP commands executed without on-board SW support; (ii) "nominal" commands supported by CDMS software.

order to recover from unforeseen anomalies and dead lock situations to be able to disable some FDIR functions temporarily[8].

In the nominal case the MTL will execute continuously, even during ground contact. During the scheduled DTCP, there may be fewer commands executing on the MTL, but the MTL will continue to execute.

It will be essential during the AIV activities to perform a series of tests using the MTL. This will ensure that the nominal way of operating the satellite is properly tested on ground. At both AVM and PFM test levels one should foresee a test covering at least the execution of a representative 2-hour MTL (TBC).

The FDIR should be enabled throughout system testing, independently of the way it is implemented (hardware, software, OBCP, etc.)

3.2 Solid State Mass Memory (SSMM)

The "On-board Storage and Retrieval Service" (Service Type 15 in AD3) provides the facilities required to manage the Packet Stores.

At all times, even during the DTCP when the spacecraft is communicating with the ground, all data (TM and other data) are stored in the SSMM.

The SSMM is organised in several Packet Stores. The TM data is stored into (and retrieved from) the Packet Stores according to a few basic criteria which can be modified according to the mission profile. The basic concept is to organise the Packet Stores in such a way that the critical HK TM (e.g. event packets) can be dumped first during the DTCP. Packet Stores can be defined to be circular or linear with an upper bound. From an operations point of view circular buffers with overwrite are preferred.

Several possible organisations of the Packet Stores are possible. The current baseline is to allocate per observation period (typically 24 or 48 hours):

- (Planck) one store per instrument for science data plus one for LFI Calibration Science
- (Herschel) one store for the science data
- one store for the Non-essential HK TM
- one store for the Essential HK TM
- one store for spacecraft events and TC verification

Combined with the use of sub-schedules this organisation allows to easily select particular events/observations for downloading. It is thus very flexible. The current baseline for the number of Packet Stores is 5 for Herschel and 7 for Planck. See Packet Store Usage on Herschel/Planck [RD26]. In this document each Packet Store has been defined to be large enough for 50 hours at maximum

[8] With release 4.0 of the PS-ICD the TC source identifier of 000bin for ground commands, having the highest priority, has been introduced

nominal mean rate for Herschel and 51.5 hours for Planck. During the PV phase there will be observations of the instruments detectors and data compression algorithm tests to confirm the validity of the science packet store allocations or to determine a resize as necessary. Although routine Packet Store resizing will not be performed[9], it may occasionally be necessary based on in-flight experience. The timescale for re-allocation is days. Each instrument is responsible not to overfill its own data allocation.

3.3 On Board Control Procedures (OBCPs)

A satellite that is going to spend most of its lifetime operating autonomously, while generating meaningful mission products, must to some extent rely on OBCP's.

The fundamental paradigm underlying the use of OBCPs is the "Operator in the sky" concept. For a spacecraft in continuous contact with the ground the operator (SPACON) constantly monitors via the relevant Flight Control Procedure (FCP), the behaviour of the spacecraft by looking at specific TM items, and sending via the FCP the TCs necessary to react to the on-board events reflected in the TM. In an autonomous spacecraft this role is taken over by a combination of FDIR and OBCPs.

Another crucial aspect of OBCPs is the flexibility they provide to adapt to unforeseen behaviours of the spacecraft.
They provide a higher degree of autonomy and a more flexible way of changing the functionality of the software than the traditional software "patching" mechanism.

An OBCP is a high level task (which can correspond to one or more software tasks) and that can be changed by the operations team without having to change the "core" OBSW.
The requirements for OBCPs are specified in AD2 and RD10. OBCPs are implemented in a "Spacecraft Control Language" (SCL), which is, compared to a traditional programming language, much simpler, in the sense that it allows relatively simple constructs. The SCL can be easily mastered by test engineers who are non-programmers.
Briefly the SCL contains reference to TM parameter values, pre-defined limits, simple functions, comparisons, Boolean logic, IF, THEN and ELSE statements, and other logical switches. An OBCP can refer to data in a "data pool" (global variables), which is managed by the CDMU. OBCPs can send Telecommands and call other OBCPs. An OBCP can also send TM packets such as event reports or exception packets.

The major objectives of OBCPs are listed below:

- Allow the response to a monitoring item to include flexible, pre-defined logic that can be updated by the Flight Control Team when necessary.
- Reduce the number of Telecommands that are needed in the MTL.

[9] Every time a packet store is resized the data in the store is lost if it has not already been downlinked.

- Provide a standard “Application Programming Interface” (API) that can be called from the planning system, in order to harmonise interfaces e.g. for instruments although they behave in very different ways.
- Provide an easy way to change spacecraft behaviour without having to resort to the expensive On-Board Software Maintenance (OBSM) mechanism[10].

Herschel/Planck has Monitoring and Event/Action services (AD3). These can be combined so that a change in status of a parameter, or an Out Of Limit (OOL) condition (both detected by the monitoring service) can result in a telecommand to be sent. This could be a simple telecommand (e.g. switch heater off) or a more complex action such as “Perform a Function” or “Run an OBCP”. The Function is hard-coded in the OBSW (although the set of parameters which can be provided to the Function allows a certain flexibility). The OBCP on the other hand provides the maximum flexibility and ease of change if the action needs to be modified post-launch based on operational experience. OBCP’s could thus provide a means to override baseline “Actions”. The “Action” to be triggered if Monitoring detects an anomaly condition could be hard-coded in the software, in particular if it is unlikely to change, but a mechanism could be installed which would allow to override the baseline action by an OBCP. This should be decided on a case by case basis. OBCPs should run in the background with a somewhat reduced priority. They should not be used when precise timing constraints or short reaction times are applicable.

EURECA had around 250 OBCPs. Rosetta has of the order of 200 OBCPs. Based on this experience and on Herschel/Planck mission profiles it seems reasonable to assume an absolute upper limit of 200 OBCPs for Herschel[11]. Many should be common to both. The maximum size allocated to a Rosetta OBCP is 4 Kbytes. It is proposed to use the same value for Herschel/Planck.

It is expected that there will be a mix of low-level OBCPs consisting of a few SCL instructions (less than 50) and running in a few seconds to more complex procedures consisting of several hundreds of instructions with execution times in the order of minutes or hours. In all cases it seems reasonable to limit the number of parameters associated with an OBCP to around 10 (TBD).

It has been agreed that no OBCPs will run in the ACC. If any ACMS-related OBCPs are required they will execute in the CDMU. It has been further agreed that in case of a switch over between CDMU A and CDMU B, there are no requirements to resume the OBCPs which were running at the time of the

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[10] An OBCP is subject to a smaller burden of proof than other software on board because it is designed to be safer, and to have fewer capabilities than the conventional software, e.g. no hard real time requirements, restricted memory access, etc. An OBCP can be validated in isolation, like any ground-related FCP. This means that the process is much quicker than if the corresponding change would have been performed via a modification of the OBSW which in many cases requires regression testing. OBCP validation can be carried out within a few hours rather than a few days (or weeks!) for conventional software. It must be clear, however, that OBCPs are not a remedy for poor OBSW design or inadequate FDIR.

[11] The same absolute upper limit could be applied to Planck currently, although it is likely that a smaller number will be eventually required.

switch-over, nor to preserve their context. If necessary an "Initialisation" OBCP may be run on the new processor (TBD).

It is assumed that an OBCP runs in a location in memory called a "slot". 16 slots are A minimum of 16 (TBD) slots should be reserved for OBCP use (Note that OBCP have lowest priority in on-board TC handling). It is a fundamental requirement that an OBCP should be able to execute, without modification, in any one of the available slots provided the slot size is sufficient. It is assumed that OBCP's can be stored in non volatile memory (e.g. SSMM), and loaded, as required, from this storage for execution. An arbitrary selection of OBCPs from those on-board should be allowed to execute. This means that constraints on physical address, "slot" size, "slot" location shall not require regeneration of the OBCP. The operating environment must relocate code/data, as necessary, in a transparent way.

RD10 specifies the high level functional requirements which must be fulfilled by the OBCP's implementation in order that OBCP become an effective spacecraft control tool for the Flight Control Team.

The major requirements are listed below:

- An OBCP cannot interfere with OBSW tasks operating within hard real time constraints.
- Any run-time error occuring during execution of an OBCP shall result in a clearly defined behaviour (e.g. termination, continuation with clearly identified error conditions, or execution of a "tidy up" sequence followed by termination)
- An OBCP shall be able to access TM values by name (as defined in the Satellite Data Base)
- It shall be possible for an OBCP to submit any TC packet contained in the MOC Data Base for processing by the CDMS.
- It shall be possible for an OBCP to transmit event packets.
- The CDMS shall implement an OBCP reporting mechanism which allows to periodically report to the ground the status of each OBCP, as well as the occupancy of the OBCP slots. The system shall maintain the information required to be able to trace the execution status of the active OBCPs. This information should be readily available in case an FDIR action or any other critical event occur.
- It shall be possible for an OBCP to "wait" for specific events (e.g. update of a given TM item, completion of another OBCP, etc.)
- It shall be possible for an OBCP to start and stop execution of other OBCPs.
- It shall be possible for a number (e.g. 16 TBC) of OBCPs to execute in parallel.
- It shall be possible for an OBCP to save and retrieve data from a previous activation.

An OBCP Development Environment shall be implemented in order to allow fast and easy generation and validation of OBCPs. It shall be possible to:

- Write and update OBCPs using standard ASCII based editors.
- Invoke the complete production process from OBCP source code to uploadable spacecraft commands, i.e. translation, database extraction, verification/validation, command generation.

- The OBCP Development Environment shall provide the means to check the syntax and semantics of OBCPs, taking into account the constraints from the Satellite Data Base.
- The OBCP Environment shall, to the maximum extent possible, allow ~~to validate~~the validation of the dynamic behaviour of the OBCPs.
- The OBCP validation process shall offer a significant improvement in terms of turn around time and required human and computer resources when compared to a traditional OBSW validation activity.

These requirements will be consolidated an expanded during the process of CDMS software design.

4 OPERATIONS PREPARATION

For both Herschel and Planck and for all mission phases the satellite operations will be planned well in advance of their actual execution. They are described in the Flight Operations Plan (FOP) which is basically, for each mission phase, a timed sequence of individual operational activities. Each activity is described in detail in the corresponding Flight Control Procedure (FCP). All foreseeable anomalous situations are covered by a Contingency Recovery Procedure (CRP) which specifies the steps necessary to recover from the anomaly.

Generation, testing and validation of the FOP, FCPs and CRPs is an ESOC responsibility. The documents are based on procedures supplied by industry and generated using generic tools available in ESOC. These tools will be customised for Herschel/Planck as required.

The input for the FCPs and CRPs related to the spacecraft itself is provided by the Prime Contractor via the spacecraft User's Manual (UM). The input for the instrument-related FCPs and CRPs is provided by the Instrument Teams via the Instrument User's Manual (IUM). There is one IUM per instrument. The requirements on the contents and delivery schedule for the UM and IUMs are contained in AD2.

Testing and Validation of spacecraft and instruments take place throughout the H/P programme from Instrument Level Tests (ILTs) to Integrated System Tests (IST) using a variety of instrument and spacecraft models (AVM, QM, PFM) and a variety of ground based tools e.g. MGSE, EGSE, CCS, etc.

Similarly the ground facilities are tested and validated with the real spacecraft as well as using various tools such as Spacecraft and Instrument Simulators[12] in a series of tests run at element, sub-system and system level. The major ground segment-related tests are:

- System Validation Tests (SVTs) with the satellite[13]
- Simulations[14]

[12] The Spacecraft Simulator is built by ESOC based on inputs provided by the Prime Contractor. ESOC will implement and integrate into the spacecraft simulator functional models of the scientific instruments based on input provided by the Instrument Teams.

[13] Three SVTs per spacecraft are foreseen: (i) SVT0 at L-21 months with the Service Module alone (duration 5 working days); (ii) SVT1 at L-12 months (duration 15 working days); (iii) SVT2 at L-8 months (duration 10 working days). SVT1 and SVT2 involve the instruments. These two tests are followed by End-to-End Tests (EEs). The EEs provide the opportunity to validate the ground segment with the spacecraft and the instruments.

[14] The Simulation programme involves the entire ground segment and to the maximum extent possible the entire operations team. The spacecraft is not involved. Spacecraft and Instrument Simulators are used. The Simulations provide the opportunity to exercise the various phases of the mission (in particular the critical phases such as LEOP and commissioning), validate FOP, FCPs and CRPs and complete the training of the operations team.

Additional activities such as Listen-In Tests (LITs), dress rehearsal, data flow tests complete SVTs and Simulations in order to achieve ground segment readiness and to demonstrate compatibility between the satellite and the ground segment. The ground segment readiness to support the operations is verified at the Ground Segment Readiness Review (GSRR) which takes place around L – 3 months.

It is expected that the reference mission scenario will be used as a basis for the preparation of the SVTs and Simulations as well as for the definition of specific tests to be carried out during the AIV programme e.g. during AVM testing.

The essential operational feature of the Herschel mission is that although the Herschel Science Centre (HSC) set up and operated by ESA/RSSD and the Instrument Control Centres (ICCs), one per instrument, set up and operated by the PI-teams, are actively involved in the planning of the operations and subsequent processing of the data, commanding of the satellite (spacecraft and instruments) is carried out exclusively by the Mission Operations Centre (MOC) located at ESOC. The MOC is also responsible for ensuring the “health and safety” of both spacecraft and instruments.[15]

The operational philosophy is the same for Planck as for Herschel. The Planck Science Office (PSO) and the Planck Data Processing Centres (DPC’s) are actively involved in the planning of the Planck scientific activities but all commanding activities are done by the MOC.

[15] Due to the autonomous mode of operations of Herschel this responsibility is de-facto limited since during the non-contact period spacecraft and instruments shall be able to operate without ground supervision. The “Failure Detection Isolation and Recovery” (FDIR) principles (AD5) establish the rules ensuring health and safety of the spacecraft. Similar (TBW) documents will establish, along the same principles, the rules applicable to the instruments.

5 INSTRUMENT OPERATING CONSTRAINTS AND ASSUMPTIONS

There are characteristic mission constraints and assumptions that are applicable to both Herschel and Planck:

- The instruments always accept the TC packets sent to them by the CDMS.

- Provided the instrument operates nominally, schedule generation during scientific mission planning will ensure that the TC packets sent to an instrument will not overflow the instrument internal command buffer.

- No command sent to an instrument can endanger the health of the instrument regardless of the state of the instrument at the time the command is received.

- If an instrument has to be switched on this is always done manually, i.e. under ground control during the DTCP.

- When an instrument is found to be in a non-nominal state it is either switched off or configured to safe mode by the CDMS. There will be **no** attempt to bring the instrument back on line outside ground control.

- The reaction time in case of instrument problem, from detection to readiness to resume instrument operations is typically of order 72 hours.

In addition to these characteristics there are the practical limitations of the AIV environment (equipment, time available for the various tests, etc.) that also have an impact on the scenarios that can be implemented. Furthermore, in order to generate "feasible" scenarios several assumptions (in particular w.r.t. the extent of the test coverage) must be made. They are listed in the following sections. Assumptions and constraints must be carefully verified before the scenarios are implemented.

5.1 Herschel

Before considering the practical limitations of a test environment, there are further mission characteristics particular to Herschel that must be identified.
The Herschel reference mission scenario shall take the following (currently known) constraints and assumptions into account:

- The overall 'data rate' constraint, i.e. the total amount of data generated during an operational day (OD), will force restrictions on the operational modes used, and on possible multi-instrument (parallel, etc.) modes.

- It is assumed that operation of (the) HIFI (local oscillator) will preclude operation of any other instrument.

- It is assumed that HIFI cannot perform any astronomical observations when the spacecraft transmitter is operating, i.e. during the DTCP.

- Operation of a HIFI specific band requires that the appropriate local oscillator (LO) power for that band is available, each mixer band has two LO bands. This requires: (i) that the LO source unit is operational (requiring of order 15 min –TBC- of 'stabilisation' when turning HIFI from standby to prime); (ii) that the LO power amplifier/multiplier chain is operational (requiring 5-15 min –TBC- of 'stabilisation' time when changing LO band)

- HIFI operation will require knowledge of the radial velocity between Herschel and the target with an accuracy down to (a few) tens of m/s in extreme cases. This will have implications especially for the scheduling of solar system object observations.

- No more than 24 hours (TBC) may have elapsed between the most recent PACS vs. star-tracker boresight calibration and the beginning of a requested observation that uses HIFI.

- Operations of SPIRE require that the internal cooler has been recycled. The recycling time is 2 hours, enabling 46 hours of subsequent operations (expected durations – TBC).

- Operations of PACS in photometric mode require that the internal cooler has been recycled. The recycling time is 2 hours, enabling 46 hours of subsequent operations.

- No more than 24 hours (TBC) may have elapsed between the most recent PACS vs. star-tracker boresight calibration and the beginning of a requested observation that uses PACS. The actual need and frequency of this calibration need further assessment.

- All significant time blocks (idle periods, observations and slews) are considered 'observations' in that they (i) are separately schedulable, (ii) can generate science and or HK data for all instruments and (iii) have their own, unique observation identifier (OBS_ID)

- At times when one instrument is prime, the others may be observing in parallel (SPIRE) or serendipity mode, delivering only HK data.

- The instruments always accept the TC packets send to them by the CDMS.

- Provided the instrument operates nominally, schedule generation during scientific mission planning will ensure that the TC packets sent to an instrument will not overflow the instrument internal command buffer.

- No command sent to an instrument can endanger the health of the instrument regardless of the state of the instrument at the time the command is received.

- If an instrument has to be switched on this is always done manually, i.e. under ground control during the DTCP.

- When an instrument is found to be in a non-nominal state it is either switched off or configured to safe mode by the CDMS. There will be **no** attempt to bring the instrument back on line outside ground control.

- The reaction time in case of instrument problem, from detection to readiness to resume instrument operations is typically of order 72 hours.

These constraints and assumptions might have a significant impact on the Herschel operations.

The HSC Calibration Group has taken the responsibility to capture, document, and keep updated a detailed list of instrument operating constraints and assumptions (RD14).

Below are the considerations demanded by the more practical limitations of the AIV environment and the aim of having a feasible reference scenario.

1. With one exception noted later in the text the scenarios will **not** attempt to exercise any failure case[16]. In particular the scenarios are not intended to test the CDMS SW, ACMS SW or Instrument OBSW[17]. These are assumed to have been tested elsewhere and to be operational when the scenarios are run.

2. It is also assumed that the SVM and instruments have been debugged prior to running the scenarios and that the satellites should operate error-free during the test.

3. It is further assumed that no ground processing and/or operators errors will be introduced into the scenarios. As a consequence the MTL generated from the scenarios shall be error-free. Similarly the HPSDB required to support the routine scenario is assumed to have been verified/debugged prior to running the scenarios therefore to be equally error-free.

4. A representative scenario must exercise **all** three Herschel instruments: HIFI, PACS and SPIRE as well as the special cases of the PACS + SPIRE “parallel” mode and the SPIRE “serendipity”

[16] It is assumed that the failure cases are best handled via dedicated tests (possibly of short duration) not part of the routine scenario. One of the reasons is that the routine scenario will be used (as is or in a slightly modified form) to support a long duration **soak test** of the system. Such a test is likely to be run unattended.

[17] It is therefore assumed that the Instrument OBSW properly supports the PS-ICD services applicable to the instruments.

mode. However it is **not** the intention to exercise **all** observing modes of the various instruments within the scenario.

5. It is assumed that the Herschel PLM is cold for the test. Cooler recycling: Both PACS and SPIRE carry a (identical) ^{3}He cooler which needs recycling every ~ 48 hours in order to become operational again. Expected duration of the recycling: ~ 2 hours. The required Procedures need to be defined by both instruments. The baseline is to carry out the procedure during the DTCP (every other DTCP) from the MTL. For the purpose of the scenario only one of the procedures (TBC) will be exercised during the DTCP[18].

6. Degraded modes: All three instruments have defined (or are in the process of defining) degraded modes of operations that will allow the instrument to carry out useful scientific observations in case of failure of one (or several) instrument subsystem(s) or element(s). **None** of these modes will be included in any of the scenarios (routine and/or Commissioning / PV phase scenarios.)

7. Test modes: All three instruments have defined a series of TEST modes or non-standard configurations of the instrument including specific calibrations with internal sources, generation of test data patterns, diagnostic tools for failure investigations and/or exploration of optimum instrument operating parameters (e.g. heater and bias levels), etc. These modes are very much instrument-specific. They are expected to be debugged during the ILTs and to be used extensively during the Commissioning / PV phase. They are not particularly interesting for the purpose of the scenario. **None** of these modes will be included in any of the scenarios (routine and/or Commissioning / PV phase scenarios.)

8. The authorised instrument nominal configurations are:
   - HIFI Prime, PACS[19] and SPIRE in stand-by (STBY)[20]
   - PACS Prime, SPIRE and HIFI in STBY
   - SPIRE Prime, PACS and HIFI in STBY
   - “Parallel” mode i.e. **PACS Prime** in Photometer mode, **SPIRE Parallel** in Photometer mode, HIFI in STBY.
   - “Serendipity”[21] mode i.e. SPIRE Prime in Photometer mode, PACS and HIFI in STBY

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[18] Recycling will take place in parallel with other DTCP activities such as the dump of the SSMM. For SPIRE it is initiated when SPIRE is in its “REDY” mode. Upon completion of the procedure SPIRE goes back to “REDY”. The process is similar for PACS. The Procedure starts from PACS in its SAFE mode. PACS is returned to SAFE upon completion of the Procedure. It might be advantageous to exercise recycling in the Commissioning / PV scenario rather than in the routine scenario (TBD) although for the sake of realism the routine scenario should be preferred.

[19] PACS and SPIRE can be operated either in “Spectrometer” mode or in “Photometer” mode. They both have, therefore, two different STBY modes, the PHT-STBY and the SPC-STBY modes

[20] An instrument in STBY mode is powered on and ready to execute the STBY → “Prime” activation sequence. It produces only HK data.

9. The mission scenario will simulate 48 hours of operations with one max. 27hour OD plus shorter ODs

10. The routine scenario will **not** consider the situation in which a DTCP is missed.

11. The routine scenario will run entirely with the Satellite in its **Nominal (Science)** System mode of operations. The ACMS will run in its **Normal (NOM)** mode of operations. In line with the error-free routine scenario assumption no transition to Sun Acquisition mode (ACMS failure), Earth Acquisition mode (CDMS computer failure) or spacecraft Survival mode (CDMS system failure) will be commanded in the routine scenario.

12. In order to exercise a realistic case the routine scenario will include a **recoverable** instrument anomaly (corresponding to a FDIR failure Level 1) leading to the "Autonomous Fail Operational" (AFO) FDIR mode. Recovery is expected to occur at the next sub-schedule[22]. This AFO will be exercised in the **2nd** OP of the routine scenario.

13. The order in which the instruments are put into their "prime" mode is not important for the scenario, although, during real operations, instrument-specific constraints may prohibit certain sequences.

14. The Herschel instruments are not switched-off during the mission under nominal conditions. Instrument switch-on takes place manually during the commissioning phase[23] or, during the mission, after a serious instrument or spacecraft anomaly that led to their switch off. Switch-on is thus outside the routine scenario. At the beginning of the scenario all three instruments are therefore assumed to be in STBY.

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[21] The "serendipity" mode is exercised during slews. It is possible (likely) that some restrictions/conditions will have to be satisfied before the serendipity mode is activated e.g. minimum slew duration. This is ignored in the scenario. The scenario will include **one** slew of duration 20 mins (TBC) during which serendipity will be active.

[22] The sequence of events is roughly as follows (details TBD):
1) Instrument notifies CDMS of an internal problem via an "Exception Report" [TM (5,2)]
2) CDMS runs an OBCP on instrument's behalf and disables MTL commanding to this instrument
3) Instrument "recovers" and signals to the CDMS via an "Event Report" [TM (5,1)] that it has returned to an operational state
4) CDMS re-enables the next sub-schedule for this instrument

[23] Instrument Switch-on will be exercised in the Commissioning /PV phase scenario. The complete switch-on procedure includes instrument transitions to specific "modes" not used in nominal operations e.g. "INIT", "ON"," REDY" for SPIRE; "INTERMEDIATE" for HIFI; "INIT", "SAFE" for PACS. These modes are **not** considered in the routine scenario.

15. In case of anomaly an instrument can be switched into its SAFE[24] mode from any of its operating modes. This transition will **not** be exercised in the routine scenario. Instrument transition into SAFE mode will be exercised in the Commissioning / PV phase scenario (TBC).

16. The baseline scheduling scheme is to allocate "prime" time to the individual instruments in units of one OD, e.g. 2 OD's PACS Photometer, one or more OD's PACS Spectrometer, one OD SPIRE Photometer, one OD SPIRE Spectrometer, etc.

17. Instrument-specific constraints (e.g. internal calibration requirements, detector saturation, stabilisation times, etc.) may, while the instrument is prime, preclude certain sequences of observations (AOTs). This will be ignored in the implementation of the scenario.

18. Specific target selection and planning strategies[25] resulting in observation scheduling restrictions could be used in Mission Planning in order to improve the pointing performances e.g. reaching the pointing "goals" rather than merely meeting the pointing requirements. These limitations will be ignored in the implementation of the scenario.

19. The routine scenario will support sub-schedules as defined in [RD18].

20. During the DTCP the MTL continues to run. Manual commanding from ground, therefore, coexist with MTL-generated commanding. In order to be realistic the routine scenario will maintain this duality. A few instrument "observations" will be carried out during DTCP.

21. Reaction wheels momentum biasing: This spacecraft housekeeping type of activity (potentially disturbing for instrument scientific operations) is scheduled once per DTCP (baseline). In line with FD's preferred approach biasing will be performed towards the beginning of the DTCP before any slew is performed.

22. Main in-orbit calibrations (focal plane geometry calibration) will **not** be included in the routine scenario[26].

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[24] An instrument in SAFE mode will only be brought back to its operational state manually by ground command (i.e. during the DTCP). An instrument can, in principle, stay "indefinitely" in its SAFE mode without damage.

[25] Specific examples include: (i) avoiding large slews before high pointing performance is required; (ii) selecting (raster) off-target positions on the small circle around the sun-vector; (iii) performing long scans or big raster observations such that their main dimension are within similar SAAs.

[26] The main (focal plane geometry) calibration is performed nominally only once during the Performance Verification phase to verify pre-launch ground alignment. The offset between the STR LoS and PACS blue photometer array is measured in flight and the ground computed offset updated as required. This is a lengthy procedure (duration approximately one week) since at least three calibration sources at very different SAAs are required and the settling times at each SAA are very long. The ground alignment knowledge between the various LoS of HIFI, PACS and SPIRE (each instrument contains

23. One “Weekly calibration check” will be included at the end of a DTCP under the assumption that PACS cooler recycling will also take place in this DTCP. The weekly calibration could also be moved if more convenient or if it turns out that the time available is too short to carry out both “recycling” and “calibration” in one DTCP. This weekly calibration is intended to monitor the evolution of the “calibration residual” i.e. the calibration error that could not be compensated by the main (focal plane geometry) in-orbit calibration. Expected duration: 10 mins.[27]

24. One “Peak up” operation[28] with SPIRE will be included in the routine scenario.

25. The Standard Radiation Environment Monitor (SREM) generates data continuously in orbit with a fixed accumulation time. This data is transferred into the SVM non-essential housekeeping store. The SREM[29] will be operating and collecting data in the routine scenario.

26. The scenario will **not** include orbit correction manoeuvres. These manoeuvres nominally occur once a month.

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between 4 and 14 LoS) is expected to be sufficiently high to allow the definition of the offsets between each STR (A and B) and the respective instruments LoS based solely on the PACS measurements. PACS blue photometer array is chosen since it provides the highest accuracy during the calibration procedure. Any other main calibration performed outside the initial PV phase calibration is considered contingency planning. Due to its one-off characteristic the main calibration can be safely ignored in the routine scenario. It is TBD if a shortened main calibration needs to be implemented in the Commissioning / PV scenario.

[27] The weekly calibration check is performed with PACS (blue array). One calibration source only is required. Although the weekly calibration could be performed in principle equally well during the Observation Phase it will be carried out during the DTCP for the scenario. The SRS specifies a daily check. It is expected however that a weekly check will be sufficient. It is to be noted that a daily check would lead to instrument scheduling problems since it would require to activate PACS during every single OD even when the OD is dedicated to another instrument.

[28] Peak up is a special calibration mode used by SPIRE and HIFI e.g. for the observation of a source where uncertainties in the telescope pointing or source coordinates mean that the accuracy of blind pointing cannot be relied upon. The peak up operation results in the generation of pointing corrections to be applied to the **next** pointing request (the correction is not applied to subsequent pointings). The procedure is as follows:

1) ACMS and instrument are commanded in raster mode (small raster ‘around ‘the source)
2) At the end of the raster the ACMS keeps the spacecraft stable on the last raster point
3) The instrument computes the offsets between the commanded direction and the “true” target direction. The offsets are computed as two signed μ-rotations angles (θ_Y and θ_Z) w.r.t. Y and Z axes of the instrument focal plane. The instrument sends these offsets to the CDMS by means of a “Event Packet” [TM (5,1)].
4) The CDMS checks that the offsets computed by the instrument are within allowable limits (< 10 arcsec TBC). If this is the case the CDMS forwards the offsets to the ACMS who executes the pointing correction. If the offsets are wrong the CDMS informs the instrument via an Event Packet and the correction is not carried out by the ACMS.

[29] It is assumed that the SREM does not require routine commanding and that the accumulation time can be considered fixed. The SREM will be “set up” by manual command during the Commissioning /PV phase scenario.

27. The scenario will **not** include OBSW Maintenance activities i.e. memory loading/patching. This will be exercised in the Commissioning / PV phase scenario (TBC).

28. The PACS Burst mode (with data rates of up to 300kbps, for a limited period of time, e.g. up to 30 mins.) will be exercised in the routine scenario, since it represents the most demanding case for data collection.

29. The Visual Monitoring Camera (VMC)[30] that is assumed to operate only in LEOP is **not** included in the routine scenario.

30. "High priority" ground commands that are not used under nominal conditions but are reserved for exceptional cases will **not** be issued during execution of the routine scenario.

5.2 Planck

From an analysis of Planck operational requirements (RD20 and RD21 in particular) it is clear that (contrary to Herschel) the instrument "operations" proper constitute a relatively minor component in the overall Planck operations scheme dominated by the implementation of the "scanning law". The main reason is that once they have been turned on, tuned and calibrated (during commissioning and PV) the instruments are put into one single, well defined, "Observation Mode" and stay in this mode[31] during the entire mission.

1. With one exception noted later in the text the scenarios will **not** attempt to exercise any failure case[32]. In particular the scenarios are not intended to test the CDMS SW, ACMS SW or Instrument OBSW[33]. These are assumed to have been tested elsewhere and to be operational when the scenarios are run.

2. It is also assumed that the SVM and instruments have been debugged prior to running the scenarios and that the satellites should operate error-free during the test.

3. It is assumed that no ground processing and/or operators errors will be introduced into the scenarios. As a consequence the MTL generated from the scenarios shall be error-free.

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[30] The VMC and the SREM are considered as (non-astronomy) instruments

[31] This corresponds, of course, to the nominal case. Spacecraft and/or instrument malfunctions will cause deviations from this ideal case.

[32] It is assumed that the failure cases are best handled via dedicated tests (possibly of short duration) not part of the routine scenario. One of the reasons is that the routine scenario will be used (as is or in a slightly modified form) to support a long duration **soak test** of the system. Such a test is likely to be run unattended.

[33] It is therefore assumed that the Instrument OBSW properly supports the PS-ICD services applicable to the instruments.

Similarly the HPSDB required to support the routine scenario is assumed to have been verified/debugged prior to running the scenarios therefore to be equally error-free.

4. A representative scenario must exercise **all** three Planck instruments: HFI, LFI and the SCS[34].

5. Degraded modes: LFI, HFI and the SCS have defined (or are in the process of defining) degraded modes of operations that will allow to carry out useful scientific observations in case of failure of one (or several) instrument subsystem(s) or element(s). **None** of these modes will be included in any of the scenarios (routine and/or Commissioning / PV phase scenarios.)

6. Test modes: LFI, HFI and the SCS have defined a series of TEST modes or non-standard configurations. These modes are very much instrument-specific. They are expected to be debugged during the ILTs and to be used extensively during the Commissioning / PV phase. They are not particularly interesting for the purpose of the scenario. **None** of these modes will be included in any of the scenarios (routine and/or Commissioning / PV phase scenarios.)

7. The only instrument configurations exercised will be the "nominal" configurations, i.e. for the SCS[35], LFI and HFI the "prime" units only will be exercised[36].

8. The routine scenario will simulate 36 to 48 hours of operations, with one OD of up to 27hours, and some shorter ones)

9. The routine scenario will **not** consider the situation in which a DTCP is missed.

10. The Scanning Law (see [RD21]) dictates how Planck will be operated. Two basic "baseline" strategies need to be available: (i) RF interferences are assumed between the spacecraft transmitter and the instruments. The scanning law is suspended during the DTCP and resumed after the DTCP; (ii) No RFI assumed, scanning continues throughout the DTCP. **The first** strategy shall be implemented in the scenario**.**

11. The scenario assumes that implementation of the selected scanning law (including small gap recovery) is carried out in accordance with the "slew requirements" specified in the SRS i.e.
    - Displacement of the spin axis is always step-wise
    - Average time between manoeuvres is 45 minutes (less for small gap recovery)

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[34] The Sorption Cooler Subsystem (SCS) is considered an instrument in its own right in the implementation of the scenario.

[35] The SCS provides a cold-redundant cooler on-board. This redundant cooler will **not** be considered in the scenario. Furthermore it seems to be possible to carry out cooler sorbent regeneration on board. This is also **not** considered in the scenario.

[36] Because of their extreme sensitivity it cannot be entirely excluded that LFI and HFI interfere with one another. In such a case (which would be discovered during the PV phase) it would be necessary to operate the instruments in series rather than in parallel. This case will be covered in the PV scenario (TBC).

- Average manoeuvre amplitude is 2.5 arcminutes (max. 3.0 arcminutes)
- Maximum manoeuvre duration is 5 minutes (including settling time)

12. The routine scenario will run entirely with the Satellite in its **Nominal (Science)** System mode of operations. The ACMS will run in its **Science (SCM), Orbit Control Mode (OCM)** or **Angular Momentum Correction (HCM)** mode of operations. In line with the error-free routine scenario assumption no transition to Sun Acquisition mode (ACMS failure), Earth Acquisition mode (CDMS computer failure) or spacecraft Survival mode (CDMS system failure) will be commanded in the routine scenario.

13. In order to exercise a realistic case the routine scenario should include a **recoverable** instrument anomaly (corresponding to a FDIR failure Level 1) or a **recoverable** spacecraft anomaly leading to the “Autonomous Fail Operational” (AFO) FDIR mode. In this mode the MTL is not discontinued[37].

14. The Planck instruments are not switched-off during the mission under nominal conditions. Instrument switch-on takes place manually during the commissioning phase[38] or, during the mission, after a serious instrument or spacecraft anomaly that led to their switch off. Switch-on is thus outside the routine scenario. At the beginning of the scenario HFI and LFI are therefore assumed to be in “OBSERVATION” mode and “NORMAL SCIENCE” mode respectively and the SCS in its RUN mode.

15. In case of anomaly an instrument can be switched into its SAFE (or STBY)[39] mode from any of its operating modes. This transition will **not** be exercised in the routine scenario. Instrument transition into SAFE mode will be exercised in the Commissioning / PV phase scenario (TBC).

16. The use of subschedules for Planck is expected to be used only in the case of error recovery TBD. See [RD18].

17. During the DTCP the MTL continues to run. Manual commanding from ground, therefore, coexists with MTL-generated commanding. In order to be realistic the routine scenario shall maintain this duality.

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[37] ***To be investigated!!*** *Realistic and “feasible” failure cases must be analysed before one (or possibly several) cases are included in the scenario. It is unclear for example if it is sensible to continue the timeline if one of the instrument (HFI or LFI) fails, and is therefore reset to its “safe” state, while the other is operating normally. An SCS anomaly would invalidate HFI, while under specific conditions, LFI could continue to operate. Furthermore, since none of the instruments uses the concept of sub-schedules it is not clear how the timeline could be “rejoined” at a sensible point.*

[38] Instrument Switch-on will be exercised in the Commissioning /PV phase scenario.

[39] An instrument in SAFE mode will only be brought back to its operational state manually by ground command (i.e. during the DTCP). An instrument can, in principle, stay “indefinitely” in its SAFE mode without damage.

18. In operations Planck must satisfy 2 types of constraints:
    a. Sun constraint (10^0 cone, representing the SAA constraint –spin axis pointing-)
    b. MGA constraints (15^0 cone around the Earth position)

    It is assumed that these constraints will always be satisfied in the execution of the scenario such that no triggering of the ACMS constraints violation will occur[40]. It is further assumed, in accordance with the operational baseline, that the earth constraint is satisfied even when out of coverage in order to avoid large slew pre- and post-DTCP.

19. Photometric Calibrations: Planck does not carry on-board flux calibrators. It will therefore rely on celestial sources for photometric calibrations. Initial calibrations will be carried out during the PV phase using as calibrators: (i) the Galactic Plane, (ii) the CMB dipole, (iii) celestial sources e.g. planets, external galaxies, SSO's, etc. A realistic scenario should, in principle, include these calibrations at least in terms of commanding/ telemetry recovery, if not results.

20. Beam reconstruction: For LFI and HFI the in-flight main lobe patterns will be derived based on the observation of bright celestial sources, e.g. planets. The availability of such sources depends on the launch date. Ideally such a measurement should be carried out during the PV phase at least in terms of commanding/telemetry recovery.

21. Routine Calibrations: It is foreseen that weekly LoS calibrations will be performed by HFI and LFI in order to eliminate fixed bias errors (calibration residuals). The calibrations are performed by correlating STR data with instrument data. A realistic scenario shall include these weekly calibrations in terms of their effect on the scanning law[41].

22. Orbit correction manoeuvres: may **be** included in the scenario[42].

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[40] Constraint checking occurs at 3 different levels/locations: (i) At the Planck Science Office (PSO) when producing the initial list of pointings; (ii) at the MOC where attitude and/or timing of the pointing requests is refined; (iii) on-board at the time of command execution. In order to avoid that pointings that passed constraint checking at one stage are rejected at the next stage the baseline is to apply different sets of constraints at the various levels. The strictest constraints apply at PSO level, the least strict on-board the spacecraft. The scenario shall take this into consideration.

[41] Calibrations are discussed briefly in [RD-4] (Appendix A) but no operational details are available. *This must be clarified, in particular the impact of the calibration activities upon the scanning law.*

[42] Orbit maintenance manoeuvres are normally executed once per month (expected duration ~1 hour). They will normally be carried out during the DTCP. Due to spacecraft constraints these manoeuvres cannot be carried out near the edge of the shadow cone, thus the solar inclination during these manoeuvres needs to be below ~6^0. Dedicated slews may therefore be required to support orbit correction manoeuvres. A somewhat conflicting requirement stipulates that these manoeuvres should be carried out while maintaining the attitude imposed by the scanning law. Furthermore the orbit correction manoeuvres are likely to create (small) pointing disturbances. In view of these uncertainties the "safe" approach, **to be implemented in the scenario** is not to execute scanning law observations during orbit maintenance manoeuvres. The orbit maintenance manoeuvres can be implemented in two ways: (i) as part of the mission planning process –they would be included in the MTL-; (ii) by leaving a gap in the timeline in order to carry out the manoeuvres manually. *An approach has to be selected for the scenario.*

23. Planck is very sensitive to data loss. These losses can originate from instrument malfunctions, spacecraft and/or ground segment problems. One of the major complication in the Planck mission planning is the recovery of “gaps” in the data i.e. (i) “small” gaps < 3 days; (ii) “large” gaps > 3 days. The recovery techniques are similar in both cases. To be realistic the scenario must include (small) gap recovery[43].

24. The Standard Radiation Environment Monitor (SREM) generates data continuously in orbit with a fixed accumulation time. This data is transferred into the SVM non-essential housekeeping store. The SREM[44] will be operating and collecting data in the routine scenario.

25. Operations of the Fiber Optics Gyros (FOG) assembly will be included in the routine scenario. Details are TBD.

26. The routine scenario will **not** include OBSW Maintenance activities i.e. memory loading/patching. This will be exercised in the Commissioning / PV phase scenario (TBC).

27. It is assumed that no Visual Monitoring Camera (VMC) is included on Planck.

28. “High priority” ground commands that are not used under nominal conditions but are reserved for exceptional cases will **not** be issued during execution of the routine scenario.

[43] The detection of gaps in the data can be somewhat complicated. It can involve the MOC (it will assess the gap on the basis of event packets from one of the instruments) or the PSO (on the basis of “alerts” from the DPCs resulting from the discovery of poor data quality of missed pointings during DPC data processing). The re-planning exercise is also somewhat complicated since it involves the determination of a new sequence of pointings through the gap, the determination of the corresponding slews between these pointings and the adjustment of the dwell time on each point, in such a way that the nominal scanning law can be “rejoined”. These difficulties are however encountered in the detection and re-planning phase. It is relatively easy to incorporate the results in the scenario.

[44] It is assumed that the SREM does not require routine commanding and that the accumulation time can be considered fixed. The SREM will be “set up” by manual command during the Commissioning /PV phase scenario.

6 MISSION SCENARIO IN THE PRE-ROUTINE PHASES

During the non-routine mission phases described below the specific activities to be carried out on Herschel and Planck are different. The overall operational philosophy, the main features of the operations plan, the (CDMS)[45]on-board facilities required as well as the expected system performance are however essentially the same for the two missions. Herschel and Planck are therefore treated together.

6.1 Launch and Early Orbit Phase (LEOP)

Herschel and Planck will be launched together by Ariane 5 into a transfer orbit to a large Lissajous orbit at the L2 point. Herschel and Planck will separate in that order shortly after launch and they will proceed independently to their respective orbits. The preliminary timeline is:

L_0 – 7 min Both S/C on internal power
L_0 Lift off
L_0 + 2730 min (1627.6 sec) TBC Herschel separation (+Z axis nominally sun-pointed)
L_0 +35 32 min (1909.2 sec) TBC Planck separation (+1 rpm, -X axis nominally sun-pointed)

If T_0 = separation time, the following timeline is considered representative

T_0: separation, coverage from Vilspa and Kourou
T_0 +20 sec: start of sun acquisition and transmitter ON, start of ranging operations
T_0 +2 hours: completion of S/C initial checkout in Sun Acquisition Mode
T_0 +3 hours: preparation of initial Planck delta-V, check-out of Planck STR etc.
T_0 +5 hours: transition to OCM for Planck and check-out
T_0 +6 hours**: 1st delta-V for Planck**[46]
T_0 +7 hours: preparation of initial Herschel delta-V, check-out of Herschel STR etc.
T_0 +8 hours: end of coverage from Vilspa
T_0 +9 hours: transition to OCM for Herschel and check-out
T_0 +10 hours: **1st delta-V for Herschel**[15]
T_0 +12 hours: end of coverage from Kourou
T_0 +15 hours: coverage from Perth
T_0 +16 hours: continuation of further S/C check-out
T_0 +22 hours: ranging data available to determine Planck transfer orbit correction

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[45] For both Herschel and Planck the two Command and Data Management Systems (CDMS) are identical. Execution of both missions relies to a large extent on the facilities provided by the CDMS. These facilities will be essentially the same for the two spacecraft.

[46] The definition of this delta-V is based on two components: (i) a deterministic part related to the day of launch and Moon influence; (ii) data provided by Arianespace on the actually achieved injection accuracy.

T_0 +24 hours: **delta-V for Planck** transfer orbit correction
T_0 +26 hours: ranging data available to determine Herschel transfer orbit correction
T_0 +28 hours: **delta-V for Herschel** transfer orbit correction

During LEOP there will be 3 navigation manoeuvres per spacecraft, (L+6[47] hours, L+ ~ 1 day –see above- and L+12 days). The 1st delta-V manoeuvre can be performed without making a very accurate trajectory determination. It is very advantageous from a fuel efficiency point of view to do the coarse correction as soon as possible after separation. There is a fuel loss factor for every hour delay. Especially Planck will benefit from an early manoeuvre as its operational orbit can then be made narrower. It is clear that the ranging operations can not be completed at that early stage, thus there is a need for a refined correction manoeuvre at about T_0 + 24 hours. This 1st manoeuvre shall correct for deterministic launch day effect (Moon influence) and gross compensation for launcher injection dispersions.

During LEOP (Launch and Early Orbit Phase) which will last for about two weeks almost all the operations will be conducted from ground in real time (RT). The spacecraft will be transmitting only HK. The payload will not produce TM. During this phase the three Ground Stations (New Norcia, Kourou and Vilspa) available to Herschel and Planck will, jointly, provide coverage for approximately 22 hours per day. Although the LEOP phase will in principle be conducted as real-time operations the HK data generated on board is also stored in the Solid State Mass Memory (SSMM).There will be some time spent in the higher data rate modes to dump this data. The LEOP operations will be centred on the checkout of the spacecraft subsystems, the acquisition of the ACMS nominal mode and the performance of the delta-V to ensure correct transfer trajectory to L2.
The ground links during the LEOP phase are as follows:

> **TM**: 5 kbps TM link is available to all stations in any S/C attitude during the first 5 days. This will ensure that all essential HK TM is available in real-time through the LGA during the first two delta-V manoeuvres. After acquisition of ACMS nominal mode, typically within 4 hours of separation, 150 kbps TM link is available through the MGA in Earth pointed attitudes. For Planck the Earth pointed attitude of the MGA is not possible due to sun aspect angle constraints between day x1 and day x2 and day y1 and day y2 of the transfer phase.
>
> **TC**: 4 kbps TC link is available from all stations in any S/C attitude during the first 48 hours. After this time, 4 kbps TC link remains available through the MGA to both Kourou and New Norcia in Earth pointed attitude throughout the rest of the mission. For Planck the Earth pointed attitude of the MGA is not possible due to sun aspect angle constraints between day x1 and day x2 and day y1 and day y2 of the transfer phase.

Although the LEOP activities are pre-planned spacecraft operations will not be driven from the MTL. Specific tests will ensure that a small "model" MTL can be uplinked, loaded on board, dumped and

[47] It is a requirement on the ACMS to allow a 1st orbit correction manoeuvre to be performed within 6 hours of separation.

verified on ground prior to execution but outside this limited MTL-based activities the LEOP operations are essentially manual.

The LEOP is considered to last until the 3rd trajectory correction has been made thereafter the transfer phase begins. The transfer phase ends at injection into the final orbit at L2. The last two manoeuvres are planned to inject Planck into its final Lissajous orbit. The transfer will last between 90 and 123 days depending on launch date and time.

The launch window will be mainly determined by the propellant allocation on Planck for the amplitude reduction manoeuvre and eclipse avoidance manoeuvres for both spacecraft while at L2 and during transfer to L2. Currently two seasonal launch windows per year of 3 months each (winter and summer) are available taking into account minimum Delta V allocation and duration of the daily launch slot (Arianespace requirement). Details can be found in RD27.

An outline of the operations for the LEOP phase follows:

- Establish the correct spacecraft configuration (RF, Thermal control, power, data handling, ACMS, etc.)
- Establish basic spacecraft properties (centre of gravity, moments of inertia)[48]
- Determine spacecraft attitude (and spin rate for Planck) and transition to ACMS nominal mode.
- Correct attitude (spin rate) if necessary
- Carry out any required specific instrument-related activity, e.g. venting on (Planck) HFI dilution cooler (to be carried out within 4 days of launch)
- Carry out orbit determination
- Determine optimal attitude and magnitude of the trajectory correction manoeuvre
- Slew to correct firing attitude
- Refine magnitude and timing of the burn
- Execute trajectory correction # 1
- Determine the orbit
- Repeat for trajectory correction # 2
- Determine the orbit
- Repeat for trajectory correction # 3
- Slew to nominal attitude for further spacecraft commissioning activities
- (for Planck) adjust spin rate if necessary

As for the other mission phases all operational activities during LEOP as well as the transfer trajectory corrections necessary up to the end of the LEOP are described in the FOP and the corresponding FCPs and CRPs. These will have been validated during the SVTs and the Simulation Programme. To the maximum extent possible the foreseeable contingency situations will have been rehearsed during the

[48] This may be too early (TBC) since mass property determination is not trivial and require the spacecraft in a known and safe position before it can be performed.

simulations. Spacecraft and Instrument Simulators offer the possibility to inject various types of failures which can not be easily triggered on the real spacecraft and instruments.

The MOC Flight Control Team (FCT) is the only team actively involved in LEOP. It is expected, however, that the HSC[49] team and the ICC teams[50] located at the MOC will be in a state of readiness, and will carry out some basic data flow tests of their systems using the spacecraft HK TM made available by ESOC. These tests will be carried out on a strictly non-interference basis.

The FCT will be manned round the clock seven days a week during LEOP. At the end of this phase both spacecraft are in nominal mode and have acquired their nominal transfer trajectory to L2.

Since for both spacecraft the LEOP operations will be conducted manually, at a slow pace, the requirements on the on-board facilities and overall performance in this phase of the mission are not considered driving.

6.2 Commissioning and Performance Verification Phases

These two phases are carried out mostly during the transfer to L2. As needed they will be interrupted in order to perform the transfer orbit corrections which may be necessary from time to time during transfer to ensure optimal injection into the final L2 orbit.

During Commissioning and Performance Verification New Norcia and Kourou will, jointly, provide up to 10 hours coverage daily, to be shared between Herschel and Planck. The nominal time allocation between the two missions will be established when the commissioning and PV Plans will be available. The allocation will be adjusted in flight depending on the individual in-orbit characteristics of the two spacecraft.

During these phases spacecraft and instrument commanding will be carried out through a mixture of manual commanding under ground control (according to the FOP) and activities executed autonomously from the MTL.

Spacecraft commissioning and performance verification are intertwined with Instrument (science) commissioning and performance verification. Furthermore, both for the spacecraft and the instruments, the boundary between the two phases is not clear-cut. The proper sequence, and duration, of the (intertwined) operations is laid down in the Flight Operations Plan (FOP). Nominally, the PV phase starts at the end of the commissioning phase.

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[49] The Herschel Science Centre (HSC) will be located at Villafranca (Spain). Its real activities start with the commissioning and Performance Verification phases when instrument data become available.

[50] During commissioning and PV, for each instrument, a small operations team will be present at the MOC (the so-called ICC@MOC for Herschel and DPC@MOC for Planck). Basic facilities (essentially an Instrument Station running the RTA and QLA software) will be available to these teams at the MOC. In addition a connection to the corresponding home institute, the ICC@ICC for Herschel, the DPC@DPC for Planck will be available.

Commissioning will be carried out according to a Commissioning Plan generated by the H/P Project. It is carried out by the MOC in collaboration with the Instrument teams and with the participation of the HSC (Herschel) and the PSO (Planck), under the overall responsibility of the H/P Project.

The Flight Control Team in the MOC is expected to move gradually from 24 hours real time operations during LEOP to TBD hours coverage per day, seven days per week during Commissioning and PV. The HSC and the ICC teams are expected to run a shift per day, seven days per week during these phases.

For both spacecraft the requirements on the on-board facilities and overall performance in the commissioning and PV phases are considered less demanding than during the routine phase. Note that this is true in terms of storage and data flow, but may not be for other aspects e.g. Planck thrusters performance and link budget.

For Planck the Commissioning and PV phases are more separated than for Herschel[51]. While most of the Commissioning activities can be carried out during the transfer phase to L2 (duration ~4 months), the PV phase can only be carried out at L2. Its expected duration is 2 months. The duration of the Commissioning / PV phase for Herschel will be around 3 months. For the purposes of the RMS, the time allocated to the Commissioning/PV scenario is expected to be 4 slots of 8 hours each TBC for Herschel and Planck. It is expected that some of the activities can be run at an “accelerated” pace. In lieu of the Commissioning Plan, which can be used to aid the design of the RMS-Comm/PV scenario, the following subsections offer an initial consideration of the testing to be performed.

6.2.1 Spacecraft Commissioning and Performance Verification (PV) Phases

ESOC/Project is expected to describe the spacecraft (non-instrument) activities that are to be tested during the RMS-Comm/PV scenario.

<u>Commissioning includes</u>:

- Complete check-out of spacecraft functions and verification of all subsystems performances. Additional, more comprehensive, tests of the MTL and OBCP facilities will ensure that the satellite can be operated safely in “autonomy” mode.

- Verification of the spacecraft-instrument interfaces (e.g.CDMS / instruments, ACMS / instruments, Power / instruments, etc.)

<u>Performance Verification includes:</u>

The spacecraft PV is seen as an extension of the spacecraft commissioning. It includes mainly:

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[51] It may be advantageous in the case of Planck to clearly separate the commissioning and PV activities i.e. to generate **two scenarios:** (i) a Commissioning scenario; (ii) a PV scenario. ***This must be discussed!!***

- Performance verification of CDMS and ACMS.
- ACMS sensors calibration.

6.2.2 Instrument Commissioning and Performance Verification (PV) Phases

The following operations are merely listed for future selection/expansion.

Commissioning includes:

- Instrument switch on and functional checkout. During checkout, a subset of the test procedures used in ground Integrated System Tests will be repeated to confirm that the instruments have survived the launch. Instrument HK parameters will be monitored by the MOC. The operations teams at the MOC (ICC@MOC and IW@MOC) will analyse the RT data in order to establish the status of their instrument. The instrument data is made available to the HSC for Herschel, to the DPCs for Planck within 10 mins of its reception at the MOC[52]. The Instrument operations team at the corresponding ICC or DPC will perform further detailed analysis of this data. Instrument checkout shall verify that the basic functions required to support the scientific operations are available. This would include: proper reception of TCs, generation and handling of instrument TM, communication with the CDMU (and ACMS as necessary), ability to move mechanisms, ability to handle OBSW patches, etc. Instrument checkout does not require a specific target or pointing.

Herschel: Activate the SREM –see section 5.1[53]
Herschel: PACS switch-on (also called activation sequence). Initial instrument mode: "OFF". Final Instrument mode: "SAFE" (equivalent to STBY for PACS). The procedure basically involves step by step switch on and verification of DPU, DECMEC, BOLC, SPU (SWL) and SPU (LWL) in this order, as well as checking of the communication path between these "boxes". At each step it is possible to load/patch the corresponding OBSW and to verify correct loading/patching via a memory dump. Duration of the sequence: unknown[54]. Only HK data is produced. Spacecraft "pointing": irrelevant. A preliminary outline of the activation sequence is given in [RD4].
Herschel: PACS switch off (also called de-activation sequence). Initial instrument mode: any mode. Final instrument mode: "OFF". Basically two de-activation sequences: (i) "graceful" switch-off, (ii)

[52] Available is understood to mean "available for download from the MOC", i.e. available but not yet transferred. The data is not "pushed" from MOC to the HSC or the DPCs. HSC and DPC will poll the MOC data, as required, at their own pace. Data transmission delays, depending on bandwidth limitation, must also be added. Note that the data (NRT TM) to the ICC@MOC and IW@MOC are pushed

[53] Although, in real operations, the SREM will be activated during the Commissioning phase it might be more convenient (TBC) to carry out activation as part of the routine scenario (1st DTCP).

[54] The activation sequence, including memory loading/patching, will be tested and refined many times during the Instrument Level Tests (ILTs). Final procedure and corresponding duration will be established during these tests. The full sequence will be implemented by a (presently) TBD mixture of single instrument commands, OBCPs running in the CDMS and OBCPs running in the PACS DPU. It is TBD how much of the full PACS activation sequence needs to be "repeated" in the scenario. OBSW maintenance (memory loading/patching) is currently defined as a separate activity to be scheduled specifically in the scenario. It is TBD if it could be carried out as part of the "activation" sequence.

"emergency" switch-off. In the 1st switch-off a controlled power down sequence of each "box" is carried out (baseline: an OBCP running in the PACS DPU). After completion of its internal power down sequence PACS is in SAFE mode. The CDMU then switches off SPU (SWL) + SPU (LWL), BOLC, DECMEC and DPU in this order. In the emergency switch-off the CDMU switches off the various boxes directly (no intermediate SAFE state reached by PACS itself). In both sequences (graceful and emergency) the grating launch lock must be switched on. Duration of the "graceful" switch off: unknown[55].

Herschel: PACS burst mode: A 30-mins burst mode (300 kbps) will be scheduled with PACS in either Photometer or Spectrometer mode. In real operations the purpose of the burst mode (switching to raw data transmission) is to verify and validate the on-board data compression and data reduction algorithms. The *only* purpose in the scenario is to ensure that the "system" can properly set up the burst mode (e.g. selection of the proper "bus profile", activation of the proper PACS mode, etc.) and can sustain the corresponding data rate.

Herschel: SPIRE switch-on: Initial instrument mode: "OFF". Final Instrument mode: "REDY". The procedure basically involves a step by step switch on and verification of DPU and DRCU in this order, as well as checking of the communication path between these two "boxes". At each step it is possible to load/patch the corresponding OBSW and to verify correct loading/patching via a memory dump. Duration of the sequence: unknown. Only HK data is produced. Spacecraft "pointing": irrelevant. A preliminary outline of the activation sequence is given in [RD5].

Herschel: SPIRE switch-off: Similar to PACS. Preliminary outline in [RD5].

Herschel: HIFI switch-on: Initial instrument mode: "OFF". Final Instrument mode: "STAND-BY". The procedure basically involves a step by step switch on and verification of ICU, FCU, LCU, WBS-V, WBS-H, HRS-V and HRS-H in this order, as well as checking of the communication path between these "boxes. The "STAND-BY" configuration is reached via the "INTERMEDIATE" state where only ICU and FCU are powered. Duration of the sequence: unknown. Only HK data is produced. Spacecraft "pointing": irrelevant. A preliminary outline of the switch-on sequence is given in [RD3].

Herschel: HIFI switch-off: Similar to PACS and SPIRE. "Graceful" switch-off: "STAND-BY" → "INTERMEDIATE" → OFF. Emergency switch-off: as for PACS and SPIRE.

Herschel: PACS OBSW maintenance (memory loading/patching): Procedure TBD by PACS. To exercise the full procedure DPU, SPU and MEC memories should be loaded/patched.

Herschel: SPIRE OBSW maintenance (memory loading/patching): Procedure TBD by SPIRE. To exercise the full procedure DPU and DRCU memories should be loaded/patched.

Herschel: HIFI OBSW maintenance (memory loading/patching): Procedure TBD by HIFI. To exercise the full procedure ICU and LCU memories should be loaded/patched.

Planck: Activate the SREM –see section 5.2[56]-

Planck: SCS switch-on (for details see RD22)

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[55] The de-activation sequence will be tested and refined many times during the ILTs. Final procedure and corresponding duration will be established during these tests. It is TBD how much of the full PACS de-activation sequence needs to be "repeated" in the scenario.

[56] Although, in real operations, the SREM will be activated during the Commissioning phase it might be more convenient (TBC) to carry out activation as part of the routine scenario.

Planck: SCS switch-off[57]
Planck: LFI[58] switch-on (also called activation sequence). Initial instrument mode: "OFF". Final Instrument mode: "NORMAL SCIENCE"[59]. The procedure basically involves step by step switch on and verification of the REBA (DPU and SPU) i.e. "OFF" → "STAND-BY"; switch on and verification of the DAE i.e. "STAND-BY" → "DAE SET_UP"; then the FEU and BEU in this order to reach the "NORMAL SCIENCE" mode. The switch on procedure also includes checking of the communication path between DPU and SPU, then between REBA and DAE." At each step it is possible to load/patch the corresponding OBSW and to verify correct loading/patching via a memory dump. Duration of the sequence: unknown[60]. Spacecraft "pointing": irrelevant. A preliminary outline of the activation sequence is given in [RD7].
Planck: LFI switch-off[61]:
Planck: HFI switch-on: Initial instrument mode: "OFF". Final Instrument mode: "OBSERVATION MODE". Spacecraft "pointing": irrelevant. A preliminary outline of the switch-on sequence is given in [RD6].
Planck: HFI switch-off[32]:
Planck: SCS transition into SAFE mode (TBC)
Planck: LFI transition into SAFE (STBY) mode (TBC)
Planck: HFI transition into SAFE (STBY) mode (TBC)
Planck: SCS OBSW maintenance (memory loading/patching): Procedure TBD by LPSC.
Planck: LFI OBSW maintenance (memory loading/patching): Procedure TBD by LFI. To exercise the full procedure DPU, SPU and DAE memories should be loaded/patched.
Planck: HFI OBSW maintenance (memory loading/patching): Procedure TBD by HIFI. To exercise the full procedure DPU, REU and 4K Cooler Electronics memories should be loaded/patched.
Planck: (once both LFI and HFI are switched on) operate LFI and HFI simultaneously. Investigate potential RFI's between the two.
Planck: Operate LFI alone

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[57] Place holder only. Due to SCS expected lifetime limitations and the fact that the number of regenerations is strictly limited it is very likely that SCS switch-off will **not** be exercised in the scenario.

[58] Since HFI can only be operated when the SCS has fully reached its operational temperature it is likely that LFI will be switched on before HFI (TBC)

[59] An "EXTENDED SCIENCE MODE" is also defined for LFI. The only difference with the "normal" science mode is that, upon HFI-LFI agreement, the TM allocation for LFI is increase. This can be ignored in the scenario.

[60] The activation sequence, including memory loading/patching, will be tested and refined many times during the Instrument Level Tests (ILTs). Final procedure and corresponding duration will be established during these tests. It is TBD how much of the full activation sequence needs to be "repeated" in the scenario. OBSW maintenance (memory loading/patching) is currently defined as a separate activity to be scheduled specifically in the scenario. It is TBD if it could be carried out as part of the "activation" sequence.

[61] Place holder only. Due to the long time necessary for the Planck cooling chain to reach its operational temperature is very likely that LFI and HFI switch-off will **not** be exercised in the scenario.

Planck: Operate HFI alone (this assumes that the SCS is operating)

- End of Telescope heating.

Herschel: Telescope cool-down and cryo-cover opening. Expected Herschel commissioning duration: 4 to 5 weeks.
Planck Passive cool-down to 50K. Switch-on 20K cooler and cool-down to 20K. Switch on 4K cooler and cool down to 4K. Switch on 0.1K cooler and cool-down to 0.1 K. Expected Planck commissioning duration: 4 months.

Performance Verification includes:

- Instrument performance determination and calibration. This is intended to obtain a first characterisation of the instruments in terms of stability, sensitivity, resolution, etc. The PV schedule is prepared in the period before launch. For Herschel it contains a balanced set of internal calibrations carried out with the instrument internal calibration source(s) and external calibration observations performed on celestial objects. The predefined PV schedule will be followed as closely as possible. The schedule is changed only when detailed analysis shows that the pre-planned schedule is not suitable for further characterisation of the instrument. Since there is only limited ground contact schedule changes will only be possible on a timescale of TBD days. In this case new calibration sequences are generated and submitted to the HSC for scheduling. For Planck the operations to be carried out in the PV phase are not defined. For both missions the ICC@MOC for Herschel, the IW@MOC for Planck monitor data in real time. More detailed analysis is done off line at the ICC@ICC or IW@DPC using more sophisticated data analysis tools. The instrument data is made available to the HSC or DPCs within 10 minutes of its reception at the MOC for the HK data and within 30 minutes of reception for the science data[20].

Planck: Analyse LFI and HFI data (DPC task) to assess if the spacecraft X-band transmitter creates interference signals in the data acquired by the instruments during the DTCP. This will determine which scanning law will be selected for the 1st survey. (see point 10 in section 5.2).
Planck: Photometric Calibrations (TBC).
Planck: Beam reconstruction (TBC).

- Instrument Focal Plane geometry calibration.

Herschel: Main focal plane calibration (see section 5.1). It is TBD if a “shortened” focal plane calibration (baseline duration of the full procedure is ~ one week) needs to be implemented.

- ACMS to Instrument calibrations (attitude, time correlation, peak up procedures, etc.)

- Verification/optimisation of Instrument operations. As part of the performance verification the instrument observing modes are assessed for the first time using real astronomical observations. The verification is done by selecting (dedicated) standard observations on celestial sources and processing the data with the instrument ground-based analysis software. This shall include, for

Hershel, the verification and tuning of the Astronomical Observations Templates (AOTs) and associated instrument command sequences.

Due to the complexity of the Herschel and Planck instruments, Performance Verification of the instruments will constitute a very significant part of the overall PV. It will be carried out according to an Instrument PV Plan generated by the HSC (Herschel) and the PSO (Planck) with participation of the instrument teams. The FOP will specify the time slots allocated to spacecraft PV and instruments PV respectively.

Since Performance Verification is essentially an instrument activity, PV is carried out by the MOC on behalf of the Herschel and Planck Project Scientists who take over, from the H/P Project, the overall responsibility of the mission after the end of Commissioning.

At the end of the PV phase the spacecraft and instrument nominal configurations have been established and all tunable spacecraft and instrument parameters have been set to their optimal operating values.

After the initial PV phase described above periodic calibrations / re-calibrations of both spacecraft and instruments will be required during the routine phase. The extent and frequency of these operations will be established in the course of the PV phase. The corresponding calibration operations will be carried out as normal routine phase operations thereafter.

For Planck the cooling timescale of the payload is such that the instruments will not really be operational until some 60 days after switch-on. Taking also into account the constraints due to the transfer trajectory it is most likely that the PV phase will start only after injection into L2.

For Herschel the PV phase should be essentially completed and scientific operations (with some restrictions) will start during this phase.

It is expected that at the beginning of the PV phase, in the Spacecraft nominal mode, the MTL will include longer waiting times between individual operations in order to exercise the system under milder conditions while giving enough time to the ground to assess correctness of the operations during the visibility periods. As the PV phase progresses the pace will be accelerated in order to approach the tempo which might be expected in the routine phase.

At the end of the non-routine phase for Planck the final L2 orbit insertion manoeuvre will take place. This will be a major manoeuvre of relatively long duration (~2 days)

For Herschel a first determination of the remaining mass of Helium in the main tank will take place.

7 HERSCHEL ROUTINE MISSION SCENARIO

The Reference Mission Scenario described here corresponds to the **Routine** operations phase of the Herschel satellite. The spacecraft is at L2. Both spacecraft and instruments have been commissioned and calibrated. The satellite nominal operational configuration has been established. It includes, possibly, some redundant units if the corresponding prime units have been found defective. The ground segment is considered operational and the operation teams, properly trained, are settling into a one-shift per day operations (seven days per week for the FCT, five days per week for the HSC and ICCs[62]). The ICC@MOC personnel leave the MOC[63]. The New Norcia Ground Station alone is allocated to Herschel (and Planck) during the routine phase.

The Reference Mission scenario in the routine phase is basically a list of typical activities to be executed by the operations teams and the spacecraft in the nominal case. The reference mission scenario in this phase is therefore a yardstick against which adequacy of the human and spacecraft resources available for the execution of the mission can be assessed.

For Herschel the Operational Day (OD) has been defined as the basic planning unit. An OD nominally covers 24 hours but can be shorter or longer due to Ground Station scheduling issues. Since the spacecraft **"autonomy"** period is 48 hours the RMS-Routine scenario will cover 48 hours of nominal operations.

In any given OD, in the nominal case[64], contact with Herschel will be established for a maximum of 3 hours per day, the Daily Tele-Communication Period (DTCP). The actual length of the DTCP is a compromise between the desire to reduce the contact period as much as possible due to the fact that New Norcia is heavily used by other missions and the requirement to carry out, during this period, all the activities required to download the data that has been acquired prior to the DTCP, as well as to prepare the spacecraft for the next autonomy period.

[62] It is assumed that batch jobs or similar will run at the science centres over the weekend to retrieve data on Saturdays and Sundays. It should be noted that since daily transfer from the MOC to the science centre takes ~8 hours, failure of these batch jobs over a week end will result in something like 32 hours worth of "catching up".

[63] The ICC@MOC facilites remain at the MOC until the end of the routine operations phase. In case of an emergency affecting their instrument the corresponding ICC team would be recalled to the MOC.

[64] Under non nominal conditions deviations from this scenario are possible. For example in case of difficulties with one satellite its DTCP might be extended while the DTCP of the other satellite is reduced accordingly. If ground station visibility and ground station scheduling constraints allow, one DTCP may be extended without impact on the other DTCP. The minimum daily visibility from New Norcia is around 7 hours, the maximum around 13 hours depending on the season. In case of emergency other ground stations may be called upon or the MOC Operations Team may decide to put the spacecraft into survival mode.

During the DTCP the spacecraft must be pointed towards the Earth to allow the data that has been recorded on-board in the Solid State Mass Memory (SSMM) during the non–visibility period to be dumped to the ground.

During the DTCP, and provided the earth-pointing constraint, as well as specific (TBD) DTCP constraints are satisfied, Herschel scientific operations can continue. During this period the satellite is still operated in autonomy mode. The operations are carried out according to the portion of the MTL still loaded on-board and covering the DTCP. The data generated during the DTCP, although dumped to ground in RT is also recorded in the SSMM.

It has been agreed with the Herschel PI-teams that in order to reduce the overheads due to instrument warm-up, stabilisation times and mode[65] switching, as well as to reduce RF interferences, the baseline will be to operate one instrument at a time (the prime instrument), for periods of one or two OD's.

During this time the other instruments will be in a specific non active mode (**stand-by mode)**. In stand-by the instrument does not produce any scientific data but only HK.

The only exception is when PACS and SPIRE are in the so-called **"parallel"** mode. In this mode both instruments are producing science TM, sharing the available bandwidth. For the scientists using Herschel, for the processing of the "requests" for observing time generated by the science community as well as for scheduling purpose the parallel mode is considered as the unique mode of a "fourth" instrument.

During slews between targets, SPIRE, when it is operating, may be put into **serendipity** mode. In this mode (photometry mode) which corresponds to a specific, fixed, configuration of the instrument, SPIRE produces scientific data.

The impacts on on-board and ground processing of the parallel and serendipity modes have not been analysed in detail. It is assumed that they will not be allowed to drive in any way the requirements for on-board resources, processing and performance requirements.

A maximum of 130 kbps has been allocated to the Herschel science instruments over a period of 24 hours (one OD). This allocation includes pure science data and instrument HK data for the instrument which is prime as well as HK data for the instrument(s) in stand-by mode. For short periods of time (around 30 minutes) and infrequently during the mission PACS may be operated in a so-called **burst** mode during which science TM is produced at a higher rate (i.e. 300 kbps). This higher rate has to be "absorbed" in some way during quieter periods such that the overall amount of data produced does not exceed the 130 kbps over 24 hours average. The 1553 spacecraft bus can cope with the burst mode without any special provision and PACS on-board software has the facilities required to handle it.

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[65] Each Herschel instrument has defined several modes of operations. Each mode corresponds to a well defined instrument configuration, suitable to carry out a specific scientifically meaningful observation or a functional task such as instrument initialisation, memory patching, cooler recycling etc. These modes and the corresponding mode switching logic are described in RD3 to RD5. Appendices 1 to 3 present a brief summary of the Herschel instruments operating modes.

In any one OD (or set of two OD's) the set of Herschel instruments will be in one of the following configurations.

Config.	HIFI	PACS	SPIRE	Comments
1	Prime	Standby	Standby	
2	Standby	Prime	Standby	
3	Standby	Standby	Prime	
4	Standby	Prime	Parallel	130 kbps TM shared
5	Standby	Standby	Serendipity	During slews. All TM available

For the purpose of the reference mission scenario the various configurations are considered equivalent in terms of resources and performance requirements.

The duration of any given observation within a given OD will vary from a few minutes to several hours depending on instrument mode and characteristics of the source observed. Typical observations are expected to last around one hour. One may therefore assume for planning purpose that up to 30 observations will have, on average, to be scheduled for each OD.

In order to optimise the overall efficiency of the observing schedule the HSC planning system will attempt to sequence the observations in such a way that the slews between the targets to be observed are minimised. The ACMS performance requirements impose that the maximum duration of the largest slew (90 degrees) do not exceed 15 minutes. The shortest slew duration is of the order of a few seconds. One may therefore assume an average slew duration of 5 minutes between two consecutive targets.
An observation of a given target may consist of a single pointing on the source, or of more complex (ACMS) operations such as "rastering", line "scanning", etc. in which the ACMS performs autonomously a pre-defined series of elementary operations, e.g. cover n "points" of a raster. Such a complex operation is performed by means of a single ACMS "command". This command is expanded on-board by the ACMS, so that it corresponds to a single entry in the MTL.

An (oversimplified) sequence of operations for a given OD is shown below:

1. ACMS calibration (duration 10 minutes)
2. Instrument initialisation: transition from stand-by to prime, warm up, stabilisation, selection of instrument "mode" (30 minutes)[66]
3. Slew to target #1 (10 minutes – initial slew assumed to be longer-)
4. End of slew: On Target Flag (OTF) high
5. Pointing on target #1, data collection, HK and Science TM to CDMS (duration 60 minutes)
6. Slew to target #2: OTF low,

[66] Other instruments assumed to be in stand-by mode.

7. (optionally) mode change[67] (duration from a few seconds to a few minutes)
8. End of slew: OTF high
9. Pointing on target #2, data collection, etc.
10. Time slot blocked for spacecraft activities[68] (duration 15 minutes)
11. ---------
12. ---------
13. pointing on target #n (last target)
14. Instrument from prime to stand-by.
15. End

The Herschel Project Scientist Team (PST) has defined a preliminary list (see below) of scientific observations that are likely to be carried out by the Herschel Observatory.

Here follows a list of "types of observations". The list is only indicative and will have to be revised when sensitivity levels will be known better.

PACS:

- Extragalactic deep survey over large area. Scanning mode, covering as much area on the sky as possible per unit time (=OD) down to say 15 mJy.
- plus same thing, but in raster mode with chopper operating instead of scanning mode.
- High resolution spectroscopy of a weak single line in a single source for the whole OD.
- same but stronger sources, assume one hour (for a single line) per source.
- High resolution spectroscopy of a number of lines in an object. Assume six lines in a source for an OD.
- Measure the flux of a solar system calibrator source in all three bands. (Need to think about the spectrometer here.)

SPIRE:

- Extragalactic deep survey over large area. Scanning mode, covering as much area on the sky as possible per unit time (day=OD) down to say 15 mJy.

[67] In case observation of target #2 requires a different "mode" of the prime instrument. Mode change could take place during slews (TBD).

[68] To the maximum extent possible Mission Planning will attempt to schedule these activities during the DTCP. This might not always be possible, e.g. reaction wheel unloading.

- plus same thing, but in raster mode instead of scanning mode. This means that for each raster position the BSM needs to be operating to provide 64 different pointings to fill the gaps.

- Measure the flux of a number of point sources, think 5 mins per source.

- Do full spectral range FTS spectrophotometry (R~20) of a number of sources.

- Do full spectral range FTS spectroscopy (R~200) of a number of sources.

- Measure the flux of a solar system calibrator source in all bands. (Need to think about the spectrometer here.)

HIFI:

Note: "One line" means one LO setting, there could be more than a single line in the passband but that is of no consequence.

- Spectral scan of a given point source. Basically pointing with chopper operating stepping through frequencies, building up the entire spectrum.
- Assume the whole spectrum can be covered in one OD, since the higher frequencies are less sensitive it means they need more time per LO setting.

- Measuring a particular line in a number of sources. Assume 30 mins per source so get some slewing.

- Raster scan in a single line of a source with OFF position (could be a small number of sources = reference positions in a OD, it depends of the size of raster and sensitivity level which is required. Normally when one makes a map with an instrument like HIFI, one makes a number of relatively small rasters (say 5x5) next to each other to build up a map=an image).

- plus same with a (moving!) solar system source, e.g. a comet. Here we could condider a number of lines, but only one raster around the same (moving!) source.

Other observations:

- Peak-up mode, parallel mode, and the non-standard mode with multiple instruments in a single OD.

The list above provides an indication of the complexity of the Herschel operations. It is clear that the “scenario” can only cover a small subset of the operations listed above.

It is emphasized that:

- The best current instrument observing mode descriptions and the time estimators used to establish typical observing times are VERY RUDIMENTARY, they are NOT STABLE, and WILL CHANGE
- For any OD or set of ODs the reference mission scenario can be broken up into four consecutive phases:
  (i) planning phase
  (ii) activities during the Daily Tele-Communication Period (DTCP)
  (iii) autonomous operations,
  (iv) post-processing.

7.1 Planning phase

This phase is a preparation phase. It is performed by the various operations teams working jointly in order to establish a detailed list of activities to be executed by the spacecraft for a set of OD's covering some period in the future. Planning is normally carried out two to three weeks in advance in order to ensure that the corresponding schedules can be fully validated before they are actually used. The operation teams use a set of ground-based tools in a chain that eventually produce a Mission Timeline (MTL) to be uploaded to the spacecraft. At each stage the results of the previous step are taken and "fleshed out" with more and more data. Each time, the contents of the respective ASCII files are checked against associated planning constraints and for syntax errors. Files in error are rejected with an indication of the error. The following main activities take place:

1. The MOC provides to the Herschel Science Centre (HSC), in the form of a Planning Skeleton File (PSF) for each OD, the set of observation scheduling constraints applicable to the OD. Basically, the PSF indicates the periods which are unavailable for scientific operations. Unavailability may be due to viewing constraints or to the need to set aside specific periods for exclusive use for spacecraft activities.[69]

2. The HSC extracts from its Mission Data Base (MDB)[70] a set of observations[71], instrument calibrations and engineering requests and strings them together, within the periods available for the

[69] This approach is based upon the model which has been successfully used for the other ESA's observatories, i.e. ISO, XMM, Integral.

[70] The basic scheduling entities handled by the HSC are: (i) scientific observation requests; (ii) calibration requests; (iii) engineering requests. Observations requests come from the scientific community and the PI-teams who, because of their participation in the Herschel programme, are entitled to a percentage of Herschel observing time (guaranteed time). Calibration and engineering requests are generated by the ICCs and or the HSC. The calibration requests are generated at regular interval. Their purpose is, through the execution of the corresponding calibration observations, to maintain the instruments properly calibrated throughout the mission. Engineering requests are generated when diagnostic-type operations need to be carried out, for example because an instrument malfunction or performance degradation is suspected. Engineering requests could also be generated in case OBSW patches need to be uploaded. The HSC verifies that the requests are legitimate and syntactically correct. Upon successful validation they are entered into the MDB, where they are

science, into a coherent Planned Observation Sequence (POS)[72] (see [RD25]) taking all existing on-board, environmental and ground segment constraints into account. Various tools made available to the HSC by ESOC are used to ensure that the POS generated by the HSC is virtually error-free. Once generated by the HSC the POS is sent to the MOC.

3. The POS is then processed by Flight Dynamics (FD) to implement the attitude pointing requests (that are in the POS), insert Reaction Wheel biasing commands, ACMS sensor calibrations etc. The end result is the Enhanced POS (EPOS).

4. The Flight Control Team (FCT) at MOC takes the EPOS for the penultimate stage of processing. For each OD the MOC adds to the EPOS the spacecraft information required[73] to completely define the spacecraft and instrument activities to be carried out for the OD. The result is the Planned Spacecraft Operations File (PSOF). (See below for an example pseudo-PSOF file that can help guide the design of the Reference Mission Scenario.)

5. From the PSOF the final products of the MPS chain are generated including the MTL (per OD) for uplink and the MTL summary for review by the HSC before the uplink.

6. While the schedule is executed the HSC constantly monitors the status of execution of the observations which have been scheduled and, if necessary, readjust its planning strategy in order to ensure that the scientific aims of the mission are fulfilled e.g. that the observations with the highest priority are executed first, that failed observations are rescheduled, etc.

The following sub-sections provide a high-level meta-description of PSOF files. For the purpose of the RMS-routine scenario the following pseudo-PSOF has been generated manually. The "final" layout, format and contents of the PSOF's (in particular definition and syntax of the keywords) will only be

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available for selection. The exact mix of observation, calibration and engineering requests is not exactly known. This has no real impact on the mission scenario since regardless of the type of request the corresponding entity can be considered, in first approximation, as an 'observation' in terms of on-board resources required and typical duration.

[71] In the first year of the mission the baseline is to carry out very large programmes of coordinated observations ("key programmes"). The Key Programmes shall be large, coherent spatial and spectral surveys performed early in the mission in order to stimulate follow-up observations by Herschel. The characteristics of the key programmes (e.g. selection, implementation, data processing, data rights, etc.) are not well defined presently. This is expected to have only a minimum impact on the mission scenario since after processing by the HSC mission planning system key programmes are expected to result in a series of 'observations' indistinguishable from "normal" observations in terms of on-board resources required and typical duration.

[72] The POS will contain a sequenced list of "observations" to be carried out. For each "observation" in an OD the Plan will contain, in an agreed format: (i) the characteristics of the observation (e.g. coordinates of the source, instrument mode, duration of the observation, any required ancillary information, etc.); (ii) the information required to command the instrument in the selected mode. The POS is produced weekly, 10 working days in advance.

[73] This information will contain typically: Commands to the PCDU, CDMU commands for the selection of the 1553 bus "profile" corresponding to the OD characteristics, specification of the Packet Store "profile", specific OBCPs which may be required for this particular OD, etc.

established during the implementation of the Mission Planning system and be subject to a specific PSOF-ICD (TBW). The PSOF shown below is considered sufficiently illustrative and representative to support the definition of the scenario.

7.1.1 PSOF #1

Appendix 10 (Herschel pseudo-PSOF #1) contains in tabular form a sequence of activities making up the 1st OD of the routine operations scenario:

- The 1st column contains the relative time (i.e. starting at 00:00:00) of the various activities expressed in hh:mm:ss. Times given are approximations.
- The 2nd column is a symbolic label.
- The 3rd column provides a description.

Note: This is a faithful approximation of a Herschel PSOF, it is not an exact example.
Sub-schedules have been included in PSOF #1 primarily as placeholders. For a guide to the intended operational usage of sub-schedules see [RD18]. There are still some open points that need resolving but the schemes described in this TN should be implemented in the RMS to test their operation. One example describes how to respond to requests from SPIRE to support its recovery from anomalies whilst another demonstrates how sub-schedules can be used to allow TT commanding for platform recovery activities whilst the previously uplinked MTL is suspended.

7.1.2 Subsequent PSOFs

Subsequent PSOFs (format identical to pseudo-PSOF #1) provide the description of each subsequent OD.

7.2 Daily Tele-Communication Period (DTCP)

Each 24-hour Operational Day (OD) can be divided into two periods:

1. The DTCP during which the spacecraft is in visibility of the Ground Station and communicating with the ground (duration between 2 and 3 hours).[74]
2. The ‘autonomy’[75] period during which no communication with the ground station takes place and the satellite (spacecraft and instruments) are operating without ground support (autonomous operations duration nominally ~21 hours).

[74] It must be noted that in the period 2007 to 2011 New Norcia station scheduling conflict between Herschel/Planck and Rosetta may occur. Critical Rosetta operations are carried out during this period. Rosetta routine operations start in the 1st quarter of 2011 and Rosetta has priority! New Norcia is the only ESA ground station in the southern hemisphere so conflicts with other missions cannot be excluded. Alternate use of a ground station in the northern hemisphere would have operational implications since the DTCP would then occur during the night.

[75] The distinction between the two periods is not absolutely clear cut. During the DTCP there is still a large degree of autonomy since the operations continue to be carried out from the MTL and the FDIR is still enabled. Ground commands and MTL commands coexist according to a TBD priority scheme. Furthermore the satellite is still in visibility of the ground station during part of the autonomy period. Ground station coverage from New Norcia varies between approximately 7 hours and 13 hours per day depending on the season

By convention the DTCP will be at the start of the OD.

In case a "pass" (DTCP) is missed[76] ad-hoc measures will be taken to recover as much data as possible during the subsequent DTCPs within the overall limitations of the end-to-end system. There is however no requirement to recover **all** data which have been stored on-board, provided the overall figure of 95% data recovery throughout the mission is met.

The current baseline is to carry out the Herschel DTCP and the Planck DTCP one after the other (the order is TBD and could be reversed depending on operational or spacecraft-related constraints). It is further assumed that a single Flight Control Team (FCT) at the MOC will carry out both Herschel and Planck operations.

The activities carried out during a typical DTCP[77] are listed below (by decreasing order of priority):

- Assess spacecraft and instruments health.
- Perform ranging to determine orbit parameters.
- Dumping of stored data.
- Assess the status of the operations which happened during the 'autonomy' period.
- Carry out specific spacecraft operations e.g. reaction wheel unloading[78], star tracker calibration, etc.
- Carry out specific instrument housekeeping activities e.g. cooler recycling for PACS and SPIRE.
- Uplink a new schedule for up-coming operations[79]
- Implement any diagnostic procedure planned during the DTCP e.g. dump of specific parameters or memory areas (spacecraft and/or instruments).
- Implement any corrective action required
- Re-plan for failure cases
- Recover the stored scientific data[80]

[76] The most likely causes are ground station scheduling conflict, high winds at the ground station site, ground station or ground segment problems or spacecraft malfunction.

[77] Two 5-minute ranging operations are carried out during the visibility period, one at the beginning of the DTCP and one at the end of the DTCP.

[78] To the maximum extent possible unloading will be scheduled to occur during the DTCP in order not to disturb stable pointing while the satellite is in autonomy. This might not always be possible.

[79] In the nominal case there is still a valid MTL loaded on-board covering the next OD (48-hour autonomy requirement). The "schedule" (MTL) to be loaded needs, therefore, only to cover the last 24 hours of the 48-hour period.

[80] The end-to-end system must be dimensionned in such a way that it will be possible to dump 24 hours of stored data during the DTCP. It should be possible to dump the stored data and upload a new MTL simultaneously.

The table below provides a "typical" timeline of the DTCP activities.

DTCP Timeline of Events	
P – 15 min	Ground Station configure for H or P, 150 kbps TM rate; 4 kbps TC rate
P – 15 min	MOC configures for pre-pass tests
P – 14 min	Pre-pass data flow tests
P – 5 min	MOC configures links for RT HK, RT SCI, Events, Recorded HK, Recorded SCI by priority
P - 5 min	Slew to acquisition attitude (scheduled on-board, not applicable for Planck)
P - 1 min	Herschel in earth pointing mode (i.e. attitude fulfils MGA ± 15° to Earth) , TX on 150 Kbps
P	Start Telemetry acquisition in medium rate (scheduled on-board). Acquire TM (RT HK), if no acquisition configure for low bit rate, re-try and start problem analysis
	Start Ranging (for 5 minutes). Start transfer of RT-HK TM in near real-time to ICCs@MOC (Herschel) or IWs@MOC (Planck)
P + 5 min	Reconfigure Ground Station. Switch to high TM rate.
P + 10 min	Enable downlink of events, and stored HK (~29 minutes).
	Evaluate recorded HK and events data.
	If spacecraft OK do: Routine pass activites: RWL biasing, instrument configuration etc.
	If s/c not OK do: - start recovery, if recovery successful, original timeline can be re-enabled and original 24 h+ MTL can be uplinked. - in case of more severe contingency: kick off re-planning; new MTL may be available by the next pass, latest after 3 days; until then part of the MTL (in terms of sub-schedules) or entire MTL may be disabled - in case original MTL cannot be enabled, decide on manual TT commands to be uplinked for vital activities (Transponder ON at AOS, etc...)
P + 12 min	Uplink MTL (~30 minutes)
P + 40 min	Enable dump of stored science data (~123 minutes).
	Enable VC1 RT Science: 1hr for Herschel, 20mins for Planck
P + ~ 2 hours 45 minutes	Terminate all dump activities
P + 2 hours 50 minutes	Configure station and switch to medium rate. Start Ranging (for 5 minutes)
	Reconfigure spacecraft for out of coverage period Switch to LGA (VC0 at 5kbps)
P + ~ 3 hours	End of pass. Herschel can resume normal observation mode (no earth pointing

	constraints)
P + ~ 10 hours	Data Transfer from ground station to MOC complete (assuming 1Mbps data link between ground station and MOC for Herschel and Planck together)

The following particular activities *will be carried out in the DTCPs included in the routine scenario.* The allocation of tasks between the DTCPs is somewhat arbitrary (see section 7.1.1) and can be changed if necessary.

- Ranging
- Packet Store dumps
- MTL uplink
- Reaction wheels momentum biasing – TBD minutes duration commanded from the MTL
- Handling of RT science
- PACS Cooler recycling – ~ 2hr duration commanded from the MTL
- "weekly" calibration check – TBD what sort of calibration is to be done and when
- pointings exercised during the DTCP – TBD minutes duration commanded from the MTL and mutually exclusive with the PACS cooler recycling
- specific[81] intrument related procedures

7.3 Autonomous Operations

During this period the spacecraft is no longer monitored from the ground. It executes the corresponding portion of the MTL. The FDIR (spacecraft and instruments) and the OBCPs ensure safe operations until the next DTCP[82]. See the PSOF example in Appendix 10 for an example of the autonomous period.

7.4 Post-processing

This covers all the activities taking place at the various ground segment elements i.e. MOC, HSC and ICCs in order to process the TM and related ancillary information into scientific products which can be archived and distributed to the science community. This is considered to be outside the scope of this document. Similarly long term routine activities such as on-board S/W maintenance and Ground Segment software maintenance are not covered. It should also be noted that some of the results of this post-processing e.g. trend analysis, processing of calibration and engineering observations, etc. will result in adjustments to the instruments operating parameters and/or improvement of operating procedures. This feeds back into the planning process.

[81] There are no specific examples available at this time. This is kept as a place holder. This is considered as non-critical since the facilities are available in ESOC's Mission Control System (MCS). These operations, if required, would be carried out manually by the SPACON according to procedures specified by the instruments. Possible examples: fine tuning of specific instrument settings e..g. bias voltages, offset, etc.

[82] Normally, executing FDIR or contingency OBCPs will not be interrupted once back in a DTCP.

8 PLANCK ROUTINE MISSION SCENARIO

The Reference Mission Scenario described here corresponds to the **Routine** operations phase of the Planck satellite. The spacecraft is at L2. The spin rate is now fixed at 1 rpm and the spin rate drift over an hour is maintained at < 10^{-4} rpm[83]. Both spacecraft and instruments have been commissioned and calibrated. The satellite nominal operational configuration has been established. It includes, possibly, some redundant units if the corresponding prime units have been found defective. The ground segment is considered operational and the operation teams, properly trained, are settling into a one-shift per day operations (seven days per week for the FCT, five days per week for the DPCs). The DPC@MOC leave the MOC, though the IW@MOC remain to provide near real-time connection to the DPCs.. The New Norcia Ground Station alone is allocated to Planck (and Herschel) during the routine phase.

Despite the fact that the Herschel and Planck missions are fundamentally different in nature there are many common features between the two. These are listed below:

- It is convenient to define a 24-hour Operational Day (OD) for Planck
- A DTCP of maximum 3 hours is baselined.
- A maximum of 130 kbps has been allocated to the Planck instruments over a 24-hour period.
- The Satellite modes and mode transition logic are identical
- The FDIR philosophy and failure level definitions are the same (there will be however some differences in implementation due to the different ACMS)
- MTL and SSMM management are identical
- The OBCP Development Environment and the SCL are identical
- Herschel and Planck activities during the DTCPs are essentially the same

These similarities imply that several major aspects of both mission scenarii e.g. FDIR, MTL handling, OBCP management, etc. can be validated jointly although differences will exist at the level of the detailed procedures.

The major differences which impact the mission scenarii are listed below:

- Planck is a survey type mission. No request for Planck observation time coming from the "science community" need to be processed. The Herschel-like concept of individual observations does not exist for Planck.
- For Planck there is a direct communication between the MOC and the DPCs for instrument control matters. It is expected that instrument control parameters are updated with a timescale in the order of a few days.
- In the nominal case, for Planck, both instruments (LFI and HFI) operate simultaneously sharing the available TM bandwidth (the respective allocation is defined in the IID-Bs and will be fine-tuned during flight).

[83] The spin rate for the transfer has been selected (current baseline) at 5 rpm which is not suitable for scientific operations.

- The scientific operations continue nominally during the DTCP (dependant on the question of interference from the transmitter). The MGA shall not be re-pointed towards the Earth.
- Two sky surveys[84] shall be carried out, each of which must cover at least 95% of the sky.
- Each sky survey must allow for multiple redundancy of observations at timescales of order one minute, one hour, and one month.
- Coverage gaps of the two surveys must be minimised.
- Data loss in the end-to-end system (spacecraft, ground station, MOC, DPCs) must be minimised.
- Thermal transients due to manoeuvres and change of instrument settings must be minimised. [85]
- Pointing control on-board: The current ACMS design corrects errors from one slew in the next, i.e. they are not cumulative. In this case the main corrective action will be updating of tables characterising the actuators performance and sensors alignment.
- Pointing control on-ground: If there is a need the MOC will carry out, at appropriate intervals, on-ground monitoring and compensation of pointing drifts affecting the scanning law.
- Orbital correction manoeuvres (expected to be required once every 4 to 8 weeks) shall be carried out during the DTCP and without spacecraft re-orientation, nor interruption of the data acquisition to the maximum extent possible.

For Planck as for Herschel the reference mission scenario can be broken into four consecutive phases: (i) planning phase; (ii) activities during the DTCP; (iii) autonomous operations; (iv) post processing.

8.1 Planning phase

In the routine phase the basic operational configuration is based on parallel operations of HFI and LFI. As shown in the table below other configurations exist bust they are considered non nominal and correspond to degraded operations.

Config.	**HFI**	**LFI**	**Comments**
1	Prime	Prime	Nominal configuration
2	Prime	Standby	Degraded operations
3	Standby	Prime	Degraded operations

Each sky survey is carried out according to a “scanning law” which is determined in advance. Details can be found in RD2 (appendix 1). The scanning law is not changed during a survey. It is however possible that, based upon the results of the 1st survey, the scanning law is changed for the 2nd survey.

[84] The duration of each sky survey depends on the angle between the spin axis and the Telescope Line of Sight (LOS). This angle has been set at 85^0 which corresponds to a duration of less than 7.5 months. Taking some margin into account 15 months are planned for the duration of the routine phase.

[85] Thermal constants for Planck are very long. Switching off of the active cooling systems must be avoided Combined with the (related) requirement of data loss minimisation the thermal stability requirement is likely to have an impact on the implementation of the FDIR which needs to be particularly “robust” in order to avoid unacceptable degradation of Planck science return.

The scanning law to be used for the 1st survey is established by simulations prior to launch and refined during the PV phase if necessary.

The scanning law consists of two components of motion of the spin axis: one along the ecliptic plane such that the spin axis direction follows the Sun (1 degree per day), and one very slow motion (of the order of a few degrees per month with a maximum of 15 degrees) in the direction perpendicular to the ecliptic plane. This second component increases the overall sky coverage and level of redundancy i.e. a given location of the sky is observed many times (both with short and long time scale periodicity).

The Planck telescope defines a sparsely sampled Field of View (FOV) approximately 8° in diameter around the LOS inclined by 85° from the spin axis. As the satellite rotates, the FOV traces a circle of diameter 170° on the sky.

The scanning law is implemented as a series of spin-axis reorientation manoeuvres at 30-60 minute intervals (on average one manoeuvre every 45 minutes, of average amplitude 3.0 arcmins, and resolution 0.1 arcmins.).

The external inputs to the MOC MPS come from two sources:

1. The Planck Science Office (PSO). The process starts with the provision by MOC/FD to the PSO of two files specifying the characteristics of the Planck orbit: (i) a Long Term Orbit File (LTOF) covering one full survey (~7.5 months); (ii) a Short Term Orbit File (STOF)[86] produced monthly, and covering at least two months in the future. Based on the LTOF, the STOF, on instrument and pointing requests generated by the IOTs and on the scanning law (which has been selected/validated during the Commissioning/PV phase) the PSO produces a Planned Pointing List (PPL) every 4 weeks, 3 weeks in advance[87]. It is due to the stability of the scanning law that the pointing schedule of the satellite is known many weeks in advance. However the scanning law will be modified in flight in response to events such as: (i) instrument anomalies (e.g. detector behaviour); (ii) instrument reconfigurations; (iii) calibration needs (depending on availability of celestial objects); (iv) full or partial gaps in the survey, (v) unforeseen changes in the completeness and quality of the acquired data, etc. Such modifications will be constrained by the current orbital location and pointing of the TM antenna, and the size of the payload shadow cone (20 degrees). Updates to the scanning law will be covered by the regular Mission Planning Cycle or by pre-agreed procedures.

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[86] The STOF is used by the PSO as an input to a “constraint checker” that allows the PSO to generate constraint-free spacecraft “pointings”. The constraint-checker is delivered to the PSO by ESOC/FD.

[87] The PPL is produced by the PSO tool described in [RD23].

2. The Data Processing Centres (DPCs). The required instrument configuration[88] is provided directly to the MOC, for each instrument, by the corresponding Instrument Operations Team (IOT)[89].

Meanwhile, the Planck PSF is created at the MOC based on the weekly Ground Segment Schedule. FD at MOC then combine the PPL and the PSF to create the Augmented Planned Pointing List (APPL)[90] in which the pointing requests from the PSO are converted into appropriate attitude-related events, i.e. a set of periodic (~hourly) spacecraft manoeuvres (spin axis re-orientations) required to implement the scanning law. The associated Attitude Parameter File (APF) is also created. In this context a Planck “observation” (by analogy with Herschel) consists of a fixed ring on the sky being observed simultaneously by HFI and LFI done repeatedly over a period of 30-60 minutes. A manoeuvre (duration ~ 5 minutes) at the end of this period leads to the next “observation”.

Next the Planned Spacecraft Operations File (PSOF) is produced by adding to the APPL/APF all the routine spacecraft commanding (e.g. Tx switch-on for the DTCP) and the inputs from the IOTs.

The Planck PSOF will be stored on the MOC’s Data Distribution Systems (DDS) where it can be fetched by the DPCs and Project Scientist as needed. It covers a week of operations.

From the PSOF the MOC will generate 7 MTLs, which are individually uplinked during the appropriate DTCP.

It is expected that the RMS-routine scenario (corresponding to the activities between START_SCAN and END_SCAN in Appendix 11) can be designed simply on the basis of a PPL generated manually. In fact all the complexities of the processing leading from the PPL to the PSOF can be simulated in a straightforward way by manual construction and “adjustment” of the series of pointing requests (PREQ) making up the PPL (see [RD24] for a description and format of the PPL).

Appendix 11 contains a pseudo-PSOF making up a typical OD that can be used as a guide for the design of the RMS-routine scenario:

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[88] The Sorption Cooler which is an element common to both HFI and LFI will be managed by one IOT only (in principle LFI)

[89] It is expected that the HFI and LFI IOTs will coordinate their inputs in order to achieve an optimal joint operation of the two instruments. The MOC will take independent inputs from each IOT and run them through a set of automatic pre-agreed procedures which have as objective to ensure that each instrument’s behaviour does not adversely affect the other instrument. These procedures will be developed by the instrument teams under the coordination of a PSO-led “Instrument Coordination Working Group”. It is anticipated that the configuration will be stable during each sky survey, although minor adjustments may need to be done at time scales of a few days. The IOT inputs will contain all the information required by the MOC to carry out the instrument operations, e.g. procedures, command sequences, software images as required, etc.

[90] Generation of the APPL is a complicated process since it may involve shifting/adjusting PPL-generated observations (e.g. dwell times and/or slew times) to take into account exact DTCP times –not known at the time of PPL generation- and/or orbit manoeuvres, photometric calibrations, beam reconstruction, LoS calibrations, recovery of small gaps, etc.

- The 1st column contains the relative time (i.e. starting at 00:00:00) of the various activities expressed in hh:mm:ss. Times given are approximations.
- The 2nd column is a symbolic label.
- The 3rd column provides a description.

Note: This is a faithful approximation of a Planck PSOF, it is not an exact example.
The usage of sub-schedules for Planck is TBD. See [RD18] for the intended operational usage of sub-schedules. It describes how they can be used to allow TT commanding for platform recovery activities whilst the previously uplinked MTL is suspended.

During the routine operations it is not anticipated to interrupt a sky survey to carry out calibration operations. Similarly no instrument engineering / diagnostic operations will be required except in contingency situations. Under nominal conditions the instruments do not switch modes. The nominal operational modes are defined as:

- HFI (nominal mode)
- LFI (normal[91] science)
- Sorption Cooler (Run mode)

The other LFI, HFI and Sorption Cooler modes corresponding to initialisation / set up and/or diagnostic are normally only activated and checked at the start of the mission e.g. commissioning or in case of anomalies.
Under nominal conditions, the mode transitions for Sorption Cooler, LFI and HFI are carried out by ground command.

Due to the extreme sensitivity of Planck to data loss the following general approach is taken:

- Minor instrumental problems (e.g. failure or degradation of small number of detectors) will not lead to interruption of the surveys, though they are likely to lead to a re-allocation of the relative TM bandwidth of each instrument..
- During the 1st survey it will likely be attempted to recover minor gaps in sky coverage by means of dedicated manoeuvres, not part of the scanning law[92]. These manoeuvres must be implemented within days of gap occurrence, depending on orbital location and the on-going scanning law.
- Failure leading to large gaps in the 1st survey e.g. gaps resulting from a sorption cooler failure will be dealt with on a case by case basis.

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[91] There exists an “extended science” mode for LFI, which would be used in case HFI would become non-operational (e.g. in case of failure of the 4 K cooler). In this case all the science TM bandwidth would be allocated to LFI. An equivalent mode is foreseen for HFI in case of non-operability of LFI. It might be advantageous to consider these modes as extreme cases of re-allocation of TM bandwidth , in which one of the two is allocated zero science bandwidth. In such cases at least part of the non-operational instrument must be kept alive (to the extent possible) to allow operation of the other to proceed e.g. HFI 4 K cooler is needed for LFI loads, LFI sorption cooler and heat switches are needed to operate HFI. The non-operational instrument must therefore generate HK data.

[92] This strategy is dictated by the fact that, due to the optical arrangement, the sky will be covered in a different manner in each of the two surveys (even assuming identical scanning laws). This means that if a minor gap occurs in the 1st survey, to recover it in the 2nd survey would require severely constraining the scanning law. It is therefore more practical to try to recover minor gaps as soon as they occur.

- During the 2nd survey, efforts will be made to recover any gaps left in the 1st survey. This would be likely to require adjusting the scanning strategy, making special re-orientation manoeuvres not in the scanning law, etc.

The interaction between CDMS and instrument is expected to be very straightforward in the sense that the CDMS (i) does not wait for any packet acknowledgment from the instruments before the next packet is sent (at the MTL-specified time); (ii) does not interpret the TC verification packets generated by the instruments. Both LFI and HFI will have the capability to buffer a TBD number of TC packets. The schedule generation process shall ensure that the TC packets will be sent at a rate which will not cause overflow of the on-board buffers.

Since there is no closed-loop pointing control on board Planck, the MOC will analyse the information from the ACMS sensors and will adjust the scanning law as to compensate for drifts and other pointing anomalies. This will be done on a daily and weekly basis.

8.2 Daily Tele-Communication Period (DTCP)

The activities are essentially the same as for Herschel. Since adjustments to instrument and/or sorption cooler operating conditions are essentially manual for Planck, some specific related activities may have to be carried out during this phase. This should be minimal under nominal conditions.

8.3 Autonomous Operations

During this period the spacecraft is no longer monitored from the ground. It executes the corresponding portion of the MTL. The FDIR (spacecraft and instruments) and the OBCPs ensure safe operations until the next DTCP[93].

8.4 Post-processing

As for Herschel.

Satellite TM alone will not be sufficient to fully exploit the Planck data scientifically, e.g. satellite TM does not contain any orbital and velocity information, calibrated thermometry, or processed pointing information[94].
The MOC will make this additional, ancillary data available on the DDS. This will include predicted and measured orbital data and reconstructed attitude history.

The delay for delivery of this data is of the order of one week (TBC).

Some ancillary and/or derived data will be required for instrument Quick Look Analysis (QLA) processing and therefore must be made available by the MOC within a short period (hours) of TM

[93] Normally, executing FDIR or contingency OBCPs will not be interrupted once back in a DTCP.
[94] It is assumed that post-processing at the MOC is required in order to achieve the final pointing accuracy requirements.

delivery. This applies for example to pointing data; in this case the MOC shall deliver a less accurate product within a short period (some hours) and the fully accurate product within a longer period (one week). Further reprocessing may occur at later times during the mission as satellite knowledge grows.

9 FAILURE CASE SCENARIOS

9.1 SOHO failure case

9.1.1 Introduction

9.1.2 Objectives

If a spacecraft is lost it will be due to unforeseen reasons. Therefore the objective of this note is not to discuss all possible known failure cases, but to identify extremely degraded spacecraft conditions or spacecraft lost conditions. These conditions shall be used to evaluate that all sensible measures which could aid the recovery have been incorporated into the design, and also that there is no inbuilt design feature which could prevent recovery.

9.1.3 Background

The SOHO and Olympus missions were both recovered after the spacecraft were lost for some time and lessons were learnt in their recovery. The SOHO case in particular, is taken here as a reference case for Herschel / Planck. Below is a summary of the SOHO recovery and later the specific situation for Herschel and Planck is discussed.
A full report on the SOHO failure from which much of the data below were extracted was given in ESA paper 1999-01-2484 authors -H Fiebrich, J E Haines, P Perol,, P Rumler.

Of course there are also differences from SOHO and an important difference for Herschel is that because it relies on a cryostat any failure which allows sun onto the cryostat will result in a rapid loss of Helium and a drastic shortening of the mission. In this case it might only be relevant to consider failures which can be recovered rapidly e.g. within a few hours. Planck has no cryostat and a recovery might still be possible after an extended time e.g. weeks.

9.1.4 Overview of SOHO vs Herschel/Planck

In the table below it can be seen that there are many similarities between SOHO and Herschel/Planck. The main differences are in the S/C dynamics, attitude control for Planck and battery (type and charge method).

	SOHO	**Herschel /Planck**
Orbit	**L1**	**L2**
TT&C	HGA/LGA	MGA/LGA
MAIN Power Bus Power Regulation	28 V regulated S3R	28 V regulated S3R
Battery Battery Charge method Battery Discharge control	2 x 20 AHr NiCd 2x BCR's connected to the Main Bus, Total SA can be used for charge 4 x BDR's	1 x 29.6 AHr Li Ion (tbc) 3x SA battery charging sections, 10% of total SA can be used for charge 2 x BDR's (400W)
Solar Array # Sections	~1500W 8 x 6.3 A	~1500W 30 x 1.7A
S/C Dynamics	max inertia axis // SA	max inertia axis ⊥ SA
Attitude Control	3-axis control	Herschel: 3-axis control Planck: slow spin ⊥ SA
RCS	Hydrazine	Hydrazine
Thermal Control	S/W controlled heaters + thermostats	S/W controlled heaters

9.1.5 Failure scenarios

The SOHO spacecraft was lost for some time and intermittent contact was only made with the S/C after it had been lost for 6 weeks. When telemetry was finally received the spacecraft was slowly rotating every 53 seconds. It was near its expected position at the L1 libation point with the solar array panels almost parallel to a sun / spacecraft line.

At the time of first telemetry reception after recovery, SOHO spacecraft and payload were either extremely cold or extremely hot. For instance the batteries were at –20 deg. C, the gyros at –25 deg. C, some instruments hot at +80 deg. C and some instruments cold at –60 deg. C. In the propulsion system the hydrazine propellant was partially frozen, with the tank temperature at +1 deg. C., one feed pipe at –16 deg. C. and several thrusters at –35 deg. C.

The main power bus would recover when the solar array was facing the sun and disappear again when in shadow. The batteries were so cold that they stored little energy. Because of the intermittent solar power, the battery charge regulator (BCR) would relax into the 'off' state every time the power bus voltage dropped below 25 volts or the battery voltage below 20 volts. As a result, it was initially necessary to command 'on' the charger once every spacecraft revolution
In order to recover SOHO it was necessary to use the batteries to store energy for long enough for the AOCS to be powered to repoint the S/C. To do this, it was first necessary to unfreeze the batteries to increase their energy capacity and also to switch off all battery non essential loads

Two distinct cases can be identified and should be considered separately:

1) Recovery within a short time eg 4 hours
   Thermal conditions are close to normal, solar array periodically in sun due to nutation

2) Recovery after an extended time eg 6 weeks
   Severely degraded thermal conditions, solar array parallel to the sun with no nutation.

Each of these cases are described below in terms of the initial conditions to be considered.

Spacecraft Dynamics
Reference systems:
Orbit {O}:
Origin, CoM of satellite
z: Ecliptic pole
x: In ecliptic plane , anti sun direction
y: In ecliptic plane, completes RHS.
Body axis, as defined in SRS.

9.1.6 Scenario 1: Initial Conditions

Planck:
Spinning about body-x axis @ 1.7 RPM
Nutation 30 deg (about 10 sec thruster failure)
Body x-axis 75 deg away from Orbit x-axis, in Orbit xz-plane.
Battery Voltage below BDR trip-off (<15 V)
S/C RCS and unit temperatures: within non-operating conditions

Herschel
Spinning about body-z axis @ 1 RPM
Nutation 45 deg (major half cone angle of "nutation ellipse")
Body z-axis aligned with the Orbit z-axis.
Battery Voltage below BDR trip-off (<15 V)
S/C RCS and unit temperatures: within non-operating conditions

9.1.7 Scenario 2: Initial Conditions

Planck:
Spinning about body-x axis @ 1.7 RPM
No nutation
Body x-axis aligned with Orbit y-axis
Orbit system moves -1 deg/day around Orbit z-axis (i.e. SA moves into the sun).
Battery Voltage close to zero
S/C temperatures: steady state as given by unpowered S/C and initial SAA conditions

Herschel
N/A

9.2 Other failure case scenarios:

TBW

APPENDIX 1: SUMMARY OF HIFI OPERATING MODES

Note: Where there are differences between the following text and the applicable Instrument User Manual (to be made available at a later date), the IUM will have precedence.

Off mode

In this mode all power is removed from the instrument. Neither science nor housekeeping data will be available

Stand-by mode

In this mode all HIFI units in the SVM are active, only thermal control of the LOU is active and the FPU is inactive. Only housekeeping data will be available.

This mode will be used when HIFI is not primary during normal science operations. The thermal configuration of this mode minimises the warm-up time required when changing to prime. The instrument warm-up time will be less than 1 hour.

Primary operating mode

There is only one primary operating mode. Within this mode a single mixer band and a corresponding LO band are operational. Science and housekeeping data will be available.

Transitions – TBD

APPENDIX 2: SUMMARY OF PACS OPERATING MODES

Note: Where there are differences between the following text and the applicable Instrument User Manual (to be made available at a later date), the IUM will have precedence.

Primary operating modes

Photometer modes
These comprise all photometer observing modes. Science and housekeeping data are produced at a rate compatible with the CDMS, as defined in the IID-B. During photometer observations, the spectrometer channel and the spectrometer detectors are in stand-by.

Spectrometer modes
These comprise all spectrometer observing modes. Science and housekeeping data are produced at a rate compatible with the CDMS, as defined in the IID-B. During spectrometer observations, the photometer channel and the photometer detectors are in stand-by.

Parallel mode
At this moment the parallel mode with SPIRE is going to be implemented. Parallel means PACS is operated in parallel to and co-ordinated with SPIRE. This could allow more efficient large-scale multi-band mapping. The parallel mode has an impact on the PACS data reduction, TM rates will be shared between PACS and SPIRE. PACS and SPIRE observe at the same time.

Standby modes

The standby modes are the „warm-up" modes for either the photometry or the spectroscopy modes, during which CRE's are powered up to reach their equilibrium operating standby condition. Only housekeeping data are produced at a rate compatible with the CDMS, as defined in IID-B. The transition from standby mode to any observing mode will require several minutes of stabilisation time for some FPU components.

Recycle mode

The 3 He sorption cooler should be recycled every 2 days for 2 h. This recycling activity is supposed to take place during the earth-spacecraft transmission period, when no instrument can observe. Except for the cooler, all other subsystems are in a state identical to the SAFE mode.

Safe mode

In safe mode the mechanisms are powered down if possible and, if applicable, in their default positions, no bias is applied to the detector arrays, the CRE's are in their off mode. The grating is „parked" and actively held in its safe position. Only housekeeping data are produced at a rate compatible with the CDMS, as defined in IID-B.

Init. mode

This mode represents the state the instrument enters after a power on or re-boot. All sub-units (FPDPU, FPSPU, FPMEC/FPDEC, BOLC, and BOLA) are powered on. In this mode only a sub-set of software commands may be executed and updates of the respective sub-unit on-board software can be carried out safely.

Off mode

All power is removed from the instrument. Mechanisms may actually be in any position, depending how the switch-off was done. Even when a nominal switch-off is done via the SAFE mode, the mechanisms (especially the grating) may change its position when the spacecraft moves. No data are transmitted or received through the instrument telemetry interface, but limited temperature data will be available from spacecraft powered sensors. Transition into this mode can be either in a controlled way via the safe mode or in case of more severe anomalies instantaneously. In that case the status of some mechanisms may be unknown.

Test modes

Test modes will be mainly implemented for investigations of fault conditions. Fixed configurations of the instrument are used to generate known sets of data. They will be used during ILT's and during integration and verification for debugging of the interfaces between PACS sub-units and between the instrument and the spacecraft. Obviously, standard as well as non-standard Instrument Data Configurations will be used while running in these instrument modes. Some test possibilities will be implemented in the OBS.

Non Prime mode

The Non Prime mode is identical to the Safe mode with a H/K rate reduced to 2 kbit/s.

Transitions – TBD

APPENDIX 3: SUMMARY OF SPIRE OPERATING MODES

Note: Where there are differences between the following text and the applicable Instrument User Manual (to be made available at a later date), the IUM will have precedence.

OFF Mode

All instrument sub-systems will be switched off - including the DPU and there will be no instrument telemetry.

Initialise (INIT) Mode

This is an intermediate mode between OFF and ON. This will be the mode the instrument enters after a power on or re-boot. In this mode only a limited sub-set of commands may be executed.
This mode allows updates of DPU on-board software and/or tables to be carried out safely before they are used for instrument control.

ON Mode

The DPU will be switched on and can receive and interpret all instrument commands, but no other sub-systems will be switched on (including the DRCU). For engineering purposes it will be possible to command the instrument to switch on individual sub-systems from this mode. Full DPU housekeeping data will be telemetered.

Ready (REDY) Mode

The DPU and DRCU are powered on and the on-board software is ready to receive commands.
No other sub-systems are switched on in this mode. DRCU housekeeping data will be telemetered.

Standby (STBY) Mode

The spacecraft may be pointed in an arbitrary direction (observing with another instrument for instance). The instrument will telemeter only housekeeping information, and perhaps some degraded science data -see below, at a rate very much lower than the full telemetry bandwidth.
This is presently baselined to be the photometer detectors on and at 300 mK i.e. the cooler will have been recycled previous to entering STANDBY. All other sub-systems will be switched off.

Cooler Recycle (CREC) Mode

The 3 He cooler requires recycling every 46 hours (TBC). During this time the instrument will be switched off except for vital housekeeping and cooler functions (TBC).

SAFE Mode

The instrument will be switched to SAFE mode in the event of any anomalous situation occurring whilst in autonomous operation. This will be with the DPU on having been rebooted from a restricted set of software stored in ROM.

OBSERVE MODE (OBSV) MODE

There are two basic sub-modes for the observe mode Photometer and Spectrometer.

Photometer OBSV Modes

Point Source Photometry

The SPIRE Beam Steering Mechanism is used to chop between two positions on the sky at a frequency of typically 2 Hz. The telescope may optionally be nodded with a nod period of typically three minutes. The SPIRE BSM chops and also executes a seven-point map around the nominal position. Nodding is optional.

Jiggle Map

It is similar to point source photometry except that her a a fully sampled larger map is produced, with the option of telescope rastering.

Scan Maps

The SPIRE BSM is inactive, and the spacecraft is scanned continuously across the sky to modulate the detector signals. This can be used with or without chopping.

Other Photometer Modes

Photometer peak-up (TBD):

This mode allows the necessary pointing offsets to be determined in order to allow implementation of the photometer modes. The observation itself is similar to a jiggle map. On completion, the SPIRE DPU computes the offsets between the telescope pointed position and the source peak emission, and sends this information to the spacecraft, which can then implement the necessary pointing corrections.

Operate photometer calibrator:

The SPIRE photometer internal calibrator is energised with a pre-determined sequence and the corresponding detector signals are recorded.

Special engineering/commissioning modes (TBD).

Spectrometer OBSV Modes

There are two kinds of spectrometer observation: point source and fully sampled map. The latter is carried out by repeating the former at a number of separate pointings using the SPIRE BSM (or, alternatively the spacecraft in RASTER Pointing mode). These are implemented as two Spectrometer Observatory Functions (SOFs):

Photometer Serendipity

During spacecraft slews scientifically useful information can be obtained without the necessity of using the focal plane chopper - essentially these are rapid scan maps. The chopper and spectrometer mechanisms will be switched off in this mode. Accurate pointing information will be required from the AOCS to reconstruct the slew path in the data analysis on the ground.

Photometer Parallel

When observations are being made with PACS, scientifically useful data may be obtainable from the photometer, albeit with degraded sensitivity and spatial resolution. In this mode a science data packet will be telemetered alongside the standard housekeeping data. The chopper and spectrometer mechanisms will be switched off in this mode. The feasibility and scientific desirability of this mode is TBD.

Real-Time Commanding

During ground contact it may be necessary to command the instrument in real time and analyse the resultant data on the ground in near real time for instrument testing and debugging purposes. In this case the full telemetry bandwidth will be required for the duration of the instrument test in question. It is not anticipated that this will
occur frequently.

Commissioning/calibration Mode

During the commissioning and performance verification phases of mission operations, many housekeeping and other health check parameters will be unknown or poorly defined. This mode allows the limits on selected health check parameters to be ignored by whatever real time monitoring systems are in place on the spacecraft /instrument.

Transitions - TBD

APPENDIX 4: SUMMARY OF HFI OPERATING MODES

(Note: Descriptions will be provided with the next issue – source: Chapter 4.6 of the IID-B)

Note: Where there are differences between the following text and the applicable Instrument User Manual (to be made available at a later date), the IUM will have precedence.

OFF Mode (OOFM)

BOOT Mode (OBTM)

STAND – BY Mode (OSYM)

COOL DOWN SEQUENCE Mode (OCSM)

CONFIGURATION Mode (OCNM)

OBSERVATION Mode

COOLER MAINTENANCE Mode (OCMM)

WARM UP SEQUENCE Mode (OWSM)

WITHOUT COMPRESSION Mode (OWCM)

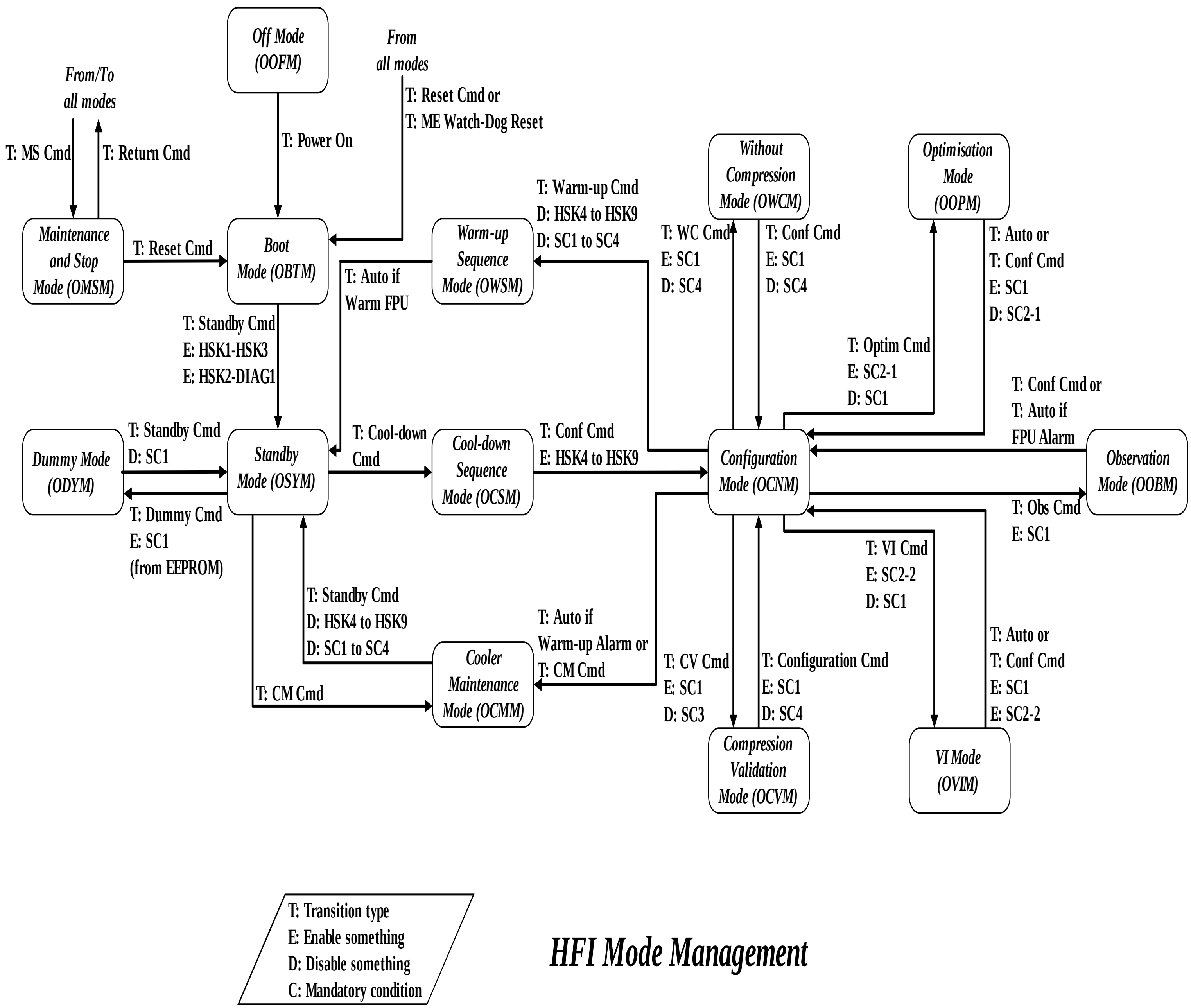
COMPRESSION VALIDATION Mode (OCVM)

OPTIMISATION Mode (OOPM)

VI Mode (OVIM)

MAINTENANCE and SET – UP Mode

DUMMY Mode (ODVM)



HFI Mode Management

APPENDIX 5: SUMMARY OF LFI OPERATING MODES

(Note: Descriptions will be provided with the next issue – source: Chapter 4.6 of the IID-B).

Note: Where there are differences between the following text and the applicable Instrument User Manual (to be made available at a later date), the IUM will have precedence.

OFF mode

STAND BY Mode

DAE SET- UP Mode

NORMAL SCIENCE MODE

EXTENDED SCIENCE MODE

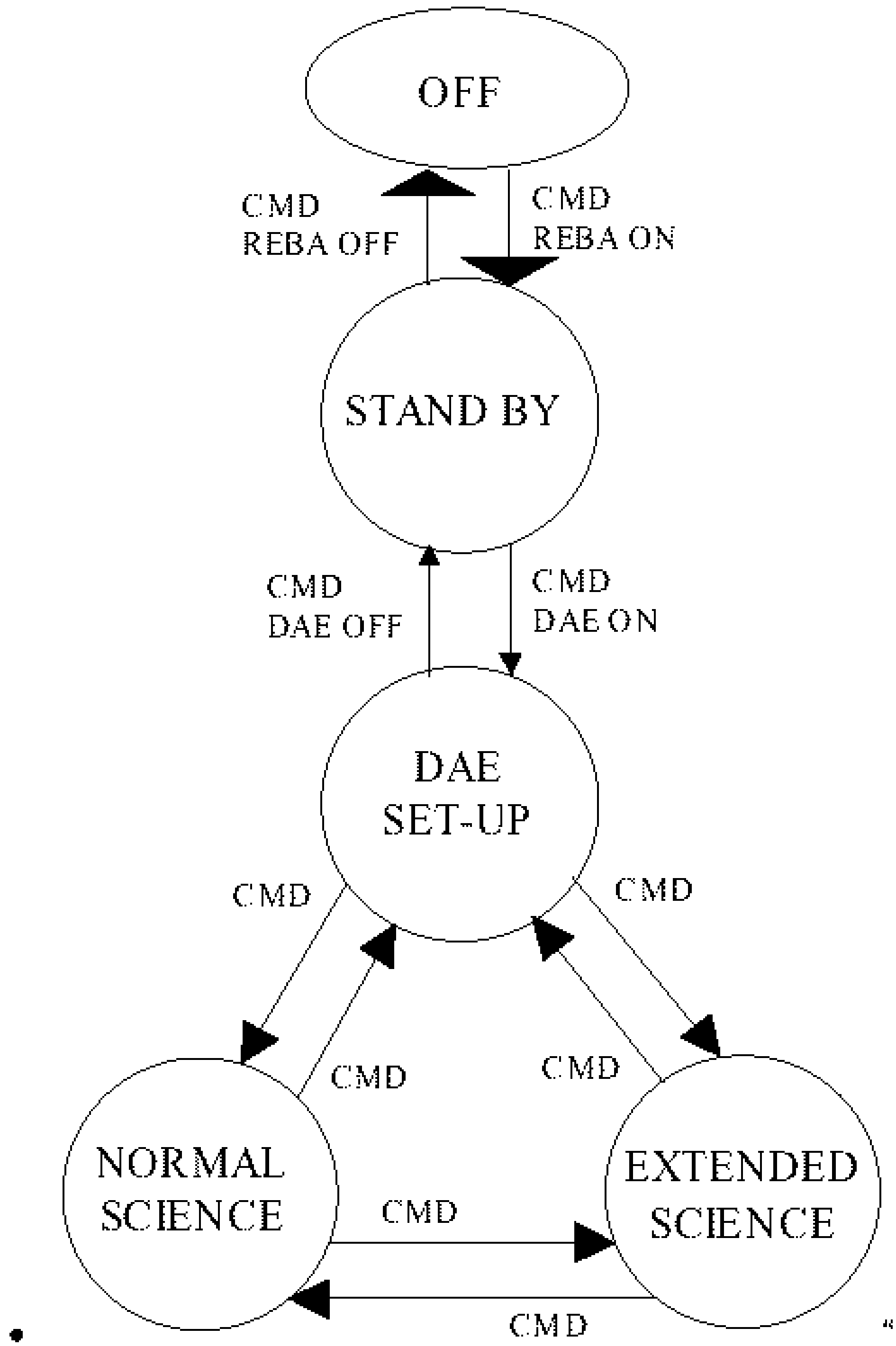


Figure 4.6-1
LFI Operating Modes and theirs nominal transitions

APPENDIX 6: SUMMARY OF SORPTION COOLER OPERATING MODES

Note: Where there are differences between the following text and the applicable Instrument User Manual (to be made available at a later date), the IUM will have precedence.

The operations modes of the sorption cooler distinguishes between modes and states. One mode can consist of one or more states.

OFF Mode
State = OFF
All power is removed from the SCE and the TMU. Equipment may be handled and transported safely.

BOOT Mode
The SCE is powered. The following operations are carried out:

-Perform system boot up.
-Initialize 1553.
-Acquire CDMS command/telemetry clock and timing signal.
-Check PROM, RAM, and EEPROM.
-Transfer program from EEPROM to RAM.
-Check software transfer.
-Housekeeping at the end (electronic & software parameters).

INIT Mode
<u>State = Initialization and health monitoring</u>

-Soft reboot of the system.
-Re-initialize 1553
-Housekeeping (electronic and software parameters).
-Software patching and memory dumping can be done from the init mode.
-Solid states relays and thermal switches are initialized: check if thermal switched are open and if gas gap are closed (or opened). It is the last thing to do before the "Go to ready" command.

<u>State = Electronic/cooler sensor health monitoring</u>
This state is entered autonomously.
Jump to this state automatically when enters in ready mode.

-Request second power line from CDMS. This is the first thing to do when enters in ready mode.
-Health monitoring. Mainly used to test P and T sensors. Note: it is just a monitoring, values are reported via telemetry but there are no fault detection and no fault output procedures.
-Send housekeeping during health monitoring (which mainly includes sorption cooler P and T sensors).

<u>State = Ground Health Check</u>
(air compatible test)
This state is entered via Command.

Can be proceeded on the ground and in flight

-Keeps all components within safe operating ranges (to both people and environment – no oxidation condensation).

-Procedure: see Flight health check procedure. Only cycle time value changes.

-All off after the end of the ground health check procedure.

State = Flight Health Check

This state is entered via Command

Can be proceeded only in flight

- Procedure: <390 seconds switch time operation through one cycle followed by operation of LPSB heater, defrost and LR3 heaters etc... No delay in gas-gap timing. All off after that

-High data rate housekeeping (full cooler dataset).

RUN Mode

All units are powered. Patch of software and memory dump can be done.

State = Start-up

This state is entered autonomously.

Gets beds nearly to basic operating pressures and temperatures.

Jump to this state automatically when enters in run mode.

Procedure assumes start from cold payload and instruments.

Currently, enters in startup state every time run command is received.

Capable of working with 6, 5 or 4 beds.

-Safety Monitoring.

- High data rate housekeeping (full cooler dataset).

- Automatically goes to “Safe Operation” state after the completion of the startup procedure.

State = Normal Operation

State can be entered autonomously or via Command

Normal operation. Cycle time 667 sec ` 0.1 sec.

Initiation of normal operation state is only allowed at the completion of a cycle in the previous state, so must finish a cycle in the safe operation state before entering to normal operation.

Each states of the run mode are operated for an integer number of cycle³1.

Fractional cycles are precluded except for critical emergency response (see “Fault Detection”).

Capability of working with 6, 5 or 4 beds.

-Safety Monitoring.

-Refill State Buffer every cycle time (667 seconds). The state buffer contains all operating parameters and values that will allow restarting from the previous point in case of power loss.

-LR3 PID regulation.

-Can exit during mid-cycle to Safe Operations or at the end of the cycle for 5 or 4 beds operation.

State = Safe Operation

State can be entered autonomously or via command
Same as NORMAL OPERATION. Only switch time changes.
Enters in safe mode after the completion of the startup procedure.
Can be entered due to safety problem at any time and anywhere in mid-cycle
Minimum residence time is one complete cycle (390 sec).
Capable of working with 6, 5 or 4 beds.

- Runs 390 sec switch time with no change in power. Maintains operating condition without increasing pressure.
-Safety monitoring.

State = 5 beds Operations

State can be entered autonomously or via command
Same as NORMAL OPERATIONS. Only beds number changes (6 → 5). Cycle time is equal as for normal operation (667 sec) or safe operation (390 sec).
Can enter in 5 beds operation by ground command or internal decision for things like heater failure.
Must finish the current cycle before enter in 5 beds operation cycle

State = 4 beds Operations

State can be entered autonomously or via command
Same as NORMAL OPERATIONS. Only beds number changes (6 → 4). Cycle time is equal as for normal operation (667 sec) or safe operation (390 sec).
Can enter in 4 beds operation by ground command or internal decision for things like heater failure.
Must finish the current cycle before entering in 4 beds operation cycle

State = Defrost type 1

State can be entered Autonomously or via Command
Same as SAFE OPERATION except that heaters are on while operating (Filter + JT ON until P<55 bars).

-Cycle time = 390 sec if autonomous or given by ground command if manual.
-When GO TO DEFROST by command, the command must include duration.

State = Defrost type 2

State can be entered via Command only
Same as NORMAL OPERATION except that heaters are on while operating.
Same as defrost 1 except cycle time and can only be entered by ground command that give the residence time in defrost 2.

Cool down

Not a state but an algorithm to pass from 390 seconds to 667 seconds. Capable of working with 6, 5 or 4 beds.

-Safety monitoring
-High data rate housekeeping

SHUT DOWN MODE

State = Monitor

-Ready-like mode with GG on, comp. Heaters off, LR3 off, etc. Cooling is halted, all heat switches are powered, and the cooler's return to ambient conditions is monitored via housekeeping data.
-When Pressures return to ambient limits, the CDMS is requested to switch off the 2nd power line. When temperatures are within limits, the CDMS is requested to switch off the 1st power line.
- Receive and acknowledge software/values (lookup table etc...) patching instructions.
-Control and monitor cool down of heated elements
-Monitor instrumentation and report out-of-limit conditions
- High data rate housekeeping.
-The end of the shutdown mode corresponds to the ready mode.

APPENDIX 7: SREM

This Appendix is added as a place-holder. This section needs to be expanded and the details of the insertion of the SREM in the Reference Mission Scenario need to be agreed between ESA and Industry.

The Standard Radiation Environment Monitor (SREM) is a monitor-class instrument intended for space radiation environment characterisation, radiation housekeeping and provision of radiation alarm functions. The SREM is capable of providing continuous directional, temporal and spectral data of high-energy electron, proton and cosmic ray fluxes encountered along the trajectory of the spacecraft. The SREM is also capable of measuring the total radiation dose absorbed by itself and at various remote locations on the spacecraft.

The SREM is an ESA CFE.

In the absence of any specific Herschel/Planck requirements on the SREM the following documents (attached) are provided.

- SREM Interface Control Document: SREM-DI-CSAG-003 Issue 1, Revision 4 (Contraves)
- SREM User Manual: SREM-UM-CSAG-003 Issue 1, Revision – (Contraves)
- SREM Rosetta Software User Requirements Document: Rosetta-SREM-SURD-v005 (ESTEC/TOS)

The CDMS BSW provides the support necessary to handle the SREM.

The SREM is physically connected to the CDMU via a ML-line (for commands) and a DS-line (for data)

APPENDIX 8: VMC

The Visual Monitoring Camera (VMC) will be used on Herschel/Planck mainly for Public Relations purposes. Its main goal will be to monitor spacecraft separation from the launcher.

The following information is extracted from the presentation made by Alcatel during PM # 13 (05-03-03). Relevance of VMC inclusion into the Reference Mission Scenario needs to be discussed between ESA and Industry.

The VMC will be switched on after spacecraft separation.
After switch on and warm-up the VMC will be set into automatic mode acquisition. In this mode the VMC will take 10 images every 2 seconds. These images will be stored into an internal VMC buffer. Expected image size: 512x512x 8 bits (TBC). The image data will then be acquired, packetized and transferred into the SSMM in a dedicated packet store. The packet store content is downloaded on ground request.

The initialisation sequence shall be executed as soon as possible after spacecraft separation.

As a baseline the number of images to download is 10 (100 as an option). If image data are not available an idle pattern will be delivered.. The acquisition rate has been fixed to be less than 10 kbps maximum in order not to overload the CDMS bus. The VMC data acquisition has a lower priority than any other IO activity.

The CDMS BSW provides the support necessary to handle the VMC.
The camera is physically connected to the CDMS via a ML-line, two ON/OFF lines (for commands) and a DS-line (for data).

APPENDIX 9: ACRONYM LIST

(TBW)

APPENDIX 10: HERSCHEL PSEUDO-PSOF #1

Note: This is a faithful approximation of a Herschel PSOF, it is not an exact example.

hh:mm:ss	label	Description
-00:03:00	TWTA_ON	Pre-heating of the TWTA. Note: we presume no interference with instrument measurements from heating up the travelling wave tube; Note2: how to proceed: do we allow entries with negative times or do we end the OD with the pre-heating of the tube i.e. in time for the next DTCP?
00:00:00	POS_START	OD start. Assumed to correspond to Acquisition of Signal (AOS). The 3 instruments are assumed to be in STBY. Satellite is in its Nominal (SCIENCE) mode. ACMS is in its normal (NOM) mode.
00:00:00	START_DTCP	DTCP Start coincides with OD start
00:00:00	RANGING	5 min ranging
00:00:00	SWITCH_ON_XMIT	Switch-on Xmitter; Downlink rate =150 kbps
00:00:00	START_RT VC0, VC4	Reception of RT TM for Essential and Non-essential HK telemetry for the entire duration of the DTCP
00:05:00	STATION_CONFIG.	(Re)configure Ground Station. Switch to high TM rate (1.5 Mbps). 3 min. allocated.
00:05:00	SWITCH_HIGH_RATE	Switch S/C to high TM rate (1.5 Mbps)
00:10:00	START_VC2 Dumps	Initiate dump of stored HK data – Dump duration ~29 min 1) Dump Packet Store for Event Packets and TC verification 2) Dump Packet Store for Essential HK TM 3) Dump Packet Store for Non-essential HK TM
00:12:00	MTL_UPLOAD	Duration ~30 min (for a nominal 24 hr duration – top up only if no missed DTCP-). MTL loading proceeds in parallel with the Dump activities.
00:14:00	START_SREM	Activate SREM (if not done in Commissioning scenario)
00:16:00	START_PACS_SORP	PACS cooler recycling (executed from the MTL). PACS already in STBY (SAFE). Duration ~ 2hr. Procedure TBD. It is assumed that no scientific observations take place during recycling.

00:18:00	START_RWL_BIASING	Reaction Wheels Biasing (executed from the MTL) – early in the DTCP (duration TBD min)
00:23:00	END_RWL_BIASING	
00:39:00	END_VC2 dumps	
00:40:--	START_VC3 Dumps	Initiate dump of stored Science data – duration ~ 2:03 h (123 min)
00:42:00	END_MTL_UPLOAD	
01:45:--	START_VC1 Science	Enable VC 1 RT Science (~1 hour @120kbps). Could in principle start earlier. Here a "large" margin is included. It is also advantageous in this particular case (weekly calibration carried out) to start collection somehow late in order to get the calibration data in real time. This is considered fine tuning. Non critical!
02:15:--	END_PACS_SORP	End of PACS Sorption Cooler Recycling – PACS returned to STBY (SAFE) mode.
02:15:--	SET_UP_PACS_PHT	Execute Procedure *SetupPhotometr*[1]*y* to set up PACS in its "Photometry" mode in order to carry out subsequent Calibration. Duration TBD. Estimate ~15 min. The procedure could be initiated in parallel with the slew. This is not considered here. It is assumed that the procedure is executed from the MTL. "manual activation" by the SPACON may be preferable (TBD)
02:30:--	SLEW_TO_CAL	Slew to Calibration Star (RA= HHMMSS.SS, DEC= +/- DDMMSS.S). Assumption Cal. Star "close" to initial S/C pointing at start of OD→ slew duration = 5min.
02:35:--	START_WHEEK_CAL	"Weekly" Calibration check with PACS (blue array). Duration ~10 min.
02:45:--	END_WHEEK_CAL[2]	
02:43:--	END_DUMPS	End of all dump-activities
02:45:00	STOP_VC1	Disable transmission of Real Time Science TM

[1] The procedure contains all photometry default settings for the bolometer detectors, chopper controller, filter wheel, calibration sources, etc. The procedure will be validated during ILT.

[2] The calibration data collected will be processed by PACS and the output forwarded to the MOC (method TBD). The PACS processed data will be correlated with the STR data by Flight Dynamics to ensure that the "current" offsets are still valid. If this is no longer the case a main calibration (focal plane geometry) will be scheduled.

02:50:00	STATION_CONFIG	(Re)configure Ground Station. Switch to medium TM rate (150 kbps). 3 min. allocated.
02:50:00	SWITCH_MED_RATE	Switch S/C to medium TM rate (150 kbps)
02:50:00	RANGING	5 min ranging
02:55:00	SWITCH_OFF_XMI	Switch off transmitter
02:55:00	STOP_RT VC0, VC4	End of reception of Real Time HK TM
02:55:00	TWTA_OFF	Switch off travelling wave tube amplifier
02:55:--	END_DTCP	Small margin left at End of DTCP
		****** *Small Margin* *****
03:00:00	LOS	Loss of Signal. This is arbitrary. LOS may occur much later. This is irrelevant for the scenario.
03:00:00	START_OP	Start of the Observation Phase. Ground is no longer in contact with the spacecraft (still in "science" mode). Operations via the MTL. HIFI and SPIRE in STBY. PACS in *Photometer* mode.
03:00:00	SELECT_BUS_PROFILE	Bus profile depends upon the "structure" of the corresponding OD. Executed by the CDMS. Permanent sub-schedule e.g. #1 (arbitrary number). Execution time negligible.
03:00:00	START_OBS	Start 1st observation (with PACS). By convention an "observation" includes the "slew" necessary to reach the desired attitude.
03:00:00	ENA_SUB_SCHD_#300	Enable release of sub-schedule # 300. **Transient** sub-schedule (number is arbitrary). Sub-schedule associated to the following "observation". Executed

		by the CDMS. Execution time negligible.
03:00:00	SET_UP_LINE_SCAN	1st Observation is in normal Line Scanning[3] mode (without OFF position). Characteristics: - RA: 15 46 11.9; DEC: +15 25 18.0 (coordinates 1st point of line) - N = 25 (# of lines); φ = 0 (rotation angle) - D1 = 3000 (angular line extent in arcsec.) - d2 = 120 (angular distance between lines: arcsec) - r = 10.0 (scanning rate in arsec/s) - T_{ll} = 10 (time to move from line n to line n+1 in sec)
03:10:00	PACS_Pht_P01[4]	PACS setting for Dual Band Photometry. AOT = P01[5]. Estimated duration 10 min.
03:20:--	ACTIVATE_SCAN[6]	Command ACMS to execute the "scan" defined previously.
03:20		PACS observing[7]. Scan duration ~2 hours 10 mins. A few minutes of idling time on the last point of the

[3] This "request" will be passed via the MTL from the CDMS to the ACMS for expansion (as required) and autonomous execution. The starting attitude selected here is arbitrary. A slew of 10 min duration is assumed to reach the requested attitude (RA and DEC), from the previous attitude (coordinates of the Cal. Star). This duration is obviously arbitrary. Once the ACMS will have reached stable pointing on the 1st point of the 1st line the "On target Flag" (OTF) will be set and made available in the ACMS TM. This "flag" is then available to PACS for its post-observation data processing. The selection of Line Scanning mode for this observation is arbitrary (Line Scanning mode, as well as "Raster" mode are expected to be used for the mapping of large, extended sources). Any other spacecraft "pointing" mode is available. The optimal pointing mode will depend eventually on the AOT and specific type of observation selected. This will be explored during the PV phase in order to select the optimal strategy.

[4] Advantage is taken of the fact that PACS was already in its *Photometry* mode ("weekly calibration" performed in the DTCP). A further advantage is due to the fact that the sorption cooler has been recycled shortly before. It is assumed that Mission Planning will carry out this type of optimisations routinely, so that this "optimistic" scenario is considered realistic.

[5] The Dual-Band Photometry mode selected via AOT P01 (name is arbitrary) is the standard photometry mode for observations with PACS as the prime instrument. Via AOT P01 the observer is expected to specify wavelength band to be used, integration time (per pointing position) and chopper throw. It is assumed that a *"Pht_P01"* procedure is required in order to prepare PACS for the "specific" observation selected, i.e. to carry out the specific instrument settings corresponding to the AOT-parameters selected by the observer. An average (arbitrary) time of 10 min is estimated for the execution of this procedure. In principle this procedure could be executed while the spacecraft is slewing to the required attitude. This possibility is ignored in the scenario.

[6] It is assumed (TBD) that a specific ACMS command (possibly using the "arm" and "fire" mechanism) is needed in order to start the actual scan. Other synchronisation mechanisms may be more appropriate.

[7] PACS baseline is that the first part and the last part of an AOT consist of internal calibrations (and associated configurations). In order to optimise the "real" observing time on the selected source these calibrations could be performed (partially if the slew time is too small) during the slew to- and from- the selected target. These complications are ignored in the scenario.

		scan could be added for synchronisation purposes (TBD)
05:30:--	DIS_SUB_SCHD_#300	Disable release of sub-schedule # 300. Executed by the CDMS. Execution time negligible.
05:30:--	END_OBS	
05:30:--	START_OBS	More Observations in PACS *Photometer* mode. All ACMS modes could be used (raster pointing with or without OFF position; line scanning with or without OFF position; nodding; position switching; Tracking of Solar System Objects). Proper selection of AOTs and spacecraft ACMS modes allow to observe point sources, small extended sources or large extended sources. Observation durations from a few minutes to several hours. 3 AOTs for the *Photometer* are currently foreseen (P01, P02 and P03)
------	-------	-------
	END_OBS	More Observations in PACS *Photometer* mode.
	START_OBS	Last Observation in PACS *Photometer* mode
	--------	--------
	DIS_SUB_SCHD_#700	Disable the sub-schedule[8] corresponding to the last observation.
15:00:00	END_OBS	End of last observation
	ENA_SUB_SCHD_#1000	Return to PACS *Photometer* STBY mode.
	PACS_Pht_STBY	Execute procedure *PhotometrytoStby (or PhotometrytoSafe)* to return PACS to the standby Photometry mode. Estimated duration 10 min.
15:10:00	DIS_SUB_SCH_#1000	
15:10:00		In operations this would coincide with the end of this OD. Since timing constraints dictate to “compress” time PACS *Spectrometer* mode is activated. 10 min. margin left.
15:20:00	*TBW*	*TBW*
24:00:00	END_OP	End of the Observation Phase

[8] To each observation (AOT) is associated a “transient” sub-schedule. A “transient” sub-schedule ID (number) must be ≥ 256 [RD-1] but is otherwise arbitrary. Sub-schedules are the mechanisms which allow the “timeline” (MTL) to be rejoined at the “next” feasible observation, if a recoverable malfunction (spacecraft or instrument) has jeopardised the “current” observation.

24:00:00	POS_END	OD end. The 3 instruments are in STBY. Satellite is in its nominal mode (SCIENCE)

APPENDIX 11: PLANCK PSEUDO-PSOF #1

Note: This is a faithful approximation of a Planck PSOF, it is not an exact example.

hh:mm:ss	label	Description
-00:03:00	TWTA_ON	Pre-heating of the TWTA. Note: we presume no interference with instrument measurements from heating up the travelling wave tube; Note2: how to proceed: do we allow entries with negative times or do we end the OD with the pre-heating of the tube i.e. in time for the next DTCP?
00:00:00	OD_START (keyword TBD)	OD start. Assumed to correspond to Acquisition of Signal (AOS). LFI and HFI are assumed to be in their nominal operating mode. SCS in RUN mode. Satellite is in its Nominal (SCIENCE) mode. ACMS is in its normal (SCM) mode.
00:00:00	START_DTCP	DTCP Start coincides with OD start
00:00:00	SWITCH_ON_XMIT	Switch-on Xmitter; Downlink rate =150 kbps
00:00:00	START_RT VC0, VC4	Reception of RT TM for Essential and Non-essential HK telemetry for the entire duration of the DTCP
00:00:00	RANGING	5 min ranging
00:05:00	STATION_CONFIG.	(Re)configure Ground Station. Switch to high TM rate (1.5 Mbps). 3 min. allocated.
00:05:00	SWITCH_HIGH_RATE	Switch S/C to high TM rate (1.5 Mbps)
00:10:00	START_VC2 Dumps	Initiate dump of stored HK data – Dump duration ~29 min 4) Dump Packet Store for Event Packets and TC verification 5) Dump Packet Store for Essential HK TM 6) Dump Packet Store for Non-essential HK TM
00:12:00	MTL_UPLOAD	Duration ~30 min (for a nominal 24 hr duration – top up only if no missed DTCP-). MTL loading proceeds in parallel with the Dump activities.
00:14:00	START_SREM	Activate SREM (if not done in Commissioning scenario)
00:39:00	END_VC2 dumps	
00:40:--	START_VC3 dump of LFI calibration Science	Initiate dump of stored LFI Calibration Science data – duration ~ 5 min

00:42:00	END_MTL_UPLOAD	
00:45:00	START_VC3 dump of LFI Science	Initiate dump of stored LFI Science data – duration ~ 47 min
00:48:00	START_VC1	Enable transmission of Real Time Science TM for a duration of 20 min
01:08:00	STOP_VC1	Disable transmission of Real Time Science TM
01:32:00	START_VC3 dump of HFI Science	Initiate dump of stored HFI Science data – duration ~ 70 min
01:45:00[95]	START_ORBIT_MAN	Start of orbit manoeuvre; duration TBD; presumed to be executed from MTL
01:--:--	END_ORBIT_MAN	
02:00:00[96]	START_INSTR_PROC	Start of specific instrument procedures; presumed to be executed manually
02:--:--	END_INSTR_PROC	
02:42:--	END_DUMPS	End of all dump-activities
02:47:00	STATION_CONFIG	(Re)configure Ground Station. Switch to medium TM rate. 3 min. allocated.
02:47:00	SWITCH_MED_RATE	Switch S/C to medium TM rate (150 kbps)
02:50:00	RANGING	5 min ranging
02:55:00	SWITCH_OFF_XMI	Switch off transmitter
02:55:00	STOP_RT VC0, VC4	End of reception of Real Time HK TM
02:55:00	TWTA_OFF	Switch off travelling wave tube amplifier
02:55:--	END_DTCP	Small margin left at End of DTCP
		****** *Small Margin* *****
03:00:00	LOS	Loss of Signal. This is arbitrary. LOS may occur much later. This is irrelevant for the scenario.
03:00:00	START_OP	Ground is no longer in contact with the spacecraft (still in "science" mode). Operations via the MTL
03:00:00	SELECT_BUS_PROFILE	Bus profile. Executed by the CDMS. Execution time negligible.
03:00:00	START_SCAN	Start (resume)[97] scanning law.
		Via PPL / APPL generation the following specific

[95] Arbitrary time has been chosen
[96] Arbitrary time has been chosen
[97] Baseline is that scanning law is suspended during the DTCP due to suspected RFI from the spacecraft X-mitter.

		activities could be incorporated in this OD: 1. routine calibrations 2. photometric calibrations 3. beam reconstruction 4. orbit correction manoeuvre 5. small gap recovery 6. large gap recovery (partial)
23:mm:ss[98]	END_SCAN	End of last pointing in the OD
24:00:00	END_OP	End of the Observation Phase
24:00:00	OD_END (keyword TBD)	OD end. Instruments and spacecraft are as at the start of the OD (in their "nominal" nmodes)

[98] It is assumed that the end of the last pointing does not exactly coincide with the 24:00:00 mark. This is anyway somehow artificial since scanning with Planck is continuous.