Planck Operations Scenario

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SCOPE

This document provides an overview of the baseline scenario for operations of Planck, with emphasis on instrument operations, in particular listing all currently known constraints and requirements. It is based on the Planck Science Management Plan, approved by ESA's Science Programme Committee in May 1997, and is the highest level document specifically dedicated to operations. This document forms the basis for two lower level documents, the Science Implementation Requirements Document and the Mission Implementation Requirements Document, which describe the formal requirements to be fulfilled by the Planck Instrument Development and Data Processing Consortia, the Planck Science Office, and by the Planck Mission Operations Centre. These entities in turn describe how they will fulfill these requirements in a further set of documents, the Science Implementation Plans, and the Mission Implementation Plan.

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GLOSSARY OF TERMS

2Mass	**2** **m**icron **A**ll **S**ky **S**urvey
AAS	**A**merican **A**stronomical **S**ociety
ACMS	**Attitude Control and Measurement System**
AD	**A**pplicable **D**ocument
ADD	**A**rchitectural **D**esign **D**ocument
AGN	**A**ctive **G**alactic **N**ucleus
AO	**A**nnouncement of **O**pportunity
AOCS	**A**ttitude and **O**rbit **C**ontrol **S**ystem
AOT	**A**stronomical **O**bservation **T**emplate
API	**A**pplication **P**rogramming **I**nterface
APID	**A**pplication **P**rogramme **Id**entifier
ASCII	**A**merican **S**tandard **C**haracters **I**nternational **I**nterchange
ASTRO-F	ISAS (Japan) mission, aka Infrared Imaging Surveyor (IRIS)
AU	**A**stronomical **U**nit
AVM	**Avionics Model**
BdL	**B**ureau **d**e **L**ongitude
CA	**C**alibration **A**nalysis
CaC	**C**ost **at** **C**ompletion
CC	**C**onfiguration **C**ontrol
CCS	**Central Check-out System (S/C-level EGSE)**
CCB	**C**onfiguration **C**ontrol **B**oard
CCS	**Central Check-out System**
CDMS	**Central Data Management System**
CESR	**C**entre d'**E**tude **S**patiale des **R**ayonnements
CMS	**C**onfiguration **M**anagement **S**ystem
COBE	**Co**smic **B**ackground **E**xplorer
COP	**C**ommissioning **O**perations **P**lan
COTS	**C**ommercial **O**ff **T**he **S**helf Software
CQM	**Cryogenic Qualification Model**
CRE	**C**ryogenic **R**eadout **E**lectronics
CReMA	**Consolidated Report on Mission Analysis**
CRP	**Contingency Recovery Procedure**
CS4	**C**orner**s**tone **4** (= Herschel)
CSG	**C**entre **S**patiale **G**uyannais
CST	**C**ommunity **S**upport **T**ools
CUS	**C**ommon **U**plink **S**ystem
D/TOS	**ESA's Directorate of Technical and Operations Support**
D/SCI	**ESA's Directorate of Scientific Programmes**
DBMS	**D**ata**b**ase **M**anagement **S**ystem
DDD	**D**etailed **D**esign **D**ocument
DDS	**D**ata **D**istribution **S**ystem
DHSS	**D**ata **H**andling **S**ubsystem
DMS	**D**ocument **M**anagement **S**ystem
DPC	(Planck) **D**ata **P**rocessing **C**entre
DPU	**D**ata **P**rocessing **U**nit
DTCP	**D**aily **T**elecommunications **P**eriod

EAS	**E**uropean **A**stronomical **S**ociety
EE	**E**nd to **E**nd
EGSE	**E**lectrical **G**round **S**upport **E**quipment
ESA	**E**uropean **S**pace **A**gency
ESOC	**E**uropean **S**pace **O**perations **C**entre (part of D/TOS)
ESTEC	**E**uropean **S**pace **Tec**hnology and Research Centre
ESTRACK	ESA Tracking Station Network
FAR	**F**light **A**cceptance **R**eview
FCS	**F**light **C**ontrol **S**ystem
FD	**F**light **D**ynamics
FDB	**Herschel** **D**ata **B**ase
FDIR	**F**ault **D**etection **I**solation and **R**ecovery
FGSAG	**Herschel** **G**round **S**egment **A**dvisory **G**roup
FM	**Flight Model**
IDIS	**Planck** **I**ntegrated **D**ata **and Information** **S**ystem
IOT	**Instrument Operations Team**
FINDAS	**Herschel Integrated Network and Data Archive System**
FIRST	**ESA's** **F**ar **I**nfra**r**ed and **S**ubmillimetre **T**elescope (now Herschel)
FITS	**F**lexible **I**mage **T**ransportation **S**ystem
FOM	**F**igure **o**f **M**erit
FOP	**F**light **O**perations **P**rocedure
FOTAC	**Herschel** **O**bservation **T**ime **A**llocation **C**ommittee
FOV	**F**ield **o**f **V**iew
FRD	**F**ormatted **R**aw **D**ata
FRR	**F**light **R**eadiness **R**eview
FS	**Herschel** **S**cheduler
FSC	**Herschel** **S**cience **C**entre
FSCDM	**HSC** **D**evelopment **M**anager
FSCDT	**HSC** **D**evelopment **T**eam
FSCOM	**HSC** **O**perations **M**anager
FSCOT	**HSC** **O**perations **T**eam
FST	**Herschel** **S**cience **T**eam
FTP	**F**ile **T**ransfer **P**rotocol
FTS	**F**ourier **T**ransform **S**pectrometer
GFURD	**G**round **F**acility **U**ser **R**equirement **D**ocument
GO	**G**uest **O**bserver
GS	**G**round **S**egment
GSE	**G**round **S**upport **E**quipment
GT	**G**uaranteed **T**ime
GTO	**G**eostationary **T**ransfer **O**rbit
GUI	**G**raphical **U**ser **I**nterface
H/RSSD	**Head of the Research and Scientific Support Dpt of ESA (a.k.a. SCI-S)**
H/W	**H**ard**w**are
HCI	**H**uman **C**omputer **I**nterface
HCSS	**Herschel Common Science System**
HEB	**H**ot **E**lectron **B**olometer
Herschel	**ESA Far Infrared and Submillimetre Telescope (formerly FIRST)**
HFI	**Planck High Frequency Instrument**
HIFI	**H**eterodyne **I**nstrument for **Herschel**

HK or H/K	**H**ouse **K**eeping (data)
HSC	**Herschel S**cience **C**entre
HSCDM	**HSC D**evelopment **M**anager
HSCDT	**HSC D**evelopment **T**eam
HSCOM	**HSC O**perations **M**anager
HSCOT	**HSC O**perations **T**eam
HST	**Herschel S**cience **T**eam
HTML	**H**yper**t**ext **M**ark-up **L**anguage
I/F	**I**nter**f**ace
IA	**I**nteractive **A**nalysis
IAS	**I**nstitut d'**a**strophysique **s**patiale
IAU	**I**nternational **A**stronomical **U**nion
IC	**I**mperial **C**ollege
ICC	**Herschel I**nstrument **C**ontrol **C**entre
DPC	**Planck Data Processing** Centre
ICD	**I**nterface **C**ontrol **D**ocument
ICR	**I**nfrastructure **C**hange **R**equest
ICS	**I**nstrument **C**ommand **S**equence
IDA	Immediate Data Access
IDIS	(Planck) **I**ntegrated **D**ata and **I**nformation **S**ystem
ILT	**I**nstrument **L**evel **T**est
INTEGRAL	**Inte**rnational **G**amma-**ra**y **A**strophysics **L**aboratory
IOM	Instrument Operations Team Manager
IOT	Instrument Operations Team
IPAC	(NASA/JPL) **I**nfrared **P**rocessing and **A**nalysis **C**enter
IR	**I**nfra**r**ed
IRD	**I**nterface **R**equirements **D**ocument
ISCL	**I**nstrument **S**pecific **C**lass **L**ibraries
ISO	**I**nfrared **S**pace **O**bservatory
IST	**I**nstrument **S**ystem **T**est
ITeSRE	**Istituto di Tecnologie e Studio delle Radiazioni Extraterrestri**
ITT	**Integration and Test Team**
IWS	**Instrument Work Station**
JCMT	**J**ames **C**lerk **M**axwell **T**elescope
kbps	**k**ilo**b**it **p**er **s**econd
KU Leuven	**K**atholieke **U**niversiteit Leuven
LAN	**L**ocal **A**rea **N**etwork
LEOP	**L**aunch and **E**arly **Op**erations
LFI	**Planck Low Frequency Instrument**
LO	**L**ocal **O**scillator
LRP	**L**ong-**R**ange **P**lan
MCR	**M**odel **C**hange **R**equest
MCS	**M**ission **C**ontrol **S**ystem
MDB	**M**ission **D**ata **B**ase
MIRD	**M**ission **I**mplementation **R**equirements **D**ocument
MMB	**M**odel **M**anagement **B**oard
MOC	**M**ission **O**perations **C**entre
MPE	**M**ax-**P**lanck Institute fűr **E**xtraterrestrische Physik
MPS	**M**ission **P**lanning **S**ubsystem
MPTS	**Multi Purpose Tracking System**

MRD	**M**ission **R**equirements **D**ocument
MT	**M**ission **T**imeline
NCTRS	Network Control and Telemetry Routing System
NDIU	**N**etwork **D**ata **I**nterface **U**nit
NMC	**Network Management Computer**
NRT	**N**ear-**R**eal**T**ime
OBC	**On-board Clock**
OBS	or **O**n-**b**oard **S**oftware
OBSW	
OBSM	**O**n-**b**oard **S**oftware **M**onitoring System
OD	**O**perational **D**ay
ODB	**O**perational **D**ata**b**ase
ODBMS	**O**bject **D**ata **B**ase **M**anagement **S**ystem
ODD	**O**n-**d**emand Processed **D**ata
ODP	**O**n-**d**emand **P**rocessing
ODR	**O**n-**d**emand Processing **R**eport
OO	**O**bject **O**riented
OODBMS	**O**bject **O**riented **D**ata Base **M**anagement **S**ystem
ORATOS	**Orbit and Attitude Operations System**
OT	**O**pen **T**ime
PA	**P**roduct **A**ssurance
PACS	**P**hotoconductor **A**rray Camera and Spectrometer
PCS	**P**ermanent **C**ommand **S**equence
PDB	**P**roposal **D**ata **B**ase
PDF	**P**ortable **D**ata **F**ormat
PDU	**P**ower **D**istribution **U**nit
PER	**P**roposal **E**valuation **R**eport
PFM	**Proto-Flight Model**
PGSAG	**Planck G**round **S**egment **A**dvisory **G**roup
PGSSE	Planck Ground Segment System Engineer
PGSSG	Planck Ground Segment System Engineering Group
PHS	**P**roposal **H**andling **S**ubsystem
PI	**P**rincipal **I**nvestigator
PLM	**P**ay**l**oad **M**odule
PM	**P**roject **M**anager
POF	**P**lanned **O**bservations **F**ile
PPS	**P**re-**P**rocessing **S**ubsystem
PR	**Primary Reflector**
PR	**P**ublic **R**elations
PS	**Planck P**roject **S**cientist
PSF	**P**lanning **S**keleton **F**ile
PSO	**Planck Science Office**
PSR	**P**roject **S**upport **R**oom
PST	**P**roject **S**cientist **T**eam
PT	**Performance Test**
PUS	**P**acket **U**tilisation **S**ervice
PV	**P**erformance **V**erification
PVOP	**P**erformance **V**erification **O**perations **P**lan
QA	**Q**uality **A**ssurance
QAR	**Q**uality **A**ssessment **R**eport

QCP	**Q**uality **C**ontrol **P**ipeline
QLA	**Q**uick**L**ook **A**ssessment
QMW	**Q**ueen **M**ary and **W**estfield College
QPD	**Q**uality **P**rocessed **D**ata
RD	**R**eference **D**ocument
RF	**R**adio **F**requency
RID	**R**eview **I**tem **D**iscrepancy
ROP	**R**outine **O**perations **P**lan
RSSD	**Research and Scientific Support Dpt of ESA (previously referred t as SSD)**
RT	**R**eal-**t**ime
RTA	**R**eal-**t**ime **A**ssessment
S/C	**S**pa**c**ecraft
S/W	**S**oft**w**are
SA	**S**cientific **A**nalysis
SAp	(CEA) **S**ervice d'**A**stro**p**hysique
SCI-S	**Research and Scientific Support Dpt of ESA (also known as RSSD)**
SCI-SD	**Science Operations and Data Systems Division of RSSD**
SCI-P	**Scientific Projects Dpt of ESA**
SCMP	**S**oftware **C**onfiguration **M**anagement **P**lan
SCOE	**S**pacecraft **C**heck-**O**ut **E**quipment
SCOM	**Sc**ience **O**perations **M**anager
SCR	**S**oftware **C**hange **R**equest
SCUBA	**S**ubmillimetre **C**ommon-**U**ser **B**olometer **A**rray
SGS	**S**cience **G**round **S**egment
SIAT	**S**ystem **I**ntegration and **A**cceptance **T**esting
SIP	**S**cience **I**mplementation **P**lan
SIRD	**S**cience **I**mplementation **R**equirements **D**ocument
SIRTF	**S**pace **I**nfra**r**ed **T**elescope **F**acility
SIS	**S**uperconductor-**I**nsulator-**S**uperconductor
SMP	**S**cience **M**anagement **P**lan
SMPS	**S**cientific **M**ission **P**lanning **S**trategy
SOB	**S**cience **O**perations **B**oard
SOFIA	(NASA/DLR) **S**tratospheric **O**bservatory **f**or **I**nfrared **A**stronomy
SOM	**S**pacecraft **O**perations **M**anager
SOVT	**S**ystem **O**peration **V**alidation **T**est
SPACON	**Spacecraft Controller**
SPC	**S**cience **P**rogramme **C**ommittee
SPG	**S**tandard **P**roduct **G**eneration
SPIRE	**S**pectral and **P**hotometric **I**maging **Re**ceiver
SPR	**S**oftware **P**roblem **R**eport
SQAP	**S**oftware **Q**uality **A**ssurance **P**lan
SR	**Secondary Reflector**
SRD	**S**oftware **R**equirements **D**ocument
SRON	**S**pace **R**esearch **O**rganisation **N**etherlands
SRR	**S**oftware **R**equirements **R**eview
SRSD	**S**cientific **R**equirement **S**cheduling **D**ocument
SSD	**S**oftware **S**pecification **D**ocument
SSD	**S**pace **S**cience **D**epartment of ESA, now referred to as RSSD (the Research and Scientific Support Department of ESA)

SSO	**S**olar **S**ystem **O**bject
SSMM	**Solid State Mass Memory**
SSR	**S**olid **S**tate **R**ecorder
STC	**Station Computer**
SVM	**S**ervice **M**odule
SVS	**S**chedule **V**isualization **S**oftware
SVT	**S**ystem **V**alidation **T**est
SVVP	**S**oftware **V**erification and **V**alidation **P**lan
TA	**T**echnical **A**ssistant
TA	**T**rend **A**nalysis
TBC	**To be C**onfirmed
TBD	**To be D**etermined
TC	**T**ele**c**ommand
TCE	**Telecommand Encoder**
TEI	**T**est **E**quipment **I**nterface
TM	**T**ele**m**etry
TMP	**T**ele**m**etry **P**rocessor
ToO	**T**arget **o**f **O**pportunity
UML	**U**nified **M**odeling **L**anguage
URD	**U**ser **R**equirements **D**ocument
VC	**V**irtual **C**hannel
Vilspa	**Vil**lafranca, **Spa**in
WBS	**W**ork **B**reakdown **S**tructure
WP	**W**ork **P**ackage
WWW	**W**orld **W**ide **W**eb
XMM	**X**-ray **M**ulti **M**irror Satellite

1. INTRODUCTION

1.1 Participants

The overall ground segment of Planck and the responsibilities of the various parties are defined at high level in the Planck Science Management Plan (SMP). This is, or will be reflected in the SIRDs and the MIRD for the DPCs and the MOC respectively. The main parties involved are:

- the Herschel/Planck Project Team
- The Planck Science Team
- The Planck Project Scientist (PS) and an associated support team referred to as the ESA Planck Science Office
- The Mission Operations Centre (MOC)
- The two instrument Data Processing Centres (DPCs)

Note: in this document, as in the Science Management Plan, it is assumed that the Instrument Operations Team (IOT) for each instrument is part of their respective DPC. Therefore, when referring to DPC both the instrument operations and the data processing functions shall be included unless specifically mentioned otherwise. However, each Instrument Consortium may decide to manage the Instrument Operations and Data Processing functions in different ways. This shall be described in the Science Implementation Plans provided by each Instrument Consortium.

In addition to the above, ESA's Research and Scientific Support DPT (RSSD) will be (via its Science Operations and Data Systems Division, SCI-SD) the provider of the final repository and distribution means of the Planck scientific products.

Fig. 1 shows the main flow of data and information during routine operations as described in the SMP. Note that additional interfaces (not drawn in Fig. 1) exist between MOC and PSO, and between DPCs and PSO.

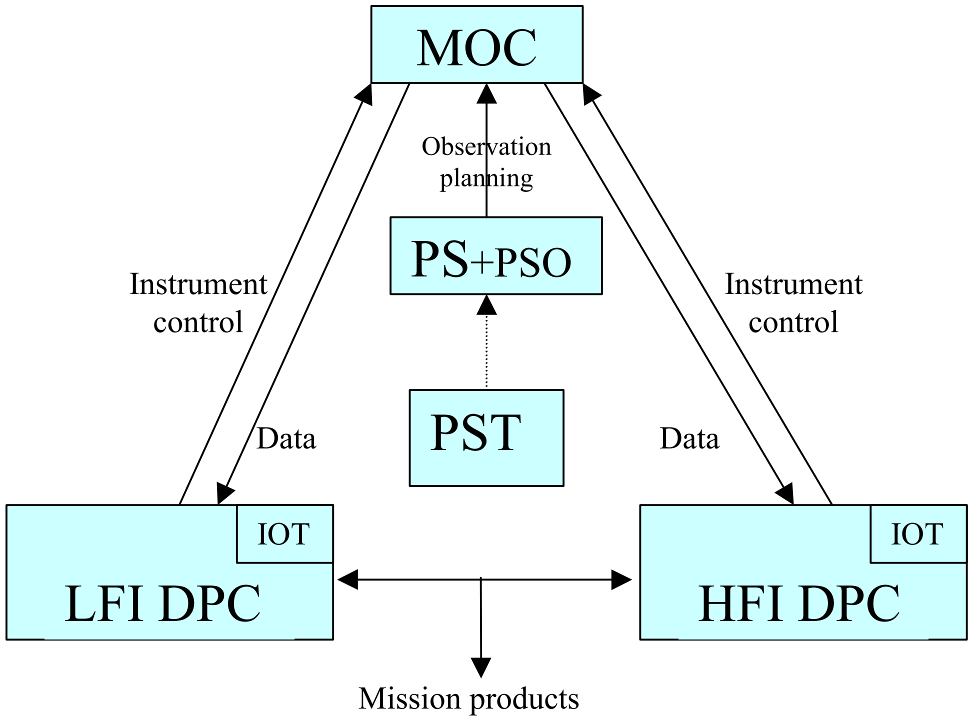


Figure 1: Participants in the Planck Ground Segment during routine operations.

1.2 Responsibilities and Management

The organisation of the project changes according to the various phases of implementation and operations. The various mission phases and top-level responsibilities for the main sectors of the project are given as an overview in the table below:

	Highest authority/responsibility for Project Sector			
Mission Phase	Project/Mission	Spacecraft Operations	Instrument Operations	Science
Development	PM	GSM	PM	PS
Launch and Early Orbit Phase (LEOP)	MD (=PM)	FOD	N/A	PS
Commissioning	PM	MOM	MOM	PS
Performance Verification	H/RSSD	MOM	MOM	PS
Routine Operations	H/RSSD	SOM	SOM	PS
Post-operations	H/RSSD	N/A	N/A	PS

PM = Herschel/Planck Project Manager (D/SCI)
MD = Mission Director (= PM in LEOP phase)

FOD = Flight Operations Director (D/TOS))
GSM = Ground Segment Manager (D/TOS)
SOM = Spacecraft Operations Manager (D/TOS)
H/RSSD= Head of RSSD
PS = Project Scientist (reports to H/RSSD)
MOM = Mission Operations Manager (D/TOS), normally the GSM (TBC)

Note: during routine operations the SOM is responsible for instrument operations to the extent that they affect the safety and integrity of the satellite, i.e. the actual commands and procedures for instrument operations are provided at appropriate intervals by the IOT Managers to MOC, who then consolidates the inputs from both IOTs (using commonly developed procedures), uplinks them, and runs whenever necessary pre-agreed procedures to cover contingency situations.

1.2.1 The Herschel/Planck Project Team

The Herschel/Planck Project Team is established by ESA and led by the Herschel/Planck Project Manager, who has overall responsibility for the Herschel/Planck Project until the end of the Commissioning Phase. This responsibility is then transferred to the Head of ESA's Research and Scientific Support Department.

The responsibilities of the Herschel/Planck Project Team are to:

- assume overall coordination and management responsibility for the definition and implementation of the elements of the Herschel/Planck Ground Segment and mission operations.
- establish the overall mission requirements.
- define the standards which ensure compatibility, commonality, and maximum re-use of hardware and software between all phases of the project.
- define the interface requirements for the scientific instruments on-board software design.
- establish and maintain interface control between the elements of the ground segment in collaboration with the DPCs, and MOC.
- review and agree the Planck instrument flight operations procedures (nominal and contingency). Ensure timely delivery.
-
- set up the Planck Ground Segment Advisory Group (PGSAG).
- set up and ensure smooth operations of the ground segment Integration and Test Team (ITT). The ITT must be established prior to the first SVT.
- establish and maintain the overall Ground Segment schedule.
- monitor design and implementation of the scientific instruments on-board software.
- organise (jointly with D/TOS) all major ground segment and mission operations reviews.
- assume overall responsibility for the definition and execution of the Satellite Commissioning phase.
- provide ad-hoc specialist support during flight operations.

1.2.2 The Planck Science Team

The Planck Science Team (PST) is composed of representatives of the two Planck Instrument Consortia and the Planck Reflector Provider. It is chaired by the Planck Project Scientist.

The role of the PST is described in the SMP.

In the context of the Ground Segment the Science Team tasks are to:

- formulate and optimise Planck's Observation Programme.
- formulate and optimise the calibration strategy, both from the scientific and operational viewpoints.
- specify updates or changes to the Observing Plan during the operational phase (for implementation by the MOC)
- monitor organisation of the Planck Archive (implemented via PSO and SCI-SD).
- direct and monitor creation and delivery to the community of the final scientific products and associated documentation.
- participate in major ground segment reviews

The Planck PS, acting as representative of the PST, is responsible for the interface between the PST and all other elements of the Ground Segment.

It is to be noted that **the PST has an advisory, not an operational, role** in the Ground Segment. Therefore it is the responsibility of the PS to ensure that the above listed tasks are carried out and endorsed by the PST.

1.2.3 The Planck Project Scientist and the Planck Science Office

The Planck Project Scientist (PS) is responsible for the coordination and management of the Planckscientific programme, the safeguard of the scientific interests of the science community,and the maximisation of the scientific return of the Planck mission during all its phases.

The PS is ESA's interface to the scientific community, the instrument/DPC consortia, and the Reflector Provider (TP) for all Planck scientific matters. He organises and chairs the Science Team (ST) meetings.

The PS liaises with the Herschel/Planck Project Manager (PM) and the Project Team in the development phase and coordinates all scientific issues with them. In particular the PS advises the project Payload Manager on technical matters when they affect scientific performance.

After completion of the in-orbit operations, the PS coordinates the creation of the scientific products, their archival (in FINDAS) and distribution to/access by the scientific community.

The Planck Project Scientist has a dedicated team (the Planck Science Office or PSO) to assist him in the

execution of all of the tasks under his responsibility. However, for certain tasks he must rely on the assistance of the

Science Team (e.g. for advice on the formulation and implementation of the overall Planck science strategy and policy) and on the DPCs for the execution of the related tasks. Within this framework the PS is responsible for the following tasks:

monitor instrument design and development activities. Check against instrument performance requirements as specified in the IID-A and IID-B’s.

monitor (and coordinate as needed) the definition of the instruments (largely carried out by the PI teams)calibration requirements.

- monitor the instrument calibration activities (on ground).
- monitor the definition of the instruments in-orbit cross-calibration Plan (largely carried out by the PI teams)
- define (assisted by the PI teams) the Instrument in-orbit Performance Verification Plan.

- Provide MOC with the inputs required to implement the observing programme of Planck
- Approve the detailed specification (by the DPCs) of the data products to be generated from the mission, as outlined in the SMP.
- monitor proper implementation of the data reduction activities carried out at the DPCs. In particular verify that the level of coordination between the two DPCs is sufficient to guarantee an integrated final set of data products. *Note: The PS will be assisted in this task by the ST and the PGSAG.*
- review and approve the Planck instrument flight operations procedures (nominal

and contingency). *Note: this task is shared with the Herschel/Planck Project team. The Project team ensures that the instrument flight procedures are safe and compatible with the spacecraft procedures. The PS ensures that, as defined, the instrument flight procedures will maximise the science return.*

- review and approve the Planck-related ground segment operations procedures (mainly operational procedures between DPCs, MOC and PSO if applicable*). Note: this task is shared with the Herschel/Planck Project team. The Project team ensures that the ground segment operations procedures are safe. The PS ensures that, as defined, the procedures will maximise the science return.*
- participate, as required, in Planck-related pre-launch ground segment integration, validation tests and simulations.
- define, in collaboration with SCI-SD and the DPCs, the facilities required from the Planck Archive to support the post-operational phase. e.g.
  - Planck archive management
  - processing tools
  - data distribution facilities.
  - Planck archive access facilities.
- support all ground segment reviews.
- Chair the *PGSAG*.

It is also to be noted that although the Head of RSSD formally inherits the management of the Project after S/C in-orbit commissioning, in practice he delegates the management tasks to the PS.

1.2.4 The DPCs

Each of the two Planck Instrument Consortia is responsible for developing and operating a Data Processing Centre. The role and responsibilities of each of these two DPCs is described in the SMP. Each DPC is led by a DPC Manager.
Each DPC supports an Instrument Operations Team, led by an Instrument Operations Manager, who is the interface to MOC for all instrument related issues (the IOM may or may not be the same person as the DPCM). The IOT is an evolution of the Instrument Development Team (IDT, described in the SIP), which is mainly active during the development phase. In this document, the "DPC" refers to all the functionality provided by the Instrument Consortia to support the pre- and post-launch instrument operations and data processing, regardless of which team actually provides it (IDT, IOT, or DPC).

In general, the DPCs (and their respective IDTs/IOTs) are responsible for:

- operating and calibrating their respective instruments
- Daily analysis of instrument health

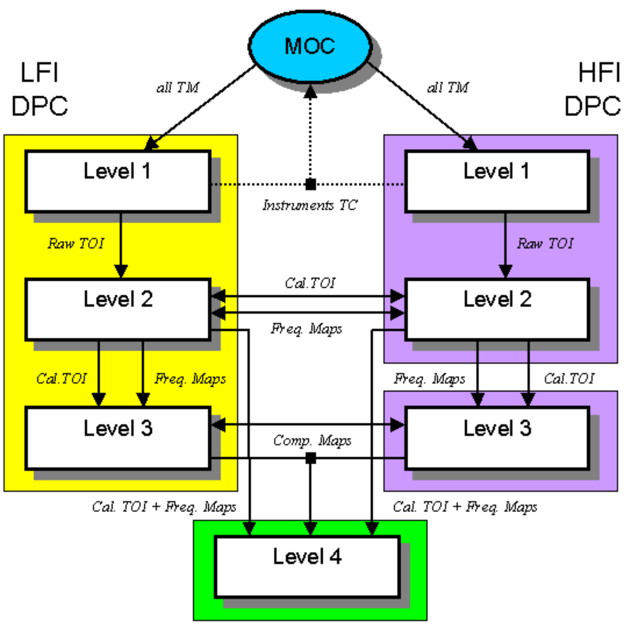
- Daily analysis of science data
- Optimisation of instrument performance
- Provision and operation of a software maintenance facility
- Support to the MOC where specialised payload knowledge is concerned.
- processing of Planck data, from raw TM to deliverable scientific products
- delivering the final scientific products

In addition, both DPCs are jointly responsible to establish and deliver to MOC the procedures required to consolidate all instrument related inputs. The joint responsibility reflects the fact that the two instruments have common hardware elements and furthermore that the operation of one of them may have an impact on the other's performance or operation.

The specific duties and tasks of the DPCs are described in the Planck SIRD, and the way in which these duties will be carried out is described in the LFI and HFI Science Operations Implementation Plans (SIPs).

The data processing activities of each DPC have been split into four "Levels" according to the type of processing required (Figure 2). The MOC makes available the data to the entrance point of each DPC ("Level 1"). Note however that in addition to this main line of data transfer, the DPCs are able to "listen in" to MOC via workstations (the so-called IW@MOC), physically located in MOC but connected via the network to the DPCs (this is further described in Section 9.5.4.5).

The data is piped sequentially from Level 1 to Level 4, from where the final scientific data products are delivered to ESA. However, it is expected that the data reduction



scheme will be iterative, such that the different Levels will be re-reducing data many times. A large amount of feedback between all the various levels is therefore required. Similarly, it is required that the two DPCs intercompare results at various stages in the data processing pipeline. Therefore a large amount of feedback between DPCs is also expected.

Figure 2: A sketch of the layout of the two Planck DPCs. Each colored box corresponds to a geographically separate location. The lines between IW@MOC and DPCs are not represented in this diagram.

In addition to these four Levels, the DPCs also support and benefit from (scientific and technical) simulation activities, instrument-level and system-level testing activities, and instrument operations.

A fundamental feature of the DPCs is that they are geographically distributed (see Figure 2).

The two DPCs share a basic information management infrastructure, the Planck Integrated Data and Information System (IDIS). The development and operation of IDIS is a shared DPC activity. The functionality required of IDIS is described in the IDIS User Requirements Document. IDIS is planned to contain five different components:

1. a Document Management Component, containing all relevant documentation;
2. a Software Management Component, encompassing the software in common between the two Consortia, and providing tools to store Consortium-specific software in a compatible environment;
3. a Process Coordinator Component, providing a single software environment for data processing (e.g. a data pipeline manager);
4. a Data Management Component, allowing the ingestion, efficient management and extraction of the data (or subsets thereof) produced by Planck activities;
5. a Federation layer, providing inter-connection among IDIS components (e.g. relating objects controlled by each component).

DPC activities are formally divided in three main phases:

- the **DPC Development phase**, that will last until launch;
- the **DPC Operations phase**, that starts a year before launch (thus there is an overlap of one year between the DPC Development and Operations phases);
- the **DPC Post-Operations phase**, that starts at spacecraft "power-off" and terminates at the end of the data proprietary period, when the final results of the mission are actually delivered to ESA for distribution to the scientific community.

It is to be noted that support to ground tests and other activities (e.g. simulations) are run during the DPC Development phase. A fourth DPC phase (**Pre-Operations**) can therefore be logically defined, which is contained within the Development phase.

1.2.5 The MOC

ESOC will establish a team to define and implement the ground segment, and conduct the mission operations in accordance to the MIRD.
The MOC is in general responsible for:

- Planning the mission on the basis of the observation programme and strategy provided by the PS.
- Executing the observation plan (the "scanning law", see Annex 1)
- Consolidating the instrument-related inputs (telecommands, databases, software images, etc) from each DPC on the basis of procedures established jointly by the two DPCs
- Command the two Planck instruments on the basis of the inputs from each DPC
- Transmission of the recovered data and pointing and auxiliary data to the DPCs
- Operation and maintenance of the spacecraft and ground segment, including the two main MOC-LFI-DPC and MOC-HFI-DPC links
- Ensuring the safety and efficient operation of the spacecraft, and of the instruments
- First line intervention in the event of payload anomalies according to pre-planned procedures.
- Archiving the data for 10 years, starting from data acquisition
- keeping the acquired data available on line until the end of the MOC run-down phase (i.e. ~3 months after end of operations).

Specific tasks of the MOC include:

- Mission analysis
- Ground network management
- Ground stations engineering
- Communications
- Networks operations
- Ground segment validation tests
- Simulations programmes
- Flight operations plans (FOPs)
- Operations database
- On-board software management
- Orbit determination and control (Flight Dynamics System)
- Attitude determination and control (Flight Dynamics System)
- Mission planning (Mission Control System)
- Mission scheduling (Mission Control System)
- Telemetry reception (Mission Control System)
- Telemetry processing (Mission Control System)
- Real-time analysis of S/C and scientific housekeeping data (i.e. limit checking)
- Telecommand processing (Mission Control System)
- Telecommand uplink (Mission Control System)

The present ground station concept for the ground segment is as follows: New Norcia, Kourou and Villafranca for LEOP/transfer, and New Norcia for Routine operations
The MOC will be located at ESOC Darmstadt.
Figure 3 shows the configuration of the ESOC ground segment for both the test and operational phase.

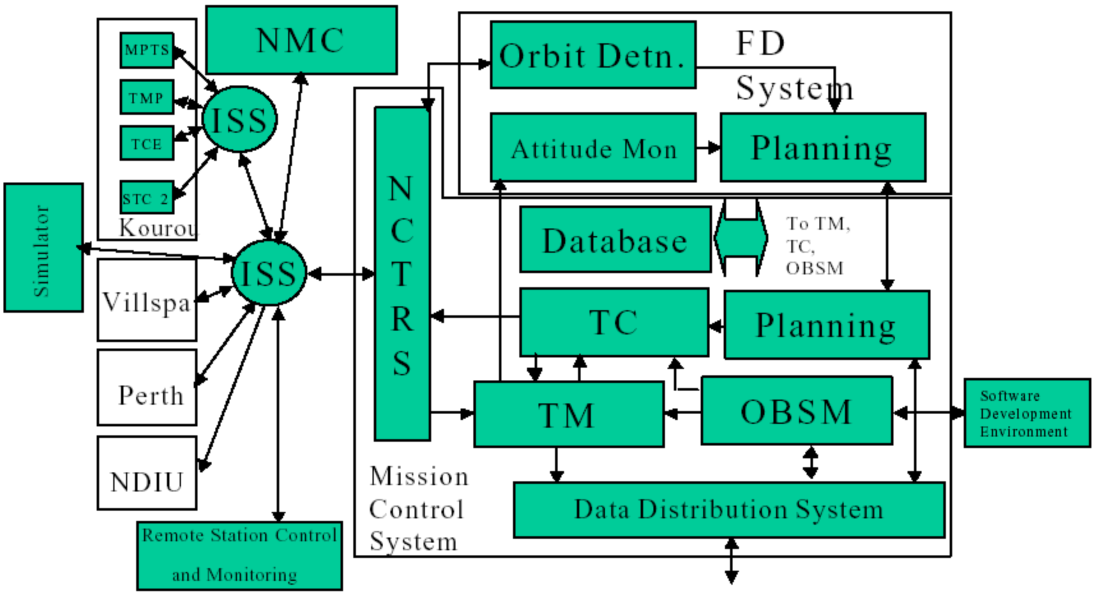


Figure 3: Overview of the MOC and Ground Station Network

1.2.6 Management during the development phase

The Ground Segment systems engineering task is the responsibility of the Herschel/Planck Project Team, supported by ESOC, SCI-S and the PI teams.

During the development phase, management and oversight of the Ground Segment are carried out based on the following elements:

1. The Planck Ground Segment Advisory Group (PGSAG), chaired by the PS, and with the following members: the Planck Science Ground Segment System Engineer (secretary), the Herschel/Planck Project Operations System Engineer, the Herschel/Planck Ground Segment Manager, the two DPCMs, and the two IOTMs. The PGSAG advises the Project Manager and PI's with respect to the overall ground segment development and monitors the different developments. Specific tasks of PGSAG are:
   - Check the overall ground segment scenario for consistency and, if necessary, propose improvements,
   - Monitor the activities of the different development teams via the lower-level PGSSG,
   - Issue recommendations taking into account:
     - smooth transitions between mission phases,
     - maximum commonality between the different ground segment elements,
     - operability of the Planck payload
     - availability of personnel,
     - schedule and funding constraints..
2. The Planck Ground Segment System Engineering Group (PGSSG), is chaired by the Planck Science Ground Segment System Engineer (PGSSE), an ESA engineer resident at ESTEC and reporting to the PS. System engineers from the Herschel/Planck Project, from MOC, and from the DPCs/IOTs are members of the PGSSG. The PGSSG formally reports to the PGSAG. The tasks of the PGSSG are to:

- Perform the ground segment top level design (elements identification) and establish an implementation baseline
- Feedback information into the space segment design
- Verify that the proposed system design is in line with the Planck Operations Scenario
- Control the interfaces between the elements
- Track the element design and implementation with respect to consistency and with the Ground Segment system design.
- Define the system-level ground segment integration, verification and acceptance tests activities
- Monitor the execution of the tests

3. Other working groups entrusted with specific tasks:

- Commonality Working Groups, which have been formed in several areas relevant to the Ground Segment (e.g. EGSE), and formed by Herschel and Planck personnel and ESA Project engineers
- The Instrument Coordination Group: is formed by LFI and HFI personnel (with ESA and ESOC participation as needed), and is entrusted in particular with:
    - Defining and controlling interfaces between the two instruments
    - Establishing common instrument input consolidation and operations procedures

Major interfaces will be controlled by means of Interface Control Documents between every major element of the GS, and held under configuration control.

Regular technical meetings will take place between ESA and the PI Consortia to ensure that adequate information flow exists regarding the development of the various GS elements.

The Ground Segment will be reviewed according to established procedures (foreseen major reviews are laid out in Section 2.2, and in more detail in the “Herschel/Planck Ground Segment Review Plan”). The calling authority for major GS reviews is the Herschel/Planck Project Manager.

Further ESA will review the development of GS elements at regular intervals. In particular the development of the DPCs will be reviewed with a periodicity similar to that of instrument (hardware) reviews. The calling authority for these reviews isSCI-S. The objectives of each Review will be established in the SIRD or in lower-level documents.

1.3 Documentation

The top-level Ground Segment documentation, their interrelations, and their approval scheme are detailed in RD14 (Ground Segment Documentation Plan).

1.3.1 Applicable documents

The following documents are to be considered as applicable to the Operations Scenario:

AD1: Planck Science Management Plan (SMP)

1.3.2 Reference documents

The following documents are listed as references for the Operations Scenario:

RD1: Planck Science Implementation Requirements Document
RD2: The Herschel/Planck Mission Implementation Requirements Document
RD3: The Herschel/Planck Operations Interface Requirements Document
RD4: The Herschel/Planck Satellite System Specification
RD5: The Planck Announcement of Opportunity (AO) documentation
RD6: The LFI Instrument Proposal
RD7: The HFI Instrument Proposal
RD8: The LFI Science Implementation Plan
RD9: The HFI Science Implementation Plan
RD10: The IDIS User Requirements Document
RD11: LFI Instrument Interface Document part B (IID-B)
RD12: HFI Instrument Interface Document part B (IID-B)
RD13: Herschel/Planck Ground Segment Review Plan
RD14: Herschel/Planck Ground Segment Documentation Plan
RD15: The Planck Science Office Science Implementation Plan
RD16: Consolidated Report on Mission Analysis
RD17: Planck Ground Segment Interface Requirements Document
RD18: Planck Ground Segment Design Description
RD19: Planck Mission Planning Cycle
RD20: Planck Scanning Strategy Reference Document

2. Schedule

2.1 Phasing

Operations are divided into the following phases:

1. Instrument-level tests
2. System-level tests
3. Ground Segment tests
4. Launch and early orbit phase
5. Commissioning phase, including spacecraft and instrument commissioning
6. Calibration and Performance Verification phase
7. Routine operations phase
8. Post-operations phase
9. Archive phase

The start and end times of each phase are determined by the following conditions:

Launch: currently foreseen for 15 February 2007
Transfer to orbit around L2: varies between 90 and 123 days depending on launch date
Duration of routine operations: approximately 15 months
Duration of post-operations phase: two years starting from completion of two full sky surveys

2.2 Review cycle

ESA will review the Ground Segment development and operation at appropriate times. The following types of reviews have been planned:

- Mission-level reviews
- Ground Segment reviews
- MOC reviews
- PSO reviews
- DPC reviews

The objectives and current planning of these reviews are detailed in RD13.

3. Instrument-level tests

3.1 Test objectives

The objective of the ILTs is to test the functional, and scientific performance and environmental response, including characterising the instrument, and establishing calibration parameters and procedures, of the various instrument models and modes (with FPUs at either room or operational temperature).

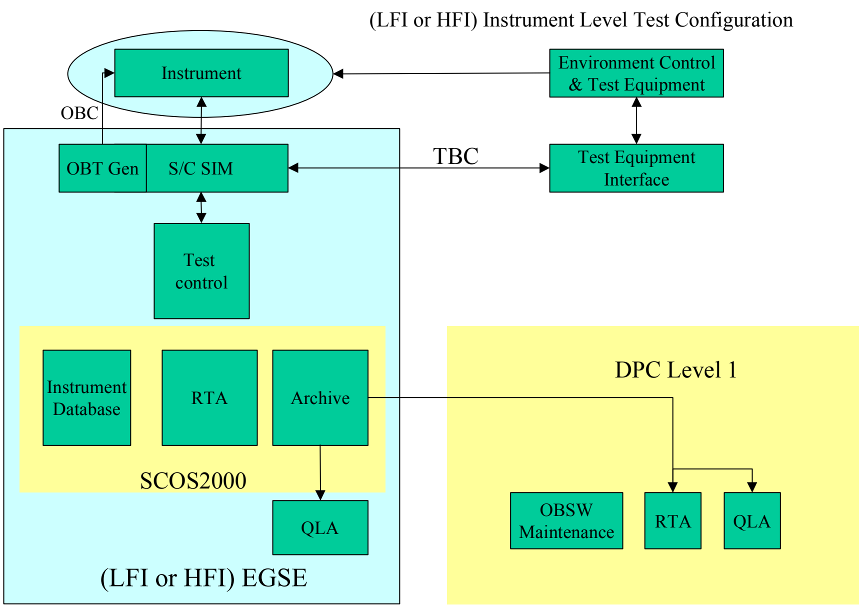
3.2 Operations

ILTs are carried out on PI premises or at a specialised test facility.
Note however that the nature of the Planck payload is such that some specific instrument-level tests (e.g. many of those related to the active cooling chain) can only be carried out at system level and therefore under ESA (or its contractor's) responsibility.

3.2.1 Operational environment

The scheme of the EGSE given in Figure 4 illustrates the functional elements of the test set-up for LFI and HFI. The goal is to facilitate a smooth transition from one mission phase to the next, by being as compatible with further tests (IST, EE-tests) and in-orbit operations as possible. All of the elements shown are developed by the Instrument Consortia. Some of these elements will be based on the SCOS-2000 system.

Figure 4: ILT configuration for the LFI and HFI instruments. Note: A SCOS-2000



add-on provides control of and data acquisition from test equipment and therefore the Test Equipment Interface could be made there. Note: SCOS2000 provides a facility to manage OBSW; if used, it would allow to generate any necessary patch commands for transfer to Test Control, if required.

To deal with practical constraints like cryogenic hold times, external set-up limitations, and missing elements of the overall ground segment (MOC and possibly parts of DPC), some shortcomings of the ILT scenario with respect to the in-orbit environment have to be accepted, but missing elements will be simulated as far as possible.

The different functions identified in Figure 4 are expected to be relevant to the different tests and operational phases in the mission. This should help designing a checkout system which can be carried across these different phases at minimal cost. In particular, the functions supported by, OBSM (On board software maintenance system), RTA (Real-time analysis, based on Housekeeping data only), QLA (which is RTA based on both science and housekeeping data), QLA/TA (off-line quick-look and trend analysis, based on both science and housekeeping data), and IDIS are relevant to all test and operational phases.

The functions which are specific to ILT are:

The **S/C SIM Unit** (TM/TC, CDMU, DC Power interfaces) and TEI (Test Equipment Interface) provide hardware interfaces to the instrument and the external test equipment required to stimulate the instrument during testing. The S/C SIM simulates (i) the telecommand and telemetry interfaces of the spacecraft data handling system (TM/TC Interface), (ii) the Spacecraft Power Distribution Unit (PDU) and (iii) the on-board clock (OBC) interface . The CDMU and PDU simulator subsystems will be treated as a subsystem of the spacecraft as far as commanding and telemetry are concerned; telecommands to this subsystem will be opened and acted upon by S/W in the S/C SIM. Telecommand packets addressed to the instrument will be passed directly to the instrument electronics for further processing. Control of the environment and of required test equipment will be done independently of the instrument control, via the TEI (TBC for LFI).

Test Control provides facilities to (i) generate commands from both test procedures and via interactive user input, and (ii) generate and execute test procedures. There is no automatic loop between Test Control and RTA/QLA facilities; all feedback will be done by manual intervention. However watch-dog functions foreseen to be present in the S/C CDMU will be simulated by the EGSE to the extent required.
Uplink/Downlink (integrated into S/C SIM) provides the facility to translate commands and produce time tagged TC packets. It also generates consolidated TM packets from S/C SIM (instrument) or test equipment output. (Note: SCOS 2000 provides packetisation service for uplink, and the S/C SIM should provide the downlink facility (e.g. framing of instrument packets etc).

The functions contained in Figure 4 which are *not* specific to ILTs but need to be available throughout all phases of development and in-orbit operations are:

The **On -board Software Maintenance** component, which provides facilities to (i) maintain the instrument on-board software (i.e. modify, validate, simulate, and keep under configuration control), (ii) generate binary images from code in a format suitable for uplink by Test Control (HFI) or manually, through a SCOS2000 interface (LFI), (iii) allow comparison of the stored on-board code with new editions.

The **RTA, QLA,** and **QLA/TA** data analysis systems are used in different modes. The RTA component labelled SCOS-2000 (which is part of the Instrument Workstation used later at MOC or IW@MOC system) will be fed with data directly from the S/C simulator (Uplink/Downlink) with a negligible delay and, as a result of the analysis of the HK data, will produce event logs and other (e.g. error) reports. The RTA, QLA, and QLA/TA (at DPC) systems will be used to display and characterise detector behaviour with a small delay, and can be used also off-line (playback mode). Note: the DPC will operate either on real-time or archived data, and may not necessarily be operating during ILTs; however, at the very least the archiving facility of the DPC must be exercised simultaneously with the ILTs. The acceptable delays between the time the data leave the instrument and the arrival at the different data analysis systems are given in Table 1.

Table 1: Acceptable data transmission delays during ILT.

Location	Data	Delay	Driver
ILT			
RTA/QLA (at DPC)	HK (RTA); Science (Fancy RTA and QLA)	As required by test (<1 min.)	At the DPC near-real-time or off-line analysis is carried out on data taken during ILTs. Feedback for tests is given after analysis of complete data sets. DPC Fancy RTA/QLA pipeline must also be runnable in "slow motion" (i.e. stopping at intermediate pipeline levels to check data products and pipeline integrity).
Real-time	HK (RTA); possibly Science (Fancy RTA/QLA)	<4 sec.	Personnel at the EGSE station need to interact with the instrument (manually or via TEI) and with Test Control. Feedback is real time.

All of these permanent functions, which happen to be used in some (not necessarily final) form for the first time during ILTs, require the following parts of a common infrastructure :

- Permanent storage of all relevant data (e.g. instrument science and housekeeping data, calibration data, etc),
- Retrieval of data,
- S/W configuration control,
- Version control of data and code,
- Document management,
- Storage and version control of test control files.

Ideally it should be possible to create links between these different database items (e.g. link documentation to test procedures and resulting calibration parameters).
Note: IDIS is the facility identified to provide these functions at the DPC. IDIS is not used in the instrument EGSEs (which are largely SCOS2000-based), though some IDIS functionality may be available for specific tasks (e.g. Data Management Component Interface to store acquired data).

3.2.2 Test scenario

Uplink:

Command sequences prepared or selected by Test Control are translated from instrument commands into time tagged command packets by the Uplink system (integrated into S/C SIM for LFI). (Notes: the Uplink system should be integrated into Test Control, so that it can store all sent packets locally. SCOS 2000 provides a packetisation facility. The S/C SIM will not include a facility to simulate command timing, therefore time tagged commands will be passed to the instrument for immediate execution. Test Control will control the execution of the schedule and S/C SIM will simulate the spacecraft autonomy functions in checking and reacting to event messages (e.g. out of limit conditions) generated by (MOC-operated) RTA. (Note: in practice it may not be possible to implement the watch-dog functions in S/C SIM, in which case they would be performed in the EGSE in an RTA-like activity. See also note in Section 3.2.1 under Test Control).

Downlink:

All specified types of telemetry packets generated by the instrument or test equipment will be transmitted by the interface and the uplink/downlink units to the RTA data analysis systems (and to the QLA system which is separate as it cannot be supported by SCOS2000). Finally, all HK data (test procedures, settings of test equipment, data produced during the test, test reports and test logs) will be stored in the SCOS-2000 archive and eventually (HK and Science) in IDIS (at the DPC). (Note: a SCOS 2000 module provides an interface to test equipment, in which case the test equipment data would be received via a standard – Ethernet - command and control link).

3.2.3 Management

ILTs are carried out under control and supervision of the test conductor, who reports to the Instrument AIV Managers.

3.2.4 Data flow

Test procedures and test data will be transferred to a repository in IDIS, for further interpretation and to ensure their smooth transfer into later stages of the development and operations.

4. System level tests

Several levels of testing are foreseen that involve S/C and payload elements;

1. Electrical and data interfaces will be tested first using instrument AVM units and S/C EM subsystems.
2. Instrument functionality and performance at operating conditions are tested on instrument CQM units and a mock-up S/C.
3. Integrated Satellite Tests are carried out on the instrument FM units and the PFM S/C with the instruments at room temperature.
4. Instrument functionality and performance at operating conditions are tested on instrument FM units and the PFM S/C.

AVM, CQM, and FM instrument units must be acceptance tested before delivery to the satellite prime contractor. The acceptance tests may be carried out at the instrument manufacturer premises, and will involve Instrument Functional and Instrument Short Functional Tests. These tests will be used repeatedly after delivery by the satellite prime to verify the good health of the instruments.

Because LFI and HFI are integrated before delivery to the prime, the Functional and Short Functional Tests will involve EGSE for both instruments.

4.1 Test objectives

4.1.1 Integrated Satellite Tests

The tests objectives of the Planck Integrated Satellite Tests (ISTs) are to verify correct operation of the fully integrated satellite in a series of representative mission modes including autonomous and backup modes, Following integration of the instruments into the satellite, ISTs provide as launch and flight-representative an environment to the instruments as possible to validate (i) instrument general health, and (ii) compatibility between instruments. As far as the test set-up and 1 g conditions allow, ISTs will cover all aspects of instrument operations, including the commanding of instruments and validation of engineering modes and astronomical observing modes – however the (cryogenic) nature of the payload is such that the scope of such tests will be limited.

4.1.2 Performance testing (CQM or PFM)

The test objectives of the Planck Performance Tests (PTs) are to (i) verify the functionality of the instruments (with FPUs at operational temperature) and (ii) validate correct implementation of all interfaces between instruments and S/C at operating (cryogenic) conditions. Following ISTs, Performance Tests provide as flight-representative an environment to the instruments as possible to validate (i) instrument general health, (ii) instrument performance and (iii) compatibility between instruments. As far as the test set-up and 1 g conditions allow, these tests will cover all aspects of instrument operations, including the commanding of instruments and validation of engineering modes and astronomical observing modes.

4.2 Operations

ISTs and Performance Tests will be conducted on the satellite prime contractor's premises or at specialised test facilities (e.g. ESTEC, CSL), under the prime's responsibility.

4.2.1 Operational environment

The functional elements of the operational environment during ISTs and PTs are shown in Figure 5 below. Compared to ILTs the following differences apply:

(i) The laboratory environment has been replaced by the S/C, which now provides the uplink/downlink functionality.

(ii) Test control is now covered by the satellite EGSE (normally referred to as Central Checkout Equipment or CCS) and as such falls under ESA or satellite prime contractor responsibility. The CCS provides command and control of the satellite functions and of the satellite environment, and stores all incoming commands and housekeeping, as well as all the data produced by the instruments. The other IST and PT functional elements are expected to be compatible with the ones of earlier (ILTs) and of later phases (SVTs, EE tests and in-orbit operations), which should lead to a similar (if not identical) design.

However, it is clear that due to potential missing S/C functions and missing ground segments elements (e.g. MOC), some shortcomings of the IST set-up with respect to the EE test or in-orbit environments have to be accepted. Missing elements or functions will be simulated to the extent possible, e.g. the ACMS will operate with special stimulation.

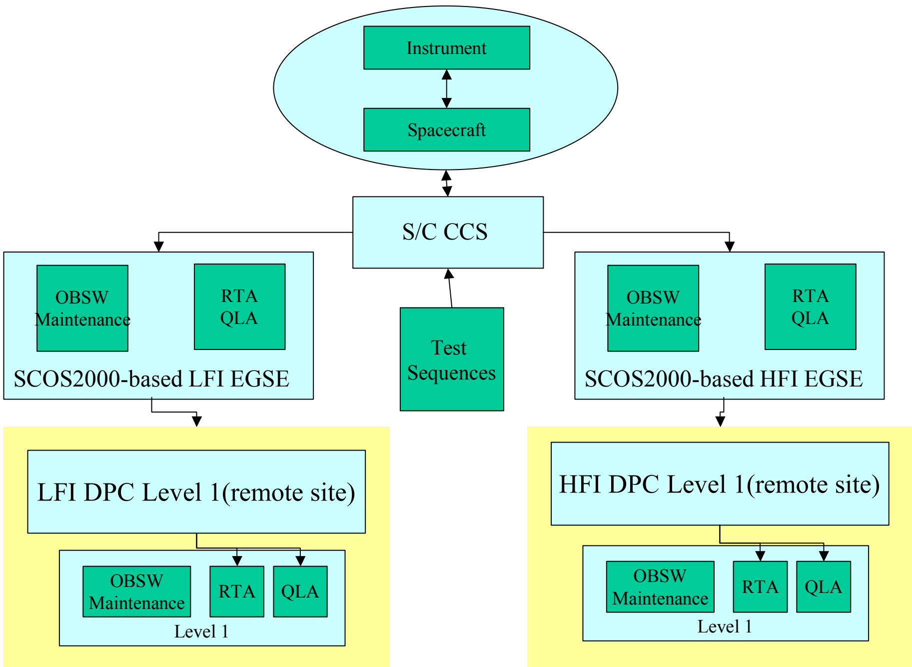


Figure 5: Configuration during ISTs and PTs. The S/C CCS will be provided by the Prime contractor.The instrument EGSE is often referred to as the "Instrument Station" (IWS).

Note: The satellite CCS will contain the functionality to archive TM/TC and satellite RTA. The link between the instrument RTA and test control, which is 'electronic' during

ILTs, may be 'human interaction' between the person responsible for instrument testing, and a test controller in charge of the CCS during ISTs or PTs.

4.2.2 Test scenario

Uplink

It is expected that test procedures related to instrument commanding will be implemented as observation commanding compatible with the concept of observations as it is used in in-flight operations. Commanding of S/C and external test environment will be taken care of at CCS level. With respect to Figure 5, the CCS covers the generation of the corresponding instruments TCs. A copy of the TCs will be provided by the CCS to the DPCs.

Downlink

All specified TM packets generated by the instruments will be transmitted to the instrument EGSEs (or "Instrument Work Stations"), sorted by APIDs, for analysis by RTA, /QLA and later transmission to DPCs, QLA/TA at DPC, and ingestion into IDIS. Note: these tests (in particular PTs) require rapid feedback from data evaluation, and therefore QLA must be available on site (not only at DPC).

4.2.3 Management

ISTs are carried out by the contractor for satellite integration.

4.2.4 Data flow

IDIS will be used as the main repository of test procedures and test results. The data flow within the DPCs is described in more detail in RD8, RD9 and RD18.

5. Ground segment tests

Following the FM ISTs and PTs a series of tests and simulations are carried out, which involve

- the MOC and the real S/C (System Validation Tests - SVTs),
- the MOC, the real S/C, and the DPCs (End to End tests - EEs),
- different configurations of GS elements, during all of which the real S/C is replaced by a satellite simulator.

The overall purpose of these tests and simulations is to prepare all GS centres for in-flight operations individually and as an integrated whole.
The last two SVTs will be followed by an EE.

5.1 System Validation Tests

An early SVT (referred to as SVT-0) is carried out in which only the MOC and the satellite SVM are included (not the instruments); SVT-0 is not followed by an EE test. Two full System Validation Tests (SVT-1 at L-13 months, and SVT-2 at L-6 months) are carried out in which the MOC is connected to and commanding the real satellite; each of these will be followed by an EE test.

5.1.1 Test objectives

The purpose of these tests, each of which lasts ~2 weeks, is to validate the MOC Operational Data Base (ODB) contents and Flight Operations Procedures (FOPs) — which up to then have only been exercised against the S/C simulator—against the real spacecraft. These tests are *not* intended to and do not address instrument scientific operability, except insofar as instrument operations are relevant to the MOC (e.g. database and procedure validation, telemetry types, etc); indeed, SVTs are carried out without MOC to DPC data flow and they produce satellite HK and science data (note that since the instruments are switched on during SVTs, it is mandatory for the DPCs/IOTs to check their status and health, and therefore they have to support these tests). In particular, the objectives are as follows:

- Validation of the capability of the MCS to correctly communicate with the spacecraft
- Validation of the data base for telemetry, telecommanding and on-board software maintenance
- Validation of MCS and FD processes
- Validation of spacecraft behaviour
- Validation of procedures
- Validation of the MOC spacecraft simulator as a representative test tool by comparison of the behaviour with respect to the “real thing”
- Collection of data sets for use in further test campaigns

5.1.2 Operational environment

For these tests the overall ESOC ground segment is in a configuration that is as close as possible to the operational case, given the development status of the system (see Figure

6). Thus, the first SVT may not include all the MOC elements, but ultimately the MOC should be complete at least in the critical areas for the final SVT.

The FM satellite will be fully integrated and located at either the satellite AIV contractor premises or at ESTEC. The satellite is linked to the MOC by a representative part of a standard ESA ground station (the Network Data Interface Unit, NDIU), and in parallel to the CCS. In this configuration, the CCS controls the satellite environment, puts it into a basic mode (i.e. powered), and then switches into a transparent mode, letting the MOC command and control it.

5.1.3 Test scenario

SVTs do not involve the DPCs (except for the IW@MOC, which will be remotely accessible from the DPCs). Test scenarios will be defined by ESOC as a matter of routine work with the aim of maximizing (i) the number of critical flight operations procedures and (ii) the number of commands in the database that are validated against the real S/C.

5.1.4 Management

The H/P Project Manager has final responsibility for SVTs, and will nominate a Test Director. The Test Director establishes the test plan and test procedures, and coordinates with the AIV contractor as required. The DPCs (and the PSO as needed) will support the definition of the instrument specific parts of the tests.

5.2 End-to-end tests (EEs)

Just as for the MOC, the DPCs and their procedures are developed and tested using simulators. Since the FM satellite is only rarely available to be connected to by equipment other than the spacecraft CCS and instrument electrical check-out equipments (EGSEs), the opportunity of having the FM satellite connected to the MOC during SVTs is taken to append a one-week end-to-end test which involves further ground station elements (in the case of Planck: including the DPCs).

5.2.1 Test objectives

Complementary to the immediately preceding SVT, the emphasis of an EE-test is on the scientific operability of the instruments and on validating—in as realistic an environment as possible—the I/Fs between the DPCs and the MOC. Whereas SVTs mostly use manual commanding, EE-tests rely on and exercise satellite commanding through an automatically generated command schedule. In particular, the main objectives are:

- Validation of the overall ground and space segment compatibility and performance from end-to-end in its different operational configurations.
- Validation of the mission planning process and interfaces
- Validation of the data transfer processes and access mechanisms
- Validation of OBSM interfaces for payload elements
- Validation of the DPC capability to receive and process all the data from the MOC
- Validation of the DPC processes and procedures

Except for the Ground Station and antenna, the EE-tests require all the elements of the ground segment interfacing with the MOC to be involved in the testing. In particular the DPCs (and IW@MOC) need to be functional and with resources (infrastructure, personnel) available to an extent compatible with the test.

5.2.2 Test environment

During EE tests the satellite is at the same location as during the preceding SVT. The MOC will be at Darmstadt, and the DPCs (and IW@MOC) will be at their operational locations.

5.2.3 Test scenario

The test scenario consists of exercising routine mission phase activities for a number of ODs on a compressed time scale (with respect to the nominal planning cycle during routine operations). These activities include:

- Delivery by the PSO of an observation plan to the MOC
- Conversion of the observation plan to a real manoeuvre schedule and to a command timeline at the MOC
- Uplink of this timeline to the FM satellite
- Execution of this timeline by the FM satellite, resulting in satellite TM, including science data (to the extent that they can operate at room temperature) and external stimuli.
- Processing of this telemetry at the MOC, and DPCs (including IW@MOC) using the operational interfaces and procedures.

5.2.4 Management

The AIV contractor is responsible for the FM satellite. ESOC is responsible for the planning of the test and commanding of the satellite.

5.3 Simulations

Simulations have the aim of (i) validating operational procedures and databases, (ii) training operators in nominal and contingency situations, (iii) completing GS system tests at higher levels of integration where several (sub)systems, their data and procedural I/Fs are exercised together. Depending on the roles of the different ground segment elements and the time remaining to launch, several types of simulations can be distinguished.

- MOC stand-alone simulations; these simulations are conducted with a spacecraft simulator that more or less realistically responds to telecommands and environmental effects in terms of producing the corresponding HK telemetry for all spacecraft subsystems and (at reduced fidelity) instruments. No realistic science data are generated during these tests; if such data are produced at all it is for the sole purpose of providing a realistic load of incoming telemetry on the system. Numerous such stand-alone simulations are conducted pre-launch, with the majority concentrating on critical mission phases such as the launch and early orbit phase (LEOP). The DPCs play no role in these simulations.

DPC (including IW@MOC, which for the purpose of these tests may be located at MOC or elsewhere) stand-alone simulations; these simulations are conducted with a MOC simulator (which is simplified to include at least a simulator of the DDS interface and a real time TM generator as interface to IW@MOC). The simulator is operated in a mode which puts the emphasis on modelling the instrument HK and science telemetry as realistically as possible while the modelling of S/C HK data is rudimentary and limited to essential instrument/spacecraft I/Fs; the data provided by the simulator should be "real data" (potentially acquired during previous tests), and the simulation should reflect the timing/sequence of events of a real acquisition over several days (including e.g. a DTCP, consolidated data availability events, contingency events, etc). These simulations bring together individual tests that have been carried out before by running the entire DPC systems as one unit for a limited duration in time. It is envisaged that up to two such simulations of up to one week duration each will be conducted before any joint simulations with the MOC.

- MOC/DPC (including IW@MOC) combined simulations; these simulations are conducted as (i) dry runs for EE-tests, (ii) to exercise the data and procedural I/Fs between all ground segment elements. It is envisaged to conduct two such simulations for ~1 week each prior to launch, mixing elements of the commissioning phase, of the calibration/performance verification phase and routine phase operations to a different degree.

Note that for simulation purposes recorded spacecraft and payload AIT data can be used in playback mode.

5.4 Data flow

The data flow for SVTs and EEs is driven by the following considerations:

- RT command and monitoring from the MOC via the NDIU
- Monitoring of the test by the Integration team using the CCS (and payload EGSE)
- Requirements for reaction in the case of contingency.
- Test objectives
- Spacecraft/payload constraints (operating constraints in the clean room environment)
- Special equipment/stimulation constraints
- Communication capabilities (bandwidth)
- Location of payload monitoring equipment provided by DPC.
- Location of expert personnel.

Figure 6 shows a typical SVT configuration.

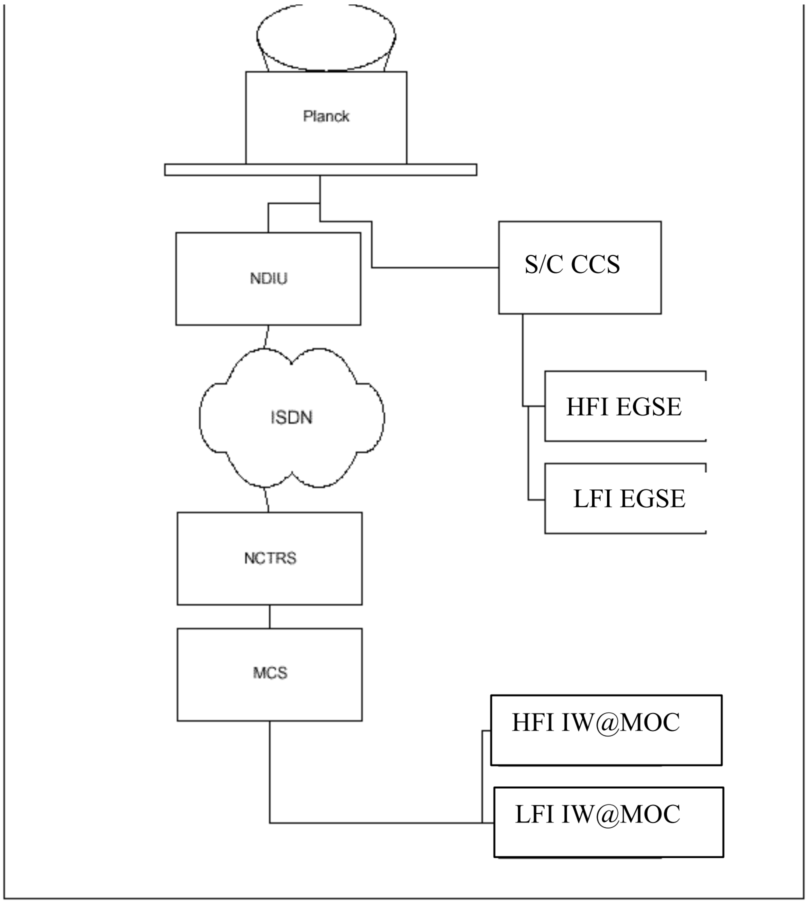


Figure 6: Typical configuration for system level tests. The NDIU simulates the GS. The NCTRS and MCS simulate the MOC.

Depending on the completeness of the ground segment other elements may be involved for thetransfer of data :

- To and from the OBSM subsystem
- To and from the data distribution system

The EE requires all the elements of the ground segment interfacing with the MOC to be involved in the testing. .
In addition the Instrument Stations (EGSEs) must remain connected to the S/C CCS, and the IW@MOCs, being an integral part of the DPCs, must be connected to the MOC.

The data which has to be transferred is the same as that for the routine phase, namely (TBC):

PSO to MOC

Data	**Form**
Requirements for the scan, i.e. series of pointing directions for the next n days	File
Updates for the scan, i.e. new pointing directions	File

MOC to PSO

Data	**Form**
Scan Planning	File
Attitude history and prediction	File

Orbit reconstitution and prediction	File
Updates	Document
Reporting	Document

DPC to MOC

Data	Form
Data base	File
Command Sequences	File
On-board software images or patch commands	Files
Software memory maps/definition	Files/document
Procedures	Document

MOC to DPC

Data	Form
Telemetry and ancillary data	File
Telecommand History	File
Orbit reconstitution and prediction	File
Attitude planning	File
Attitude reconstituted	File
Reports	Document
Database	File

MOC to Instrument Station (IW@MOC)

Data	Form
Telemetry from MCS	SCOS Packets
Telemetry and ancillary data from DDS	Files

Instrument Station (IW@MOC) to MOC

Data	Form
Telemetry requests	TBD

DPC to PSO

Data	Form
Instrument Health and Configuration	TBD
Data quality reports	TBD
Scanning Strategy Change Requests	TBD
Calibration Observation Requests	TBD

LFI DPC to HFI DPC

Data	Form
Calibrated timelines	Database (TBC)
Frequency maps	Database (TBC)
Calibration data	Database (TBC)
Component maps and catalogs	Database (TBC)

Software Maintenance Facility to MOC

Data	Form
On-board software images	Files
Software memory maps/definition	Files/document
Procedures	Document
Configuration Information	Document

MOC to Software Maintenance Facility

Data	Form

Software images (from telemetry)	Files
Telecommand history (selected) TBC	Files
Configuration information	Document

Data flow within the DPCs is identical to that in routine operations, and is detailed in RD8, RD9, and RD18.

6. Launch and early orbit phase

6.1 Objective

To place Planck in a trajectory towards its final destination in a Lissajous orbit around L2.

6.2 Start and duration

Planck will be launched together with Herschel by Ariane 5 into a transfer orbit towards a large Lissajous orbit at the L2 point. Herschel and Planck will detach (in that order) from the last stage of Ariane 5 shortly after launch, and Planck will thereafter proceed independently to orbit. The current launch date is assumed to be 15 February 2007. The transfer time will be 3 to 4 months, and in that time there will probably be 6 navigation manoeuvres, of which three are close to the launch (L+ 2 hrs, L + 2 days and L + 12 days), and three are manoeuvres to inject Planck into the final (small, 15^{o} maximum amplitude to Earth) Lissajous orbit (L + 90-120 days). More details are available in the Consolidated Report on Mission Analysis (RD16).
The LEOP can be considered to last until the first two trajectory corrections have been made. During this phase the payload is assumed to be off.

6.3 Requirements

6.3.1 The Planck payload must not be damaged by Sun illumination

The most sensitive part of the payload includes the optical elements and the focal plane units.

6.3.2 Coolers must be launch locked

This implies electrical power must be available to the payload during launch.

6.3.3 Dilution cooler venting

To avoid plugging, the HFI dilution cooler Helium lines must be vented before the 3rd V-groove temperature reaches 100 K, i.e. about 4 days after payload starts to cool down passively.

6.4 Constraints

6.4.1 Launch window

- The launch window for the Herschel/Planck carrier option will most likely be constrained to two seasonal periods. Details are available in RD16.

6.5 Operations

Operations during this phase are pre-planned and carried out using New Norcia 35m station, Kourou (15m) and Villafranca (15m) antennas, providing as close as possible to continuous contact with the spacecraft.

The LEOP operations will be centred around the check-out of the spacecraft subsystems and the navigation into the correct transfer trajectory. The spacecraft will be transmitting only HK data at low rate, and operations will generally be conducted in RT, unless the coverage does not permit this. Data will be stored on-board for the non-coverage periods, and there will be some time spent in the higher data rate modes to dump this data. An outline of the operations for this Phase follows:

- establish the correct spacecraft configuration
- determine the spacecraft attitude/ spin rate
- correct attitude/spin rate if necessary
- determine the orbit
- determine the optimal attitude and magnitude of the trajectory correction manoeuvre
- execute the attitude slews to the firing attitude
- refine the magnitude and timing of the burn
- execute trajectory correction no 1
- determine the orbit
- determine the optimal attitude and magnitude of the fine trajectory correction manoeuvre
- execute the attitude slews to the firing attitude
- refine the magnitude and timing of the burn
- execute trajectory correction no 2
- determine the orbit
- Slew to the optimal attitude for the transfer (depends on operations and link budget).
- Adjust spin rate
- Start transfer phase operations.

6.6 Management

The entire launch and early operations phase is carried out under the responsibility of the Planck Project (ESA). Operations are actually carried out by the ESOC Flight Operations Director.

6.7 Data flow

Almost all the operations during the LEOP will be conducted in real time using only HK data so that the data flow will be quite straight forward. The payload will not be producing telemetry. The only active external interface will be the MOC to Software Maintenance Facility for the OBDH (which should be located at the MOC, anyway).

7. Commissioning phase

7.1 Objective

The purpose of this phase is to confirm that the spacecraft and instruments are able to provide all the functions anticipated on the ground.

7.2 Start and duration

Following the launch of Planck and Herschel, Planck will be on a transfer trajectory towards L2 (see Figure 7 for a typical trajectory; the current one is described in RD16).

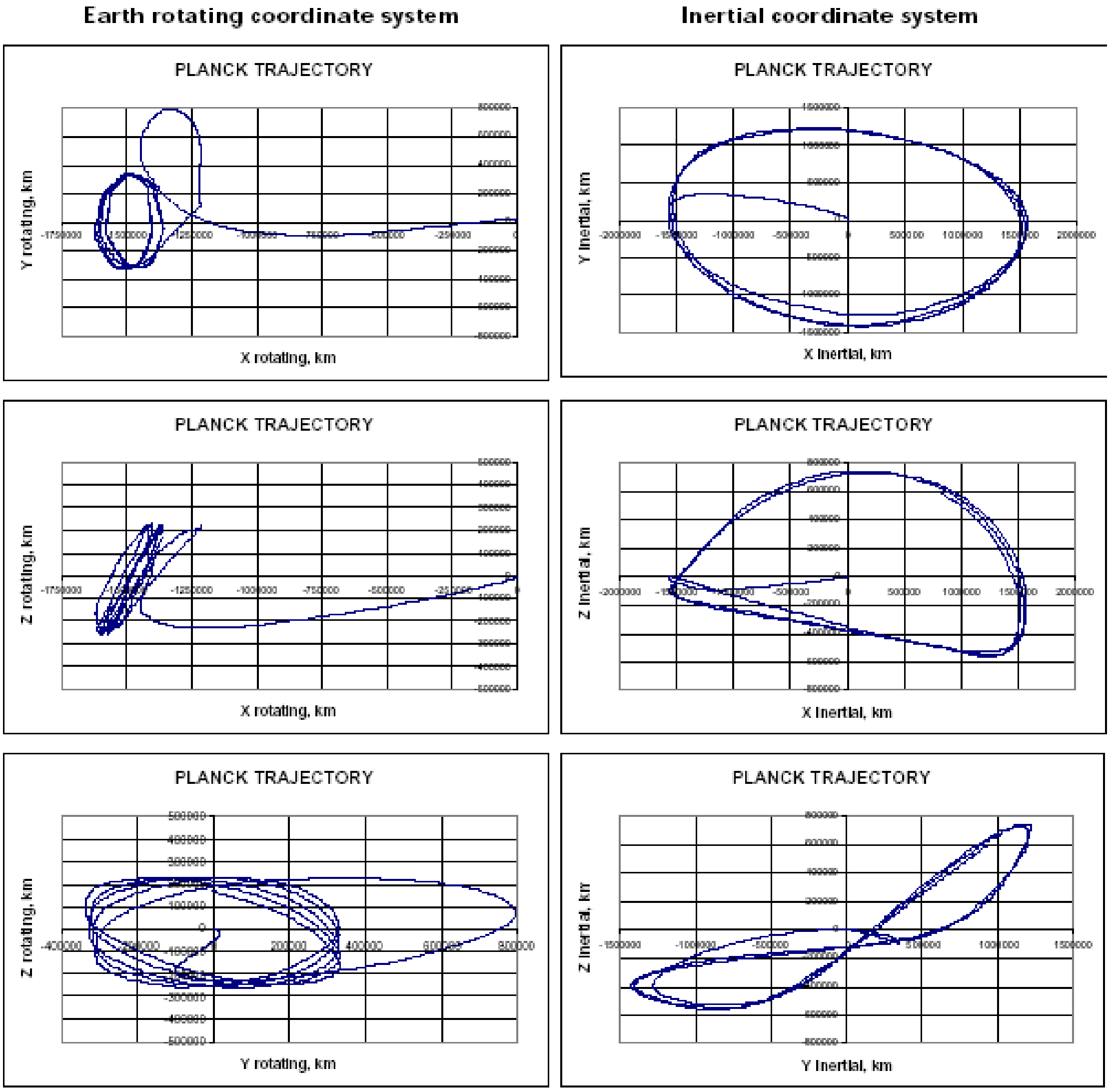


Figure 7: Typical transfer and Lissajous orbit for Planck, 15/2/2007 launch. Manoeuvres are indicated by square symbols.

It is expected that the transfer phase has a duration of between 3 and 4 months depending on the exact launch date and time. The transfer period will be used for the (Spacecraft and Instrument) Commissioning phase and also for the start of the Calibration and Performance Verification phases (if possible). It is currently assumed (TBC) that Planck will not be ready to start Routine Phase operations by the time it is injected into the

Lissajous orbit (L + 1~20 days), but that only the Commissioning phase will have been completed.
Nominally, the commissioning phase starts after the 2nd navigation manoeuvre (L + ~12 days), and has a duration of approximately one month. The actual duration will depend in part on the cooldown of the payload, which could be rather lengthy, e.g. 50 days (TBC), and the visibility of the Earth which determines the data transfer rate.

7.3 Requirements

7.3.1 Real time interaction with spacecraft and instruments is required.

This implies that DPC staff will be located at MOC (manning the so-called IW@MOC, see Section 7.5), with DPC support, 7 days a week. PSO staff will also be located at MOC.

7.4 Constraints

7.4.1 The payload and instruments are cooling down

Long cooling times impose a significant constraint to operations. Below is a rough description of the behavior of the baseline design. Potential means to reduce the cooling timescales as much as possible are currently under study.
The cooling system is staged:

1. passive cooling of the payload to 50-60 K (see Figure 8): it takes about 14 days (TBC) after launch to cool down passively the V-groove shields to nominal conditions (~4 days for the 3rd V-groove to cool to 100 K). The focal plane unit itself will take longer to reach this temperature, unless a heat switch to the last passive stage is implemented.

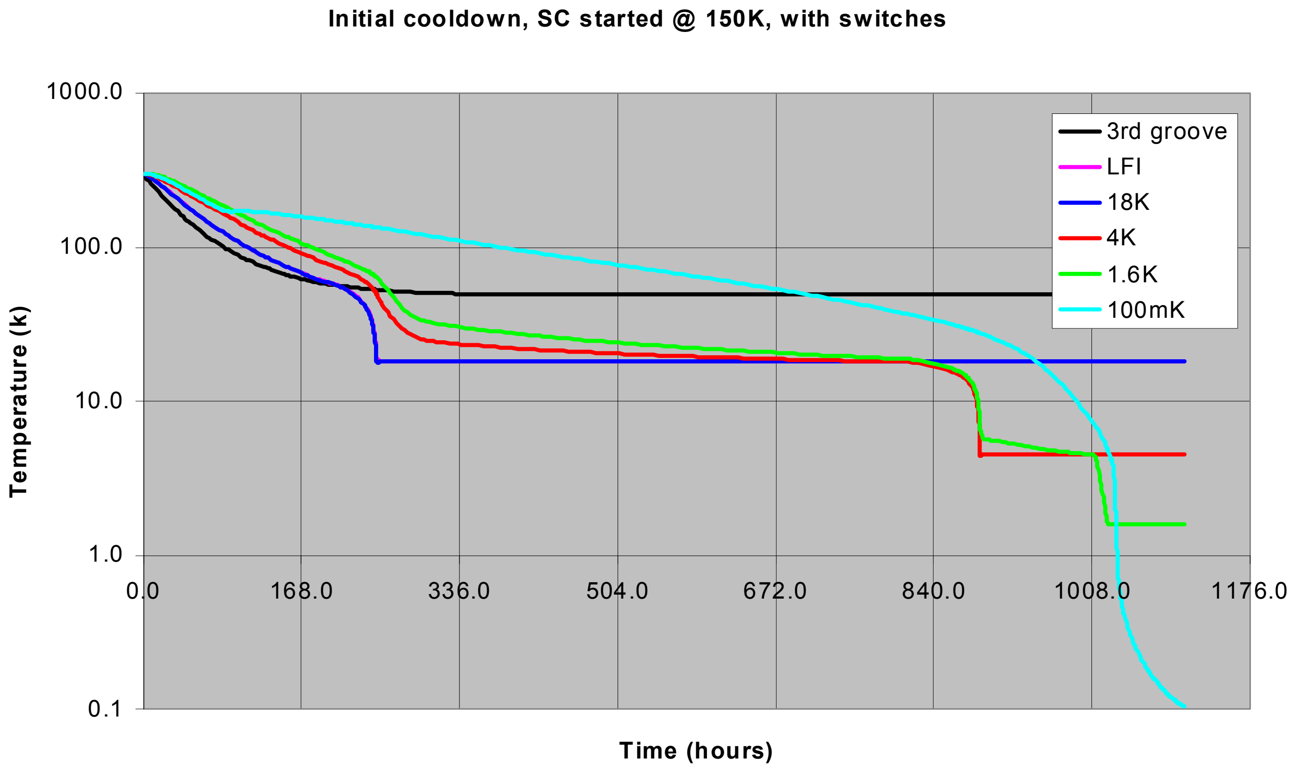


Figure 8: Potential in-orbit cooldown of Planck payload elements (analysis by Jean-Jacques Fourmond, June 2001)

2. It is only possible to switch on the 20 K cooler when the last passive stage is below about 150 K (TBC), but it will operate with very reduced performance until its cold-end is also below about 40 K (TBC). Currently it is estimated that if the 20 K sorption cooler is switched on when the 3rd V-groove has reached 100 K, it then requires about 7 days (TBC) to cool the LFI focal plane to 20 K and the HFI focal plane to 18 K (with all focal plane units turned off).
3. Switch-on of 4 K (J-T) cooler and cool to 4 K: once the HFI focal plane unit is at 18 K, current estimates indicate that about 26 days (TBC) are required to cool the HFI 4K stage (and LFI reference loads) to 4 K. However, the 0.1 K stage temperature lags far behind that of the 4 K stage.
4. Switch-on of 0.1 K (J-T + dilution) cooler and cool down to 0.1 K: the 0.1 K cooler can be switched on when the HFI stage reaches 10 K, i.e. 30 days after 4 K cooler switch-on; it then takes about 5 days (TBC) for this stage to reach the nominal 100 mK.

Given these timescales it is clear that the instrument cooling down sequence, and hence the commissioning phase could be of very long duration. The total cooldown sequence (i.e. from 300 K to 0.1 K) is currently estimated to require ~46 days (TBC), asuming the use of ideal heat switches between 60 and 20 K, between 18 and 4 K, and between 4 and 1.6 K stages. The use of a precooling loop could cut this duration to ~24 days, but is not currently in the baseline as it implies the use of a large quantity of Helium otherwise needed for routine observations.

It may be reasonable to carry out LFI commissioning first (but note that for adequate operation of the LFI the 4K stage must be active and stable) and then move on to HFI, thus also optimizing the use of the (reduced) TM bandwidth.

Note: the HFI JFET box requires about 10 hours to stabilise after being turned on; since the interface temperature of this box is 60 K, the stabilisation period does not affect the total cooldown time. However, it may become important during contingency situations where recovery timescales could eventually be dominated by the JFET box.

7.4.2 Telescope cooldown

The cooldown of the telescope is constrained by two requirements:

- It may have to be heated after launch to release absorbed water. The maximum temperature it can be heated to may be rather low (50 C) which may lead to long water release time scales.
- During cooldown, it must be kept warmer than the surrounding payload to prevent collection of contaminants on the reflector surfaces.

The detailed requirements and timescales are TBD.

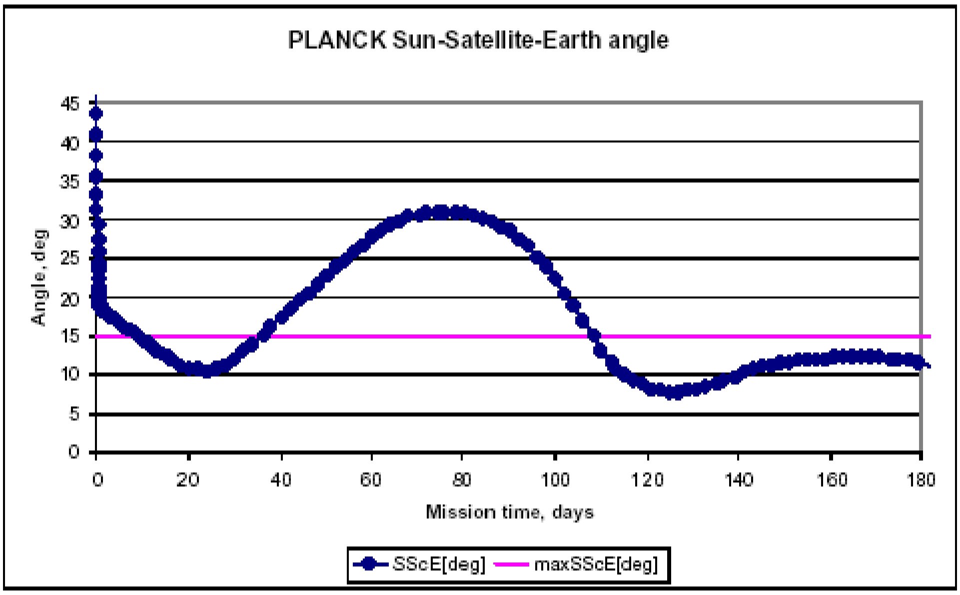
7.4.3 Cooler aging

The material in the 20 K sorption cooler degrades when operated, and thus imposes a finite lifetime to the cooler (the material can in principle be regenerated by heating during flight, but this is currently not in the baseline as it would impose excessive

temperatures on warm radiators in the SVM). Currently the sorption cooler total lifetime is specified as 1.5 yrs in orbit for each of two redundant units.
Similarly the 0.1 K cooler uses cryogens (3He and 4He) which gradually become depleted. Currently the HFI instrument baseline includes enough He for 2 yrs of operation.
Therefore the use of these two coolers during non-routine phases should be optimised and kept to a strict minimum.

7.4.4 The telemetry rate will be reduced

The telemetry rate depends on the distance to Earth and the Sun-Spacecraft-Earth angle (where the spacecraft is assumed to be pointing with the spin axis in the anti-Sun direction). In principle any Sun-S/C-Earth angle of less than 15 degrees (TBC) allows full use of the Medium Gain TM Antenna. Typical parameters are shown in Figure 9 (current values are detailed in RD16). Between about 36 and about 110 days after launch, the Sun-S/C-Earth angle is larger than about 15 degrees and therefore the TM rate will not be nominal in this phase (TBC). During this period communications will be carried out through the Low Gain TM Antennas (4 kbps up to 350000 km distance, 500 bps thereafter), or at a reduced rate through the Medium Gain Antenna, which should allow enough bandwidth (~150 kbps) for real time payload operations during the visibility periods (from New Norcia, or from Kourou within a reduced Earth visibility angular range of ~+/- 10^{o}).



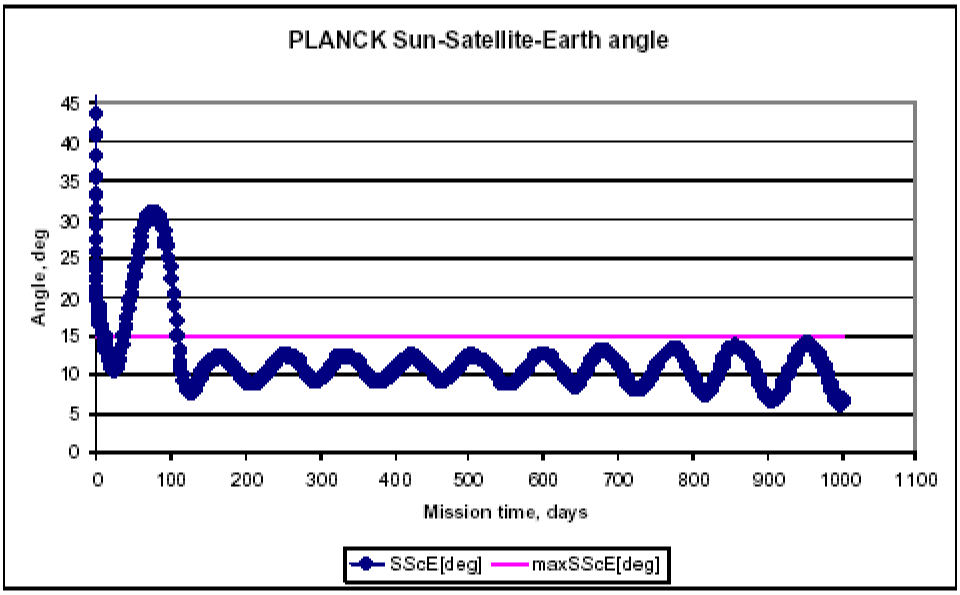


Figure 9: Typical transfer and Lissajous orbit parameters for Planck, 15/2/2007 launch.

7.4.5 Operations must be shared with Herschel

(and possibly other missions, e.g. Rosetta, Mars Express). Therefore the available visibility window will be reduced. The current baseline foresees a daily coverage window of ~10 hrs per day for Planck and Herschel during the transfer phase. It may be possible to use the Kourou antenna in addition to New Norcia (though not at full bandwidth, i.e. Kourou would allow downlinking of real time data acquisition but not of full on-board memory storage). The constraints are: (a) the ability to respond to contingencies by extending visibility periods is reduced; (b) in times of high activity or contingency situations for other missions, entire DTCPs may be missed.

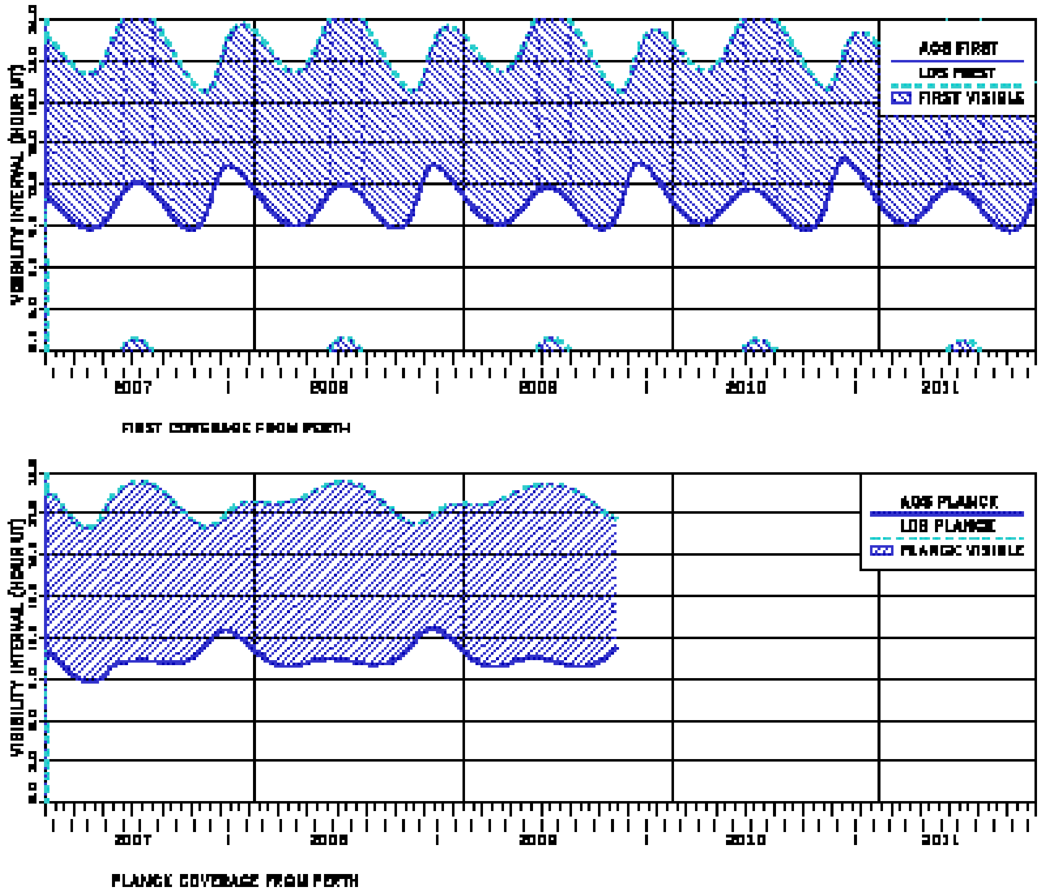


Figure 10: Typical ground station coverage from New Norcia for Planck and Herschel (15/2/2007 launch)

7.4.6 The spin rate may be different than nominal.

The spin rate for the transfer is currently selected at 5 rpm (TBC) which is not suitable for scientific operations but may be acceptable for instrument commissioning (TBC). At the cost of some fuel the spin rate could be adjusted to the nominal of 1 rpm, in which case it would have to be brought up to 5 rpm again before the orbit injection manoeuvres.

7.5 Operations

Operations will be carried out using a single antenna (New Norcia 35 m), possibly supplemented with the 15 m station at Kourou. The visibility window from New Norcia varies between 8 and 13 hours (assuming 5 degrees minimum elevation) depending on the season (TBC). The most current visibility characteristics are available in RD16.

Instrument Operations Teams staff will be located at the MOC during this phase. In order to operate the instruments, they will interact with the MOC using SCOS-2000 based workstations referred to as IW@MOC (one for each instrument). After the commissioning and PV phases are over, the IW@MOC will remain at MOC, and will be available during routine operations for remote access from the DPCs, or at MOC in case of emergencies. The IW@MOC is developed by and will remain the responsibility of DPCs.

7.5.1 Spacecraft commissioning

A significant part of S/C commissioning is already interleaved with LEOP. E.g. prior to the first trajectory manoeuvre, basic properties of the S/C (center of gravity, moments of inertia) and proper functioning of basic satellite subsystems (RF, thermal control, power subsystem, data handling, attitude and orbit control, SSMM, etc.) will already have been established, at least to the extent these subsystems are required for spacecraft operations. Spacecraft commissioning will be completed alongside instrument commissioning as and when required by the instrument commissioning plan. This includes verification of:

- Instrument/CDMS I/Fs,
- Additional ACMS modes required for instrument scientific operations,
- Instrument Focal Plane geometry,
- Instrument PDU and thermometry I/Fs,
-

7.5.2 Instrument commissioning

The activities of the instrument commissioning phase will focus on switch on, functional checkout of the instrument subsystems and their modes, similar to the tests carried out during the Integrated System Tests, plus observations to confirm the instrument/satellite system characteristics (e.g. instrument aperture pointing). In addition, the instruments are likely to take a major role in pointing-related activities, not only to establish the focal plane geometry, but also to assist generic spacecraft activities like establishing telescope boresight to startracker angle.

Commissioning of the two instruments will be done sequentially, starting with LFI and continuing with HFI. This approach is to optimise the low bandwidth available during transfer, and given the cooling time requirements for the two instruments.

Real time interaction will be necessary during this phase, arising from two different types of activities:

- During instrument checkout, execution of procedures will depend on decisions based on the analysis of procedures executed immediately before. Instrument parameters (e.g. detector settings) may be required to be updated on the same time scale, determined by the speed of data analysis and decision taking. These activities imply the satellite should be in continuous (high speed, TBC) telemetry contact with the ground
- Pointing and beam shape determination activities may require specific targets or special manoeuvres (e.g. scanning the limb of a planet) incompatible with the satellite being in real-time contact with the ground. A repeated sequence of "measurement - downlink - measurement - downlink etc." may emerge, implying several pointings and ground contacts to speed up analysis and feedback loops.

Both types of activities are incompatible with a short DTCP and require extended ground station contact and transfer to MOC. A second ground station (Kourou) may be needed. This need requires a working data analysis environment at MOC (the IW@MOC) with:

- the possibility to prepare/modify test/calibration observations and commanding procedures off line.
- the possibility to run the instrument analysis environment, in particular its real-time RTA/QLA/TA parts (Instrument status display etc.). The data transfer time from the

satellite to the IW@MOC should allow such activities on a "real time" timescale, i.e. not introducing dead periods on a timescale significantly larger than the inevitable signal travel. More refined analysis will be carried out from the DPC, which will support this activity by organising shifts and on-call availability for its staff. Table 2 lists the amount of delay between receipt of telemetry at the MOC and availability for the DPC that is acceptable.

Table 2: acceptable data transmission delays during Commissioning Phase.

DPC	HK	~30 min.	Only off-line analysis with little or no feedback to the tests. Possibly generation of command sequences as needed.
	Science	~30 min.	RTA/QLA/TA
IW@MOC	HK/science	< 1 min	Personnel at the instrument station need to monitor the instrument in real time. Similar tests will be carried out as in IST, and thus the time scale for data to arrive should be the same Interaction with the instrument is done via the MOC spacecraft operators.

7.6 Management

The entire satellite commissioning phase is carried out under the responsibility of the Planck Project (ESA).
The IOT Managers will be relocated to the MOC, and will be responsible for the conduction of the instrument tests and confirmation of their correct execution.

7.6.1 Spacecraft commissioning

Spacecraft commissioning will be carried out with as few special operations as possible, and will be based on the analysis of the data gathered previously during the LEOP, as well as on any specific commissioning operations. The objective will be to establish the actual performance of the spacecraft as compared to the specification. Normally only the prime subsystems and equipment are used during this phase (TBC by Project).

7.6.2 Instrument commissioning

It will not be necessary for the personnel at MOC to be in continuous contact with the DPC. Indeed, it is not expected that the DPC will monitor all the tests as they may be carried out at any time of day or night (the staff at the IW@MOC will work shifts, as required by the timing of the tests). Despite this, the IW@MOC will be provided with telephone and network links to the DPCs to allow monitoring of the tests by the DPC and discussion between the instrument experts, at the DPC, and the IOT Managers at the MOC. It is noted that the DPCs are responsible for the provision and maintenance of IW@MOC -DPC network and telephone links.

A communication link from the IW@MOC to the spacecraft controller is used to provide verbal communication between the instrument representatives and the spacecraft controller during tests. Verbal communication shall be restricted to exchange of information, control of predefined operations and requests for predefined emergency actions. Any changes in procedures, sequencing/commanding shall be subject to formal approval by the responsible Instrument Manager and Project Scientist.

A set of procedures and associated command sequences are defined by the instrument groups and provided to the MOC before the tests begin.
The IOT Managers start up their respective IW@MOC systems and configure them for the tests. This includes connecting to the real-time telemetry data.
The spacecraft controller will issue commands to the instrument (and spacecraft) according to the procedure(s) to be carried out. These may include points at which the spacecraft controller will wait for the corresponding IOT Manager to confirm that it is OK to start the next stage of the test.
The IOT Managers will monitor the execution of the tests and confirm, when appropriate, the continuation of the test.
Some tests will require off-line analysis to confirm the correct completion of the test. This analysis may be made at the IW@MOC or at the DPC depending on the facilities, timescale and expertise required.

7.6.3 Contingencies

In the event that a test fails, or another problem arises, the IOT Manager may decide that the testing cannot continue. He/she will request a termination of the test. The IOT Manager will notify the DPC and any other instrument expert of the problem and the action taken.
The resolution of the problem and the recommended course of action to be taken will be decided by the IOT Manager in agreement with instrument experts. However, it is not expected that these, will be available outside normal working hours so the investigation of the problem will probably not start until the beginning of the next day (The DPC will be manned 7 days a week during this phase)
The final decision on how the overall commissioning plan proceeds in view of an instrument not being ready to continue the test as planned requires additional input from Project, MOC, PS, and all DPCs. The final decision will reside with the Flight Director (Project Manager).

7.7 Data flow

The data flow is in principle similar to that in routine operations (see RD8, RD9, and RD18), but higher data analysis activities are carried out at the MOC.

8. Calibration and Performance Verification phase

8.1 Objectives

- To obtain a first in-flight characterisation of the instruments in terms of their performance parameters: detector sensitivity and stability, frequency response, angular resolution and beam shape, magnitude of and sensitivity to systematic effects (straylight and thermal variations, RF interference, etc), data compression algorithm effectiveness.
- To determine the scanning law to be used in the Routine Operations phase.

8.2 Start and duration

This phase begins when spacecraft and instrument commissioning have been completed and after injection into the final Lissajous orbit (L + ~120 days, TBC). Its duration is TBD, however it is assumed that it should be completed within two months (i.e. before L + ~180 days, TBC).

8.3 Requirements

8.3.1 To measure the instrument performance parameters

For each detector at least the following shall be measured :

- Sensitivity and stability (to TBD accuracy)
- Frequency response (to TBD accuracy)
- Angular resolution and beam shape (to TBD accuracy and dynamic range)

For each instrument:

- Effectiveness of data compression algorithm
- Sensitivity to systematic effects

8.3.2 The spin rate must be 1 rpm

The spin rate for the transfer is currently selected at 5 rpm which is not suitable for scientific operations. In order to measure detector performance the spin rate must be the nominal value of 1 rpm.

8.3.3 The instrument environment must be stable

To measure the payload performance its environment must be as in the nominal operating conditions. It may be possible to meet the environmental requirements for LFI before the nominal environment is achieved.

8.3.4 Special manoeuvres

The routine mode of observation will be used during this phase, but specific manoeuvres will be commanded to gather information allowing to choose/confirm the scanning law for the first survey.

8.4 Constraints

8.4.1 Operations must be shared with Herschel

See section 7.4.5.

8.5 Operations

This phase will be carried out in a pre-programmed mode similar to that used in Routine Operations. As soon as the instruments are turned on, it is necessary that all HK packets are collected from the ground to ensure the instrument health and safety.

Specific instrument settings and possibly specific repointing manoeuvres will be commanded, and data will be acquired in nominal mode (with the exception of data compression tests, for which special modes allowing downlink of uncompressed data are designed).

Operations will be carried out using a single antenna (New Norcia 35 m). The visibility window from New Norcia varies between 8 and 13 hours (assuming 5 degrees minimum elevation) depending on the season. The stringent DTCP definition that applies during routine operations may be relaxed in this phase depending on other operational constraints.

The need for DPC staff at the MOC is TBD.

Table 3 lists the amount of delay between receipt of telemetry at the MOC and availability for the DPC that is acceptable during PV.

Table 3: acceptable data transmission delays during Performance Verification

DPC	HK	~30 min.	Only off-line analysis with little or no feedback.
	Science	~30 min.	Only off-line analysis with feedback to the observing schedule on timescale of day(s).
IW@MOC	HK/Science	< 1 min. (typical, 1 hr guaranteed)	Only for monitoring of live TM, little or no feedback to operations expected.

8.6 Management

As for routine operations, see Section 9.7.

8.7 Data flow

As for routine operations, see Chapter 9.8.

9. Routine operations phase

9.1 Objectives

To carry out two surveys of the full sky.

9.2 Start and duration

This phase of the mission begins after the end of the Performance Verification Phase (i.e. before L + ~180 days).
The duration of each sky survey depends on the angle between the spin axis and the main telescope Line of Sight (LOS). If this angle is 90 degrees (80 degrees), each sky survey requires 6 months (7.5 months). Therefore the duration of this phase is between 12 and 15 months. In this document it is assumed that the duration is 15 months, even though the angle has an actual value of 85^{o}.

9.3 Requirements

9.3.1 Two sky surveys shall be carried out, each of which must cover at least 95% of the sky.

A survey is defined as the maximum portion of the sky which can be traced out (within operational constraints) by the FOV of the focal plane, during 7.5 months of continuous operations. See RD20 and Annex 1 for a description of the scanning strategy. The choice of a particular scanning strategy may affect the actual fraction of the sky covered.

9.3.2 Coverage gaps of the two surveys together must be minimized.

Modelling indicates that a random distribution of daily gaps in data acquisition, such that the total data loss is less than 5% of the total duration of the routine phase, will lead to acceptably small gaps in the final combined sky coverage of the two surveys.
It is further assumed that small gaps (much shorter than a day) can be recovered by ad-hoc means.

9.3.3 Data lost in the Ground Segment must be minimized

Contributors to data loss include on-board problems, transmission loss (normally negligible) and ground problems. On-board problems result in real data loss. The probability of frame loss in the S/C to GS link is small (currently specified to be less than 10^{-5} , TBC), but real data loss occurs as a result of Ground Segment failures. Current experience indicates that about 98% of data acquired reaches the final user (but see also 9.3.2).

9.3.4 The payload must remain in the shadow of the Sun

The maximum angle between spin axis and Sun-S/C direction is 10^{o}.

9.3.5 Thermal transients must be minimized

There are two types of transients to be considered:

- Transients due to manoeuvres.
- Transients due to change of instrument settings. Thermal constants are very long (see e.g. Section 7.4.1) and changes (in particular due to switching off of active cooling

systems) must be avoided. This may have implications on the autonomy requirements.

Transients related to S/C changes (thermal control, DTCP related on-board activities, etc) are reduced by design.

9.3.6 The duration of the DTCP should be minimised

During the DTCP the data acquired may be contaminated by RFI due to TM transponder. The current maximum duration of the DTCP is specified to be less than 3 hours.

9.3.7 The angle between the spin axis and the S/C-Earth direction must be less or equal to 15^{o}

This is to ensure the TM data rate via the Medium Gain Antenna.

9.4 Constraints

9.4.1 Lifetime

The HFI lifetime is limited by the availibility of cryogens for the cooling system. Currently the cooling system is designed for a total operational lifetime of 24 months (TBC). Note that cryogen is also being spent when the instrument is turned off. The cooling timescales preclude frequent turning on and off of the instrument. Similarly the lifetime of the 20 K sorption cooler is limited by degradation of the sorbent. As the sorbent degrades the heat lift capacity of the cooler is reduced. Currently the estimate of sorbent degradation allows the completion of two nominal sky surveys with no diminution of the nominal heat lift capacity; however these estimates depend sensitively on the specific S/C and payload models used.

9.4.2 Pointing control on board and on-ground

The current ACMS design is such that errors in a given slew are corrected in the next – i.e. they are not cumulative. In this case the main corrective action will be updating of tables characterising the actuator performance and sensor alignments. If there is need of on-ground monitoring and compensatation of pointing drifts affecting the scanning law, this will be done by MOC at appropriate intervals.

9.4.3 DPCs are manned 5 days a week

The timing of the shifts shall be synchronized if possible with the contact times with the satellite. A capability to respond to contingencies 7 days a week shall be provided by the DPCs.

9.4.4 There will be occasional orbital correction manoeuvres

Currently it is assumed that one monthly manoeuvre is required. These manoeuvres will be carried out during DTCP and will not entail reorientation of the spacecraft or interruption of the data acquisition, but small disturbances of the attitude will be generated.

9.4.5 Spacecraft engineering time

Spacecraft maintenance and engineering will be required occasionally. This downtime is currently limited to 10 hours per month, and may or may not entail interruption of observations (TBD).

9.4.6 Reaction Timescales in Ground Segment

The timescales of reaction to spacecraft events imposed by the Ground Segment is of order days, unless the event is detectable in the HK data and has an associated procedure to be executed by MOC, in which case the reaction time is within minutes of the data defining the event being available - which depends on when the event occurred, and whether the spacecraft was in ground contact at the time.

9.5 Operations

During routine operations the S/C spin axis is repointed about once every hour to follow a pre-determined trajectory called the "scanning law" (see Annex 1 and RD20). 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 order degrees per month) in the direction perpendicular to the ecliptic plane and maximum amplitude 10 degrees. This motion is implemented with active manoeuvres approximately every hour (of about 2.5 arcminutes along the ecliptic plane).

The scanning law is determined before the start of each sky survey and is not changed thereafter unless major surprises or instrument reconfigurations occur (but note that the law may change from the first to the second survey). Therefore the pointing schedule of the satellite is known many weeks in advance. However it is possible that contingency procedures may include reorientation manoeuvres to make up for missed observations. Because the payload shadow cone implies limitations in the reorientation angle (of maximum ~20 degrees currently, and even lower near the orbit extremes), the reaction time for implementation of updates to the scanning law must be at most of order days.

The two instruments are operated in parallel in a single mode, acquire data continuously and store it in on-board memory. The data is dumped to Earth via a Medium gain Antenna every day within a given DTCP.

9.5.1 DTCP

The nominal duration of a DTCP is <3 hrs.

During each DTCP, the MOC will go through a sequence of interactions with the S/C which typically includes:

1. Acquisition of S/C in low TM rate:
2. Confirm S/C attitude is as expected to start DTCP operations
3. Start telemetry transmission in low rate (scheduled on-board)
4. Start Ranging
5. Configure station and switch to high TM rate
6. Enable dump of events and stored HK
7. Enable RT science
8. Enable dump of stored science
9. Replenish on-board schedule to cover the next 48 hours
10. Terminate dump
11. Configure station and switch to low TM rate
12. Start Ranging
13. End of pass

Ranging will take place during two 5 minute periods at the beginning and end of each DTCP.

9.5.2 Planning of operations

In the routine phase it is anticipated that both instruments will operate in parallel continuously during each sky survey. The scanning law which is followed by the spin axis is decided before the beginning of each survey and is not changed unless there is a strong recommendation to do so by the PST. The scanning law is implemented as a series of manoeuvres at 30-60 minute intervals.
The inputs to MOC operations therefore consists of two parts:

1. The set of manoeuvres to be carried out by the spacecraft. The PSO will provide to MOC the definition of the scanning law as a time series of absolute pointing positions. MOC will convert this series to the corresponding set of required periodic (~hourly) spacecraft manoeuvres. The exchange of information between PSO and MOC is regulated within the context of a "Mission Planning Cycle" (RD19). Before any change to an approved scanning law is implemented, it will be reviewed and formally authorized by the PS or his appointed representative. Updates to the scanning law will be driven by engineering/calibration needs, and by contingencies, i.e. unforeseen changes in the completeness and quality of the acquired data, see Section 9.5.8. These updates will be covered by the regular Mission Planning Cycle (RD19) or pre-agreed procedures.
2. The instrument configuration. Each instrument (via its corresponding IOT/DPC) will be responsible for defining the instrument configuration. It is anticipated that the configuration will be stable during each sky survey, though minor adjustments may have to be made at time scales of a few days. Each DPC will deliver directly to MOC the configuration of its corresponding instrument and all other instrument related inputs (e.g. procedures, command sequences, software images etc). Common hardware elements (e.g. sorption cooler) will be operated by one IOT only. MOC will consolidate the inputs from the two instruments on the basis of procedures established by the two DPCs jointly. These procedures will have as objective to ensure the safe and optimal joint operation of the two instruments.

The observation plan will be contained in an observation database from which it can be retrieved for assessment. MOC will inform the PSO and the IOTs of periods of time which are required for spacecraft activities which may hamper or prevent observations from being carried out, e.g. spacecraft maintenance requirements.

9.5.3 Engineering time

Orbit maintenance operations will be required at roughly monthly intervals. These operations will take place only during DTCP, will not require interruption of instrument operation, and will not affect the spacecraft attitude (except in a minor way).
During routine operations it is not anticipated to interrupt a sky survey to carry out calibration observations. Similarly no specific instrument engineering observations will be required except in contingency situations.
The Planck surveys will only be interrupted:

- for regular spacecraft engineering/maintenance. It is currently specified that these periods will be limited to a maximum of 10 hours per month, and during those periods the instruments may continue to gather data.

- in case of instrument or spacecraft contingencies. These occasions will be covered by Contingency Recovery Procedures.

9.5.4 Execution of operations

9.5.4.1 CDMS - instrument interaction

On-board, the command schedule is executed autonomously by the CDMS. At the times specified in this schedule, TCs are sent to the instruments in the form of TC source packets (i.e. stripped of the time information). This is performed in a 'fire and forget' fashion in the sense that the CDMS does (i) not wait for any packet acknowledgement from the instrument and (ii) does not interpret any TC verification packets sent by the instruments.

The CDMS may detect abnormal instrument conditions (e.g. failure to transfer data correctly) in two ways:

- Monitoring of the bus traffic
- Event packets transferred from the instruments to the CDMS

In these cases the CDMS will take some pre-defined action (e.g. switch the instrument off). Further information on instrument failures is contained in section 9.5.8.2 below.

At all times instruments source TM packets are retrieved by the CDMS for storage in the SSMM and for RT downlink during the DTCP.

9.5.4.2 Assumptions

Some assumptions that are relevant in the context of on-board observation execution are indicated here:

1. Each instrument (i) is separately schedulable (though the normal mode of operation has both instruments working in parallel), (ii) can generate science and/or house keeping data for itself, and (iii) has its own, unique instrument identifier (INS_ID).
2. The instruments always accept the packets that get sent to them.
3. If one of the two instruments enters a contingency mode (off or standby), it may deliver no data, or HK only. The other instrument should be unaffected.
4. Provided the instrument operates nominally, schedule generation during scientific mission planning will ensure that the command packets sent to an instrument can never overflow the instrument internal packet/command buffers.
5. No command sent to an instrument can endanger the health of the instrument independent of the state of the instrument at the time the command is received (e.g. also when a command is skipped for any reason).
6. All science TM packets contain enough information required to process that particular bit of data on the ground (e.g. OBS_ID, relevant instrument parameters).
7. The reaction time in case of problems (from detection of the problem in available TM to having scheduled and/or manual TCs available to

investigate or cure the problem) is typically of order 72 hours (TBC, assuming that IOTs have access to near real time data via the IW@MOC).

8. CDMS generated commands are formatted according to the ESA packet standard.
9. TC reception and execution verification information is recorded on board for down-load at the next DTCP.
10. If an instrument has to be switched on this is always done manually, i.e. under ground control during the DTCP.
11. 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 (depending on details of instrument status).

9.5.4.3 Instrument monitoring and evaluation

First level monitoring of the instruments will be carried out by MOC, which will open Instrument HK packets, extract a subset of instrument parameters and based on these will carry out basic checks of the instrument health. Any anomalies in the instruments will be dealt with by pre-agreed CRPs.

Each DPC will monitor the health and performance of their instrument throughout Routine Phase. It does this by

1. collecting instrument anomalies identified by the instrument itself, the CDMS, or reported by the MOC,
2. identifying unexpected instrument events reported in instrument HK TM,
3. analysing (both in real time and off line) instrument HK and Science data to identify anomalous behaviors
4. analysing trend data extracted routinely from instrument HK and Science TM, S/C HK TM, and calibration/scientific AOT products,
5. periodically dumping instrument on-board memory for comparison with the expected image.

In the event of an anomalous situation being detected, the DPC will investigate the problem using data from the observation, previous observations, ground testing; instrument simulators or other software tools; the instrument flight spare; specific diagnostic observations submitted to the satellite; or a combination of these.

A panel of instrument experts will be convened to evaluate the information from the investigation and to recommend a course of action to the CCB chaired by the PS or his appointed delegate. This may be: do nothing; update on-board software, change procedures, etc.

Routine monitoring activities will be carried out as a background task (i.e. there is no requirement to carry out the task each day) although monitoring should not lag behind data reception by more than a few days; instrument anomalies will, of course, be dealt with as soon as possible after they have been reported. In general, the DPC will work five days per week, with an instrument specialist (who has remote access to the DPC software) being available on call during weekends (at least during the early parts of the mission).

9.5.4.4 Spacecraft monitoring and evaluation

Monitoring and evaluation of the spacecraft will be carried out by the MOC in a similar fashion as described in the previous section. The various spacecraft on-board failure modes and corresponding recovery actions (on-board and/or ground; to be taken by MOC or DPCs) will be defined by the Prime Contractor during phase B.

The ground segment related failure modes will be defined jointly between ESOC, the DPCs, and the PSO, including identification of which GS parties are involved how in the recovery action. For each failure case a thorough analysis will be required, which is outside the scope of this document. The major failure modes are briefly listed in section 9.5.8 as far as they can be identified at this early stage.

One specific task of the MOC is to make sure the pointing requirements of Planck are kept at all times. Since there is no closed-loop pointing control on board Planck, the MOC will analyse the information from the on board ACMS sensors, and will adjust the scanning law so as to compensate for drifts and other pointing anomalies. This will be done at appropriate intervals.

9.5.4.5 TM delivery

9.5.4.5.1 On-board TM generation data rate

Satellite TM is assumed to be generated at an average rate of ~130 Kbps, which is allocated to the different on-board sources as follows:

- S/C HK: 4 Kbps,
- Science data: 130 Kbps, including instrument HK, overheads, and margins. The current allocation between the two instruments is: LFI:54 kbps; HFI: 76 kbps. The relative allocations will be adjustable in flight in steps of 0.5 kbps (TBC) to account for changes in observation strategy or instrument configuration.

9.5.4.5.2 TM mapping to virtual channels

Data sources on board will be allocated a virtual channel number to identify them to the ground processing facilities as follows:

- VC0: Live (real time) essential spacecraft HK and critical instrument HK
- VC1: Live (real time) science (i.e. science data generated during DTCP),
- VC2: Dump (stored) HK (HK data from SSMM), including events, TC verification, and memory dumps,
- VC3: Dump (stored) science (science data from SSMM),
- VC4: Live (rel time) spacecraft and instrument HK (HK data generated during DTCP), including events, TC verification, and memory dumps,
- VC5-6: Not used.
- VC7: Idle Frames (A full frame where the data field is filled with random data)

During DTCP at least VC0 is transmitted from the Ground Station to MOC; a small fraction of VC1 must also be transmitted on a need-only basis during DTCP; it is currently estimated that about 1500 seconds of real-time science data are needed by each instrument to assess the instrument status. Note that the science data itself will be compressed by a factor in the range 3-4, and therefore requires correspondingly less bandwidth of the Ground Station to MOC line, but since it is NRT data it will be available over the real time acquisition period.

(Note that during commissioning and PV phases VC1 is piped down during DTCP per default.)

9.5.4.5.3 Solid State Mass Memory data volume

SSMM data storage is to be sized for 2 days of TM data, i.e. around 22.5 Gbit [130 Kbit/s * 48 hours], taking into account that *all* TM data will be recorded on-board (even if it had already been transmitted live during a DTCP) and assuming storage of instrument TM data including packetisation overhead.

9.5.4.5.4 Solid State Mass Memory and download data organization

It is assumed that

- The SSMM can be organised in such a way that the event and TC verification packets can be dumped before the remaining HK data.
- The download of data from the SSMM can be prioritised so that data of high interest (e.g. HK) can be dumped first.
- The CDMS is flexible enough to allow any combination of data to be downloaded during DTCP:
  - Live HK only,
  - Live HK + live Science,
  - Live HK + SSMM dump,
  - Live HK + live Science + SSMM dump.

9.5.4.5.5 DTCP duration and S/C to ground station data rate

If we assume that

- TM download from the S/C to the ground station requires a 20% overhead for both dump and live TM (130 Kbit/s expanding to 0.56 Gbits/hour),
- live and dump TM are downloaded at the same time,

we find the total data volume to be downloaded from the S/C to the ground station during DTCP to be 13.4 Gbits, or a satellite to ground station bandwidth of about 1.25 Mbits/s for a 3 hour DTCP; or conversely, a downlink time of ~2.5 hrs for a nominal downlink bandwidth of 1.5 Mbit/s.
Note: these numbers are to be taken as rough estimates only.

9.5.4.5.6 Data transfer from ground station to MOC

The ground systems involved in this data transfer are the TMP at the ground station and the NCTRS at the MOC. The TMP will permit the selection of data in two modes: Real time and IDA mode;

- The real time mode, intended largely for control purposes, ensures that real time S/C data arrives at the MOC in real time (discarding data if the link to the MOC cannot keep up with the data rate). No recovery measures are made for data lost between TMP and MOC. (Note: all the data, including real time data, is transmitted anyway in IDA mode).
- The IDA (Immediate Data Access) mode ensures (by buffering if necessary) the complete transmission of data from the ground station to the MOC. Recovery measures for data lost due to partial or total link failures are discussed in Section 9.5.8.5.

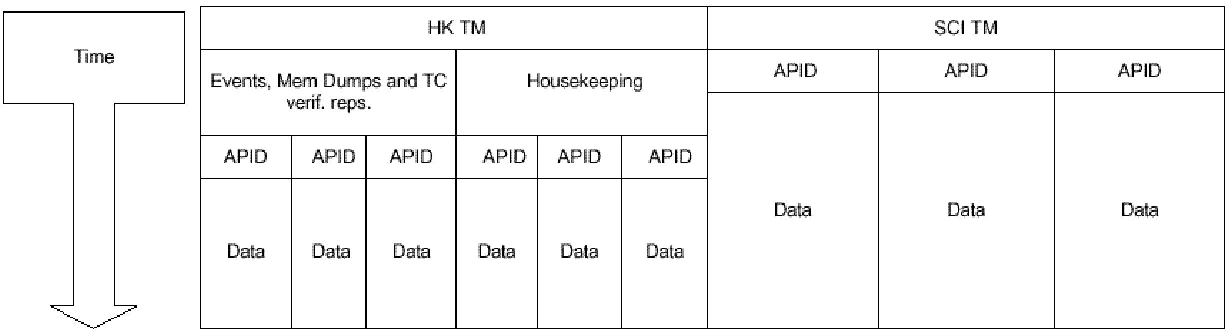
Real time data has priority over IDA data. The selection of data from the TMP will be based on VC (note that idle frames will be discarded). Thus, for a pass in which data from all VCs will be transmitted, the scheme will be as follows:

- Connect to the TMP for Live HK (VC 0)
- Connect to the TMP for Live science (VC 1) (only a fraction of VC1 is downloaded)
- Connect to the TMP for IDA dump HK (VC 2)
- Connect to the TMP for IDA dump science (VC 3)

The bandwidth for the data transfer from the ground station to the MOC will be sized such that all the data corresponding to one OD can be transferred to MOC within 24 hrs, including a margin of ~8 hrs to allow retransmission and consolidation when needed. The bandwidth sizing will take into account that it is not necessary to transfer 48 hours worth of satellite data (in case the previous DTCP has been missed) over a single physical line; such a terrestrial, operational line can be assumed to be backed up (TBC) such that the bandwidth of the nominal line can be sized for only 24 hours worth of satellite data and both the nominal and the backup line will be used in case of having missed the previous DTCP.
In addition to the above requirement (i.e. nominal transmission in less than 16 hrs), it is recommended to add as a goal to improve the transmission time (to ~2 hrs) to allow more flexibility in the retrieval of data from the DPC.

9.5.4.5.7 TM made available by MOC

All telemetry (S/C and instrument) is archived at the MOC in the Data Distribution System (DDS) from which it is accessible to the DPCs in the form of TM source packets. The DDS "makes available" TM data but does not "distribute" data. TM are made available in the DDS by categories (events, HK, science), APID and time period:



Data will be available in two modes:

- **Consolidated TM:** TM made available after consolidation (the consolidation time is the time after which no more data can be expected to be received pertaining to the time period for which the data is being merged into a time ordered stream.). The consolidation process ensures that for a given period all TM correctly downloaded to the ground station are made available in a time ordered manner. Consolidated TM are made available on a time range basis (e.g. one OD, one week). For a given period, events TM will be made available to Planck, followed by the remaining HK TM, followed by science TM. In a routine scenario (where all data for one OD is recovered within 24 hours), consolidated data will be available 24 hours after its acquisition by the GS. Anomalous situations may lead to a lengthening of the consolidation period (see Section 9.5.8).

- **NRT TM:** TM made available almost as soon as received by MOC. As "unconsolidated" data, NRT TM will appear in the DDS with a latency of approximately one minute after actual reception at the MOC, independent of whether it is live or dumped TM. NRT TM is made available on a TM packets basis. However, note that the main mode of acquisition of NRT data will be through the IW@MOC (see Section 9.5.4.5.10). Heavy downloads of NRT data to the DPCs would affect the capacity of the line to deliver the consolidated data within the routine periods.

Access to the data from the data distribution system will be via a catalogue, which defines the files which have reached the DDS (i.e. those which are considered to be complete, either because they are (e.g. NRT data), or because the "consolidation time " has expired). It may be practical to declare the consolidation time earlier for certain types of data (e.g. events and TC reports) so that they appear in the archive very quickly.

9.5.4.5.8 Ancillary data made available by the MOC

Satellite TM alone will not be sufficient to fully exploit the Planck data scientifically; e.g. satellite TM does not contain any orbital position and velocity information, calibrated thermometry, or processed pointing information (assuming post processing at MOC is required to achieve the final pointing accuracy specification). For this reason the MOC will make available additional, ancillary data on the DDS, including predicted and measured orbital data and a reconstructed attitude history.

The delay for delivery by MOC of ancillary data, in particular flight dynamics information (i.e. pointing), is of order one week (TBC).

9.5.4.5.9 Access to data stored on DDS by DPCs

During the routine phase, the DPCs are expected to retrieve consolidated data from MOC (for each type of TM and ancillary information) on a daily basis. Retrieval on two out of seven days may be done by an automatic process or under manual control by a skeleton staff (TBC).

The delay for arrival of consolidated MOC data to DPC is TBD. However, assuming the same bandwidth as for the GS-MOC link, an additional delay of ~16 hours (over the GS-MOC ~16 hour transfer plus consolidation time) can be foreseen.

Views of the (non-consolidated) NRT data may be accessed by the DPC via the IW@MOC (TBC). This is expected to occur on a daily basis.

9.5.4.5.10 Access to data via IW@MOC

The IW@MOC, mainly used during commissioning and PV phases by DPC personnel located at MOC, will remain at MOC during routine operations and provides a means to access NRT data bypassing the DDS. From a DPC it will be possible to remotely log into the IW@MOC to be able to support instrument diagnosis and download NRT data to the DPC. It is expected that this will occur on a daily basis as well as during contingencies.

On a daily basis, this mechanism will be used to evaluate NRT HK data, as well as the minimum fraction (~1500 seconds) of NRT science data needed to adequately evaluate instrument health (see also Section 9.5.4.5.2).

In case of contingencies procedures may be put in place to allow larger fractions of NRT science data to be visible to the DPCs via the IW@MOC. However, if a serious instrument anomaly is detected by the MOC that cannot be dealt with by SPACON using available CRPs, DPC presence at the MOC may be needed for an interactive session with the instrument during a DTCP.

Note that Spacecraft Controllers (SPACONs) are not expected to set up, man or maintain any of the IW@MOC equipment, including the network and/or telephone lines connecting it to the DPCs.

9.5.5 Data processing and evaluation

The DPCs will routinely query the DDS for newly arrived consolidated TM and ancillary data, retrieve this data, and ingest it into IDIS. TM will be initially stored in an archive at the DPCs in the form of source TM packets. The scientific data will subsequently be extracted from the TM packets, decompressed, and stored as raw data in IDIS.

Scientific data processing will be carried out using automatic and/or interactive analysis packages developed by the DPCs. These packages will be available from IDIS and include the best instrument calibration knowledge available at the time, which is expected to evolve significantly during the mission.

The DPCs will systematically process all observational data for quality control purposes. The processing will be done by running some IA and other dedicated modules in batch mode with default parameters, and will require additional information, such as MOC operational logs, the TM event packets and the RTA logs. As a result of the evaluation, a quality flag will be assigned to each unit of observation (possibly a “ring”), which reflects (i) whether the observation has executed nominally, (ii) whether all data generated are available in the archive, (iii) whether quality control processing has completed without error messages having been generated, and (iv) whether the corresponding quick-look output is available. Although it is assumed that the quality flag will be assigned automatically for most observations, in some cases a deeper analysis by an instrument specialist may be required. It is planned to store the products generated during quality control processing in the archive.

As part of the quality control process, detailed periodic comparisons of pipeline products will be conducted between LFI and HFI DPCs.

Bulk processing of all observations in the archive, with generation and storage of all products, will be carried out at periodic intervals during the routine and post-operations phase.

9.5.6 Processed data delivery within the Planck community

The DPCs will periodically make available to the Planck community specific sets of processed data. Different types of data sets will be delivered with different time periodicities. Roughly, updated sets of processed timelines and of frequency maps will be produced at monthly intervals, and updated sets of component maps at half-yearly intervals. Each successive set will include the latest and best calibration and pipeline processing.

The access to the data by the Planck community will be done through the IDIS archive interface, and it will be controlled following the Planck data policy, the data policy of each Consortium, and in accordance with the subsequent data proprietary rights. The IDIS archive interface will allow the user to make queries selecting on all parameters that characterize the data , and to browse and retrieve selected parts of it.

9.5.7 Scientific product delivery

The final scientific products of the mission, including explanatory documents, ancillary data, and some access/visualisation tools will be delivered by the Consortia to PSO two years after the end of the second sky survey. The details of the delivery will be covered via a specific agreement between PSO and the two DPCs.

9.5.8 Contingencies and recovery

In the absence of satellite contingencies, data acquisition is carried out automatically (i.e. outside ground station contact and without ground intervention) by the instruments from the on-board schedule, which is loaded/updated from the ground during the DTCP. Several types of failure occurring on-board may cause this autonomous mode of operations to be abandoned. In addition, GS elements (ground station, MOC, DPCs) as well as the ground communication network or the space-to-ground link can fail in various modes that affect operations.

Failure modes lead to interruptions of the Planck sky surveys. However, data continuity is an important requirement for Planck, as any gaps in the sky coverage imply degradations in the quality of the processed (final) scientific products. Given the needs for environmental and instrumental stability, and the long reaction timescales to any anomalous events, a possible general approach could include the following elements:

- Minor instrumental problems (e.g. failure or degradation of small numbers of detectors) will not be allowed to interrupt the surveys.
- During the first survey, it will be attempted to recover minor gaps in sky coverage with special manoeuvres which are not part of the scanning law. By minor are meant gaps of order one day (which may occur from e.g. GS failures) within the maximum 5% tolerable data loss.
- Failures leading to large gaps in the first survey (i.e several days to several weeks which may result from e.g. cooler failures) will be dealt with by the PST on an ad-hoc basis.
- During the second survey, efforts will be made to recover any gaps left in the first survey. This may mean: adjusting the scanning strategy, making special reorientation manoeuvres not in the scanning law, etc.

The various on-board failure modes and corresponding recovery actions (to be initiated on-board and/or on ground) will be defined by the Prime Contractor during phase B. The GS-related failure modes will be defined jointly between ESOC, the PSO and the DPCs. For each case a thorough analysis will be required, which is outside the scope of this chapter. The major failure modes are briefly listed here as far as they can be identified at this early stage:

9.5.8.1 Spacecraft failure modes

- Survival mode: The S/C will enter "survival mode"

  (i) automatically, if a major failure is detected by the on-board fault detection logic;
  (ii) automatically, if a violation of attitude constraints is detected;
  (iii) automatically, if no ground command has been received for a given, ground-programmable time;
  (iv) if the ground has commanded the S/C into survival mode.

  Upon entering survival mode, the S/C will configure itself and the two Planck instruments into their respective "safe" modes (possibly switch-off for the instruments) and will abandon execution of the on-board schedule. The S/C will be able to maintain the survival mode for at least seven days without ground control. The attitude constraints are satisfied while in survival mode. Exit from the survival mode will only be possible via ground command.

- Other S/C anomalies: The on-board FDIR (Fault Detection, Isolation and Recovery) logic may detect other on-board failures whose criticality do not require entry into the survival mode, e.g. when switching to a healthy redundant unit is possible. Minor failures (e.g. out of limit conditions) may possibly be rectified by the spacecraft autonomously (e.g. through gain setting adjustment) without the need to switch to redundant units. Minor anomalies might not even require any specific actions apart from reporting their occurrence in telemetry.

In all cases failures and anomalies detected on-board are reported to the ground in the TM via specific "event" packets. In addition, specific events not related to any error condition may also be reported via the "event" packet mechanism (e.g. successful completion of an observation).

9.5.8.2 Instrument failure autonomous detection and recovery

It is assumed that no command can harm the instruments. All commands will be checked by the DPUs for their validity, wrong commands will be rejected and an event packet will be sent to the CDMS (which, however, will not take any action other than storing it on the SSMM). Missing commands may influence the ensuing data quality but should not harm the instruments. Conditional execution of commands (i.e. that the CDMS should send them on to instruments only if some condition is met) is only possible via on-board procedures; i.e. command packet headers do not contain conditional fields.

Two types of autonomy functions will be used to control the status and health of the instruments. The first level of autonomy is handled by the CDMS.

- The CDMS will regularly check important instrument parameters like primary voltages and currents or temperature read-outs controlled by the spacecraft. In case of anomalies or failures, the CDMS will react according to predefined procedures and put the instrument either in a safe state or power it off. Event packets will be issued by the CDMS accordingly.

- The CDMS will regularly check if the DPUs of the instruments are alive. In case of an anomaly the CDMS will react according to predefined procedures, e.g. microprocessor reset (TBC) or power-off.

The second level of autonomy functions will be handled by the instrument DPUs, which will regularly check important instrument parameters. In case of an anomaly they will take corrective actions according to predefined instrument on-board procedures, e.g. changing bias voltages, commanding the subunits into a safe state, or even requesting the CDMS to switch off the instrument. To request such CDMS action the DPUs will use event packets.

The DPUs will also verify the execution of commands or procedures by the instrument subunits, which communicate with the DPUs through event messages. To make these events available in TM, the DPUs pass them to the CDMS. In case of anomalies they will either take corrective actions themselves or ask the CDMS to switch off the instrument or put it into a safe mode.

Neither the CDMS nor the DPUs will initiate recovery actions in case of major instrument anomalies or power-off. Instead, agreed procedures for detailed failure analysis and recovery will be carried out from ground.

Specific severe failure modes which have been recognised include:

- Failure of the (non-redundant) HFI 0.1 K cooler: results in loss of HFI. If the cooler can be brought back into operation it still requires many days (or even weeks, TBC) to cool the HFI bolometers to nominal temperature.

- Failure of the (non-redundant) HFI 4 K cooler: failure of this cooler results in warming up of the 4 K stage (to 15 K in ~24 hours – TBC - and to 20 K in ~50 hours TBC) and immediate warming of lower temperature stages, with consequent immediate loss of HFI observations. In the worst case this failure is only detected from the ground 21 hours from occurrence. If the 4 K cooler can be brought back to normal operation within 24 hours (i.e. from ~15 K), it will require about 100 hours (TBC) to cool back down to 4 K. This would then be followed by cooling down of lower stages. Therefore, in a typical case, this failure mode entails a recovery time of many days. A permanent failure of the 4 K cooler would not only render the HFI inoperable, but would also affect the performance of LFI, which relies on reference loads cooled by HFI to 4 K.

- Failure of the (cold redundant) 20 K cooler: failure of this cooler results in warming up of the 20 K stage to ~70 K in ~120 hours (TBC). Failure of the HFI 4 K cooler and lower stages is immediately triggered. Both instruments are therefore affected. Recovery of the 20 K stage may be very lengthy, and a return to normal operating conditions from this failure mode can probably be measured in weeks. Autonomous switchover from the failed cooler to the cold-redundant cooler is not currently being considered due to the severe difficulties and risks associated to this functionality (e.g. a large fraction of the total S/C power is consumed by this unit; the redundant cooler would not be commissioned, etc), which would make this solution probably not acceptable.

Current modelling (which incorporates ideal heat switches between most cryogenic temperature stages) implies that when all coolers are switched off, nominal conditions can be recovered after ~10 days (resp. 12 days) TBC, if the coolers are restarted within 24 hrs (resp. 48 hrs) of failure.

9.5.8.3 Ground recovery from spacecraft and instrument failure modes

At the beginning of the DTCP the "event" packets (S/C and instruments) are downloaded from Planck to allow the ground to assess as quickly as possible spacecraft and instrument health, as well as the status of the operations which were executed outside ground coverage.

Three main types of activities can be carried out on ground depending on the nature of the failures/ anomalies detected (details are TBD):

- implement diagnostic procedures (spacecraft and/or instruments),
- implement corrective action through manual commands from MOC (recovery),
- replan and uplink new instrument settings (to minimise loss of science until the failure/anomaly has been analysed to a level that diagnostic or recovery action can be attempted).

For all the cases above, approved Contingency Recovery Procedures (CRPs) must be available.

9.5.8.4 GS Node failure

- Pass missed: Problems at the ground station or scheduling conflicts with other spacecraft having higher priority than Planck may cause a pass to be missed (i.e. the DTCP to be cancelled). No data is lost on board in this case since the Solid State Mass Memory (SSMM) on-board the S/C is dimensioned to store 48 hours of data. **Specific provisions (to be discussed and agreed) will have to be made in order to recover the data over the subsequent passes.** Currently it is foreseen that in the event of loss of a complete pass, ad-hoc measures will be taken by MOC to either extend the coverage period (e.g. by extending the DTCP or using additional ground stations), or to get more time in the future passes. The last 24 hours of data will always be recovered before attempting to recover older data. The older data will be transmitted to MOC from the ground station either by using left-over line capacity or line backup capability (see Section 9.5.8.5). In this case the consolidation period will be extended until all relevant data has trickled back to MOC.
  If more than one pass is missed, data will be lost. It is likely that in this case (TBD) the ground will command the S/C into survival mode from another station.
- MOC failures: To be described in lower level documents.
- DPC failures: To be described in lower level documents.

All identifiable failure modes listed above must be covered by the corresponding approved Ground Segment Procedures.

9.5.8.5 Ground communications failures

- Ground station-to-MOC link failure: The line capacity of the GS-to-MOC link includes a margin for recovery of data lost during transmission: within each 24 hour period, ~16 hours are required for full transmission and ~8 hours are available for

retransmission. This margin will cover most problems. A backup line, if present (TBC, see Section 9.5.4.5.6), could also be used for retransmission of lost data.
Other measures will be required to cover the case of a partial or total failure of the New Norcia-MOC link (and its back-up), which cannot be recovered before the next pass. The TM downloaded from the S/C is always recorded at the Ground Station (nominally New Norcia). Depending on the duration of the failure, the data recorded at the station can either be re-transmitted when the link is restored or a CD can be written and mailed to the MOC (TBC). It is also conceivable that the low volume TM (HK TM, which includes event and TC verification packets from the S/C and instruments) can be re-transmitted (or transmitted using public networks) while the complete TM is recorded on CD and mailed to the MOC. Such measures would also require specific software at MOC (currently not planned) to ingest the old data.

- MOC-DPC link failure: To be covered in a MOC/DPC Interface Control Document (ICD), which will cover MOC-to-DPC as well as DPC-to-MOC link failure. The ICD will also cover error cases which are not related to a link H/W failure (e.g. missing input, input in the wrong format, etc.). Because the MOC-DPC links might become operationally critical in contingency situations (not safety critical but critical to achieving the Planck scientific objectives), suitable backup strategies for a failure of these links need to be investigated
- DPC-IW@MOC link failures: For this link standard internet connections will be used. Failure cases will be covered in the MOC/DPC ICDs.
- PSO-MOC link failures: for this link standard internet connections or telephone communication will be used. Failure cases will be covered in the PSO/MOC ICD.
- Internal DPC link failures (Level 2 to Level 3, etc): to be described in lower level documents.

For all the failure modes listed above approved Ground Segment Procedures must be available.

9.5.8.6 Space-to-ground link failure

Space-to-ground link errors may affect the communication between the spacecraft and the ground resulting in lost packets or incomplete packets being received at the ground station. The current specification for probability of frame loss in the Space-to-ground link is 10^{-5}.(TBC) Since all TM generated on-board is stored in the SSMM, these failures do not result in loss of data per se. In principle, packets lost in the space-to-ground link could be identified (by scanning the incoming data for gaps), and during the subsequent pass retrieved from the SSMM and dumped. This is however a non-trivial operation in terms of planning and consolidation of the MOC Archive (DDS). It is therefore not in the MOC baseline to recover such data.

More severe failures that lead to large data losses will be treated as "pass missed" failures (see Section 9.5.8.4) to the extent possible.

9.6 Maintenance

9.6.1 On-board S/W maintenance

In the event that on-board software in an instrument needs to be changed to accommodate an instrument anomaly or for operational reasons, the DPC will be responsible for modifying the code, or on-board tables, as necessary, using the OBS maintenance facility provided by the DPC/IOT. The updated code will be used to generate memory images required to implement the change on board. This may be in the form of a complete image of the code resident in the instrument (required if the instrument unit cannot retain code changes on board when switched off) plus, possibly, a patch to the current code on board. In any case, all such images will be tested on either the Flight Spare instrument or other instrument simulators available before being made available to the Ground Segment.

An SPR/SCR will be raised at the time of the anomaly/change arising and, when verified, the software change will be delivered to the MOC with a software release note describing the implications of the change, plus updated documentation reflecting the change. At this point the software should be approved for uplink by the PS, subject to successful ESOC validation.

There are two possible (mutually exclusive) alternatives for the delivery of software changes:

1. The modified image is delivered complete to ESOC and the ESOC OBS Management System generates the necessary patch commands to upload the image.
2. The modified software is delivered as a command sequence containing the necessary patch commands.

In both cases the change has to be accompanied by a procedure for implementing the change.

The MOC will validate the patch and the procedure as far as feasible using the satellite simulator and submit the results to the PS (TBC) for final approval. When approved, the patch will be uplinked to the satellite by the MOC. MOC will also be in charge of verifying that the update has been successfully performed. In the case of delivered patch commands, this will be limited to observing the correct execution of the patch commands, and e.g. checking checksum values specified in the procedure. If an image is delivered it will be possible to dump and compare the memory contents.

The timescale for implementation of (instrument on-board) software changes will depend on the maturity of the change requested. It is foreseen that software related to scientific processing (which need not be validated by MOC) may require a few days for actual patching, whereas changes which may affect interfaces or operations procedures may require 1-2 weeks for implementation.

In the event, where an instrument on board memory needs to be analysed (e.g. following an instrument failure), the DPC may request MOC to dump partially or totally its memory image. The memory dump will be planned by MOC in co-ordination with the DPC. The resulting memory dump will then be transferred to the DPC via the MOC-DPC link.

9.6.2 Ground segment S/W maintenance

Ground segment S/W maintenance will officially start with the S/W transfer phase, which ends with the successful completion of the last EE test. The MOC on one side and the DPCs on the other side will set-up separate S/W maintenance teams and environments, reflecting the separate way in which the GS S/W has been developed. At the time the GS S/W enters into maintenance, the MOC/DPCs S/W and data interfaces are expected to be stable enough to be managed in an ad-hoc fashion (e.g. through specific meetings) with two possible exceptions:

- Maintenance of the instrument and S/C databases, which are shared by MOC and the DPCs, and which are very likely to change regularly during the early phases of the missions (commissioning and calibration/performance verification).
- Maintenance of the SCOS-2000 system, which is likely to be common to both the MOC and the DPCs.

The maintenance of these two entities is likely to require specific bodies with representatives from MOC and DPCs (TBD).

Concerning S/W maintenance at the MOC, it is expected that ESOC will make their standard provisions for maintaining Flight Control S/W; in this respect Planck is no different from any other ESOC-controlled satellite.

The two DPCs are expected to share a software infrastructure (IDIS). As a consequence, it is expected that the maintenance of all S/W which is shared between the DPCs (including S/W and data which may impact the quality of the science data taken by Planck and the efficiency with which this science data can be obtained) is managed in a centralised fashion. This implies existence of:

- a joint Change Control Board (CCB), chaired by the PS or his appointed delegate (TBC), with permanent members from the two DPCs. Only this board has the authority to approve/refuse and plan changes to the DPC systems that may have an impact on DPC/IOT interfaces or operability.
- Changes to a DPC system which relate only to its own scientific processing pipeline will be approved/refused by a different CCB, which will be chaired by the PI, and will include the PS and DPC Manager as members.
- a centralised change control system accessible to all relevant parties.
- centralised documentation and S/W configuration control systems which are used by all relevant parties.

The CCB is expected to meet at regular intervals (e.g. weekly) to review the pending SPRs, SCRs and to disposition on their analysis, implementation, and installation. Because the different CCB members will not be on the same site, CCB meetings will normally be held via tele- or videoconference.

It is expected that each DPC will set up a SW maintenance team in charge of implementing, testing and installing the S/W changes approved by the CCB for the S/W falling under their responsibility (i.e. the S/W they have developed). The different teams will co-ordinate their efforts on a day-to-day basis with the objective of meeting the work plan set by the CCB. The co-ordination will be facilitated by the centralised change, documentation and configuration control systems, which are expected to be taken over from the development phase. These systems are expected to be COTS with little or no specific development.

This set-up is expected to be in place from some time prior to the S/W transfer phase until at least the time at which the scientific products are delivered by the DPCs to ESA.

9.7 Management

The highest responsibility will lie with the Mission Director, who is appointed by ESA's Director of Science. It is currently expected that during routine operations the Head of RSSD will acts as Mission Director, and will delegate his responsibility to the PS.
During the routine operations phase the ESA Spacecraft Operations Manager (SOM) has the highest authority for spacecraft and instrument operations. His/her first responsibility is to ensure spacecraft and instrument safety and operation (in that order).
The two Instrument Operations Managers (IOMs) will be the single point interface to the SOM for all instrument matters. The IOMs will be responsible for all routine communication in this respect between MOC and the instrument teams. In particular they will provide to the MOC all instrument related inputs as necessary.
The Project Scientist (PS) will be the highest authority for all science related matters. In particular he/she will:

1. Provide the MOC with a description of the scanning law to be implemented and any modifications thereof.
2. Approve any major modifications of instrumental configuration.
3. Coordinate all necessary feedback from the DPCs which may lead to modifications of the observing plan or major changes in the instrumental configuration.

The two DPC Managers will be responsible for all matters concerning data processing within the two DPCs, and for issues concerning data interfaces with MOC and the other DPC.

Any anomalous or contingency situation which may have an impact on the scientific return of Planck will be resolved by a Board, chaired by the PS, and with participation at the very least of the SOM, the two IOMs, and other personnel as appropriate (e.g. the PIs, the DPCMs, etc). The final resolution authority will be retained by the PS, unless the situation represents a threat to the spacecraft and/or instrument safety, in which case authority will be exercised by the SOM.

9.8 Data flow

The general principle is:

1. All data generated by the satellite flows directly from the MOC to the DPCs.
2. All information required to operate the instruments is generated by the DPCs (IOTs) and flows directly from the DPCs to the MOC

The observation plan (or scanning strategy) is provided by the PS to the MOC for implementation.

3. Any changes to the preplanned scientific operations are approved by the PS.

The data which has to be transferred between MOC, DPCs, and PSO is:
The data which has to be transferred is (TBC):

PSO to MOC

Data	Form
Requirements for the scan, i.e. series of pointing	File

directions for the next n days	
Updates for the scan, i.e. new pointing directions	File

MOC to PSO

Data	Form
Scan Planning	File
Attitude history and prediction	File
Orbit reconstitution and prediction	File
Updates	Document
Reporting	Document

DPC to MOC

Data	Form
Data base	File
Command Sequences	File
On-board software images or patch commands	Files
Software memory maps/definition	Files/document
Procedures	Document

MOC to DPC

Data	Form
Telemetry and ancillary data	File
Telecommand History	File
Orbit reconstitution and prediction	File
Attitude planning	File
Attitude reconstituted	File
Reports	Document
Database	File

MOC to Instrument Station (IW@MOC)

Data	Form
Telemetry from MCS	SCOS Packets
Telemetry and ancillary data from DDS	Files

Instrument Station (IW@MOC) to MOC

Data	Form
Telemetry requests	TBD

DPCs to PSO

Data	Form
Instrument Health and Configuration	TBD
Data quality reports	TBD
Scanning Strategy Change Requests	TBD
Calibration Observation Requests	TBD

LFI DPC to HFI DPC

Data	Form
Calibrated timelines	Database (TBC)
Frequency maps	Database (TBC)
Calibration data	Database (TBC)
Component maps and catalogs	Database (TBC)

Software Maintenance Facility to MOC

Data	Form

On-board software images	Files
Software memory maps/definition	Files/document
Procedures	Document
Configuration Information	Document

MOC to Software Maintenance Facility

Data	**Form**
Software images (from telemetry)	Files
Telecommand history (selected) TBC	Files
Configuration information	Document

The flow of data and information within the DPCs isdetailed in RD8, RD9, and RD18.

10. Post-operations phase

10.1 Objectives

The objectives of this phase are to:

- Reduce all the data acquired by Planck in the scientifically best possible way
- Exploit the data from a scientific point of view
- Produce and deliver the final scientific mission products as defined in the SMP

10.2 Start and duration

This phase begins after the end of the second sky survey (i.e. approximately L+21 mos). Nominally it is intended that the main data reduction phase be finished in one year, and that the ensuing year is used as the proprietary period for scientific data exploitation. In reality these two subphases will overlap to a great extent, depending on the complexity of the data processing needs and the problems encountered. It is in any case specified in the SMP that the proprietary period finishes two years after termination of the second sky survey, at which time the final products should be delivered to PSO for integration into the Archive developed by RSSD/SCI-SD.

10.3 Management

TBW

11. Archive phase

11.1 Objectives

In the Archive phase the objective is to make the Planck products available to the wide astronomical community, to stimulate further scientific exploitation of the data, and to disseminate the scientific results to the wider public.

11.2 Start and duration

The Archive phase starts with the delivery of the scientific products by the Planck DPCs toPSO, at approximately L+3.75 yrs.
It is most likely that the official delivery of scientific products will be only the first of several generations. Therefore:

- It should be foreseen to allow the incorporation of several product generations into the Archive
- The PST must remain alive to decide on the maturity and release of successive product generations.

11.3 Management

TBW

LIST OF REFERENCES

ANNEX1: THE PLANCK SCANNING STRATEGY

An overview of the main elements of the Planck Scanning Strategy is presented here. A much more detailed description is available in RD20.

Planck will be placed in a Lissajous orbit around the 2nd lagrangian point of the Earth-Sun-Moon system, such that the Sun-S/C-Earth will not exceed 15°. The satellite will rotate at 1 rpm around a spin axis pointed within 10° of the Sun. The payload must always remain in the shadow of the Sun. The solar array ensures this as long as it is inclined with respect to the Sun-S/C line by less than 10°. The Planck telescope defines a sparsely sampled field of view (FOV) approximately 8° in diametre around a reference line-of-sight which is inclined by 85° from the spin axis. As the satellite rotates, the FOV will trace a circle of diametre 170° on the sky. These circles are referred to as “rings”.

Planck will dump each day to Earth within a period of <3 hours the data acquired during 24 hours. It is required that the observations not be interrupted during the downlink period, and that the S/C not be reoriented towards the Earth. Therefore the telemetry antenna is designed to have adequate gain within a 15° half-cone from the spin axis, ensuring that even at the extremes of its orbit the Planck telemetry can achieve full bandwidth.

The relevant elements of the orbit and payload configuration are shown schematically in Figure 11.

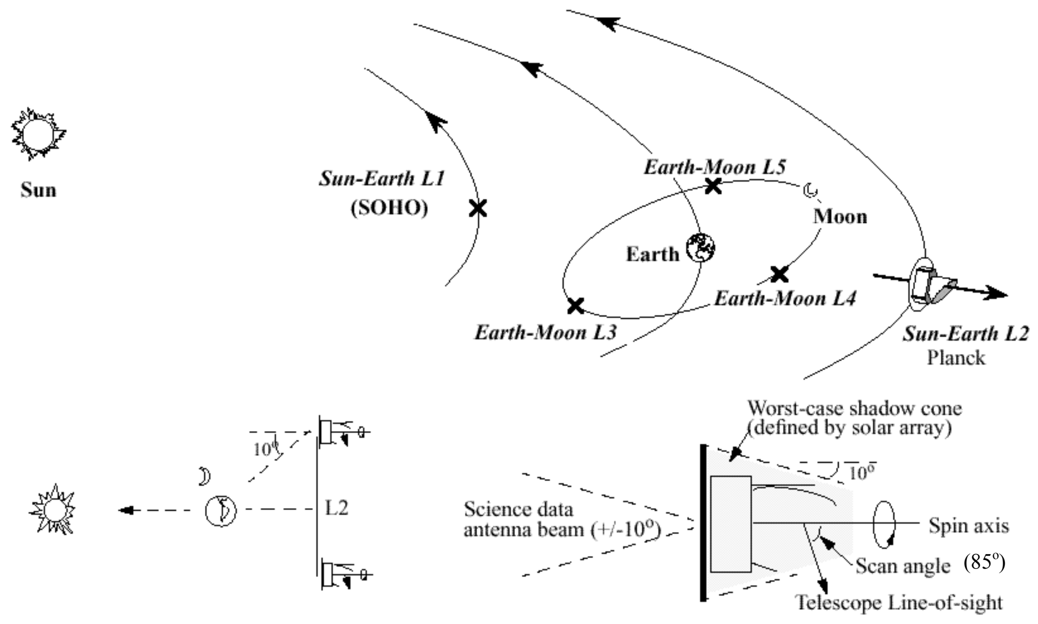


Figure 11: Relevant elements of the Planck orbit around L2. The maximum Sun-S/C-Earth angle is 15°. The payload must remain in a 10° solar shadow cone defined by the solar array. The Earth must remain within a 30° cone from the spin axis direction in order to permit telemetry downlink with full bandwidth. The telescope line-of –sight is inclined at 85° from the spin axis, so that the field of view describes a 170° circle on the sky.

The objective of Planck is to survey the whole sky twice over. By one survey of the sky is meant the coverage by the FOV of at least 95% of the full celestial sphere. The duration of a continuous sky survey depends on the specific value of the scan angle (i.e. the angle between the line-of-sight of the telescope and the spin axis). If this angle is 80^o, and observations are uninterrupted, the duration of a sky survey is ~7.5 months (TBC).

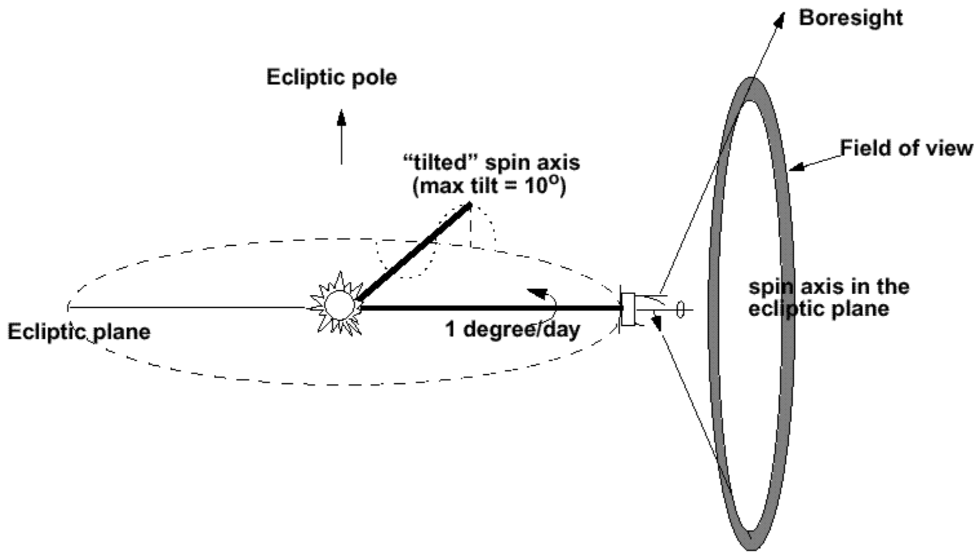


Figure 12: A sketch of the way in which Planck scans the sky. The dashed line indicates the direction of motion of the spin axis for the "nominal scanning law" i.e. along the ecliptic axis, whereas the dotted line shows a possible modification of this law which increases the sky coverage and the redundancy of the survey.

In order to carry out its surveys and maintain the payload in the solar shadow, the spin axis of Planck must be displaced on the average by 1^o per day in the direction defined by the orbital motion of the Earth around the Sun. This is achieved by spin axis depointing manoeuvres at regular intervals. As the spin axis is displaced, the observed ring also moves and gradually covers a large part of the sky. The set of depointing manoeuvres (defined by amplitude, direction, and time of execution) is referred to as the "scanning law".

The simplest possible scanning law consists of regular manoeuvres to maintain the spin axis aligned with the Sun-S/C direction, e.g. an hourly manoeuvre of amplitude 2.5 arcminutes along the ecliptic plane. This scanning law, which is referred to as the "nominal scanning law", results in less than full coverage of the sky, as two polar caps will remain unobserved for each detector within the FOV (the unobserved areas will be different for each detector depending on its location within the FOV). The diameter of the unobserved polar caps ranges between 10^o and 30^o. The sky coverage achieved by Planck may be increased by tilting the spin axis away from the ecliptic plane (within the limits allowed by the solar shadow cone and the telemetry antenna), thus allowing many detectors to observe the ecliptic poles.

It is important for Planck to be able to remove systematic effects (e.g. instrumental drifts) which contaminate the observations. To achieve this it is necessary to maintain a high level of redundancy, i.e. that a given location of the sky be observed many times (both with short and with long time scale periodicity), with different detectors and with different satellite attitudes. In this respect it may be useful to implement a scanning law which results in each ring crossing many other rings at a range of locations along it. Given the payload configuration, these crossings are clustered at high ecliptic latitudes. However, by tilting the spin axis with respect to the ecliptic plane, the distribution of crossings may be spread over a larger range of ecliptic latitudes.

Therefore, both to increase its sky coverage, and to increase the redundancy over a wider range of ecliptic latitudes, it is expected that the scanning law implemented by Planck will deviate significantly from the nominal one. The specific scanning law to be used will be established by means of detailed simulations during the development of the mission, and may also be modified by tests carried out in flight during the Performance Verification phase. It is also possible that the scanning law used during the second sky survey differs significantly from that used in the first survey. In any case, the scanning law will consist mainly of small modifications of the nominal law, such that the direction of the manoeuvre is not in the ecliptic plane but has a component perpendicular to it. The existence of an out of the ecliptic motion implies that the amplitude of each manoeuvre will be larger than that of the nominal law, and the duration between manoeuvres will be shorter than the nominal one. The motion of the spin axis in the direction perpendicular to the ecliptic plane will accumulate slowly up to a maximum which will not exceed the limits imposed by the solar shadow and the telemetry antenna. A typical scanning law is sketched in Figure 12