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HERSCHEL MISSION PLANNING CONCEPT

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1 INTRODUCTION

1.1 Scope of this document

This document presents the concept for mission planning for Herschel.
This document is specific to Herschel. Whilst the Herschel and Planck missions have much in common, they are sufficiently different in mission planning needs that separate planning documents are felt appropriate.

1.2 Reference documents

[CAL]	"Herschel pointing accuracy and calibration procedures", A.Elfving, I.Rasmussen, Issue 1.0
[CREMA]	"Herschel/Planck Consolidated Report on Mission Analysis", M.Hechler, Issue 2.1
[PSICD]	"Packet Structure Interface - Control Document (draft)", S.Thurey, Draft 4.0
[SCEN]	"Herschel/Planck Reference Mission Scenario", P.Estaria, Issue 2.1
[SRS]	"Herschel Planck System Requirements Specification", A.Elfving, Issue 3.2
[STORE]	"Packet store usage on Herschel / Planck", C.Watson, Issue 1.0
[HGSIRD]	"Herschel Ground Segment Interface Requirements Document", HGSSE, Issue 2.0
[HOSD]	"Herschel Space Observatory Operations Scenario Document", Göran Pilbratt et al., Issue 1.2
[HISS]	"Herschel Instrument Scheduling Schemes", Ana Heras, Draft 0.2
[MTL]	"On the Use of the Herschel Planck Mission Timeline", Frank de Bruin, Issue 1.2
[PMPC]	“Planck Mission Planning Concept”, C. Watson, Issue 2.1
[SCHED]	“Intended Operational Usage of Sub-schedules”, C. Watson, M. Schmidt, PT-CMOC-OPS-TN-6605-OPS-OGH, Draft 2

1.3 Acronyms

AOS	Acquisition Of Signal
APF	Attitude Parameters File
DDS	Data Distribution System
DPC	Data Processing Centre
DTCP	Daily Telecommunication Period
ED	Event Designator
EOL	End Of Life
EPOS	Enhanced Planned Observation Sequence
FD	Flight Dynamics
FDIR	Failure Detection, Isolation and Recovery
FOP	Flight Operations Plan
GSS	Ground Station Schedule
HIFI	Heterodyne Instrument for FIrst
HK	HouseKeeping
HSC	Herschel Science Centre
ICC	Instrument Control Centre
ICPF	Instrument Command Parameter File
LEOP	Launch and Early OPerations

MCS	Mission Control System
MGA	Medium Gain Antenna
MOC	Mission Operations Centre
MTL	Mission TimeLine
NCTRS	Network Control and Telemetry Routing System
OBCP	OnBoard Command Procedure
OCM	Orbit Control Mode
OD	Operational Day
PACS	Photoconductor Array Camera and Spectrometer
POS	Planned Observation Sequence
PSF	Planning Skeleton File
PSOF	Planned Spacecraft Operations File
PV	Performance Verification
SAA	Solar Aspect Angle
SC	SpaceCraft
SLE	Space Link Extension
SPIRE	Spectral and Photometric Imaging Receiver
SREM	Standard Radiation Environment Monitor
SSMM	Solid State Mass Memory
STDM	Station Tracking Data Messages
TBC	To Be Confirmed
TBD	To Be Decided
TC	TeleCommand
TM	TeleMetry
VMC	Visual Monitoring Camera

2 MISSION PLANNING INTRODUCTION

The Herschel/Planck Programme combines the two missions of the ESA long-term scientific plan Horizon 2000. Herschel, the ESA fourth cornerstone (CS4), is a multi-user observatory mission, dedicated to perform astronomical observations in the far-infrared and sub-millimetre wave-length range, covering the 60-670m band.
In 2007 a single Ariane5 launcher will place both Hershel and Planck in transfer trajectories towards the Sun-Earth L2 point. The transfer to the operational orbit will last approximately four months. The transfer trajectory is selected to take both spacecraft directly into a semi-stable Lissajous orbit around the L2 point. Cool-down and outgassing activities take place during transfer. Where possible transfer time is also used for commissioning and performance verifications.
The direct injection takes Herschel into a Lissajous orbit around L2 with an operational size of 40° (max. Sun-SC-Earth angle).
The routine mission phase for Herschel is 3.5 years.

2.1 Instruments

Herschel has three instruments -HIFI, SPIRE, and PACS. In most circumstances only one instrument is operational during a particular observation. The exception is PACS and SPIRE which may be operated in parallel. Additionally SPIRE may produce data, in serendipity mode, during slews between targets

2.2 Mission Orbit

Herschel's operational orbit is a Lissajous orbit around the L2 point of the Earth/Sun system. The L2 point is located 1.5 million kilometres away from Earth (about 4 times the distance of the Moon), in the opposite direction to the Sun. This location has the advantage of a very stable thermal environment.

Because of the choice of a direct trajectory into L2, the precise form of the Lissajous orbit is dependent on launch time and injection accuracy.

Orbital corrections are performed monthly to control the unstable component of the orbit.

2.3 Ground segment

Figure 1 provides an overview of the Herschel Ground Segment. The Instrument Control Centres interact with the Herschel Science Centre for the development of the Science-MTL. The HSC passes this to the MOC where it is first processed and augmented by Flight Dynamics before being released to the Flight Control Team for final processing and uplinking during a DTCP. New Norcia is the prime ground station backed-up by Cebreros, with Villafranca and Kourou providing support during the early flight phases. Stored TM and Science data dumped during the DTCP are available to the HSC via the DDS nominally following the process of Consolidation. The ICCs@MOC have the option of retrieving the dumped data (before consolidation and after only a short delay) via the DDS to aid in the process of anomaly investigation.

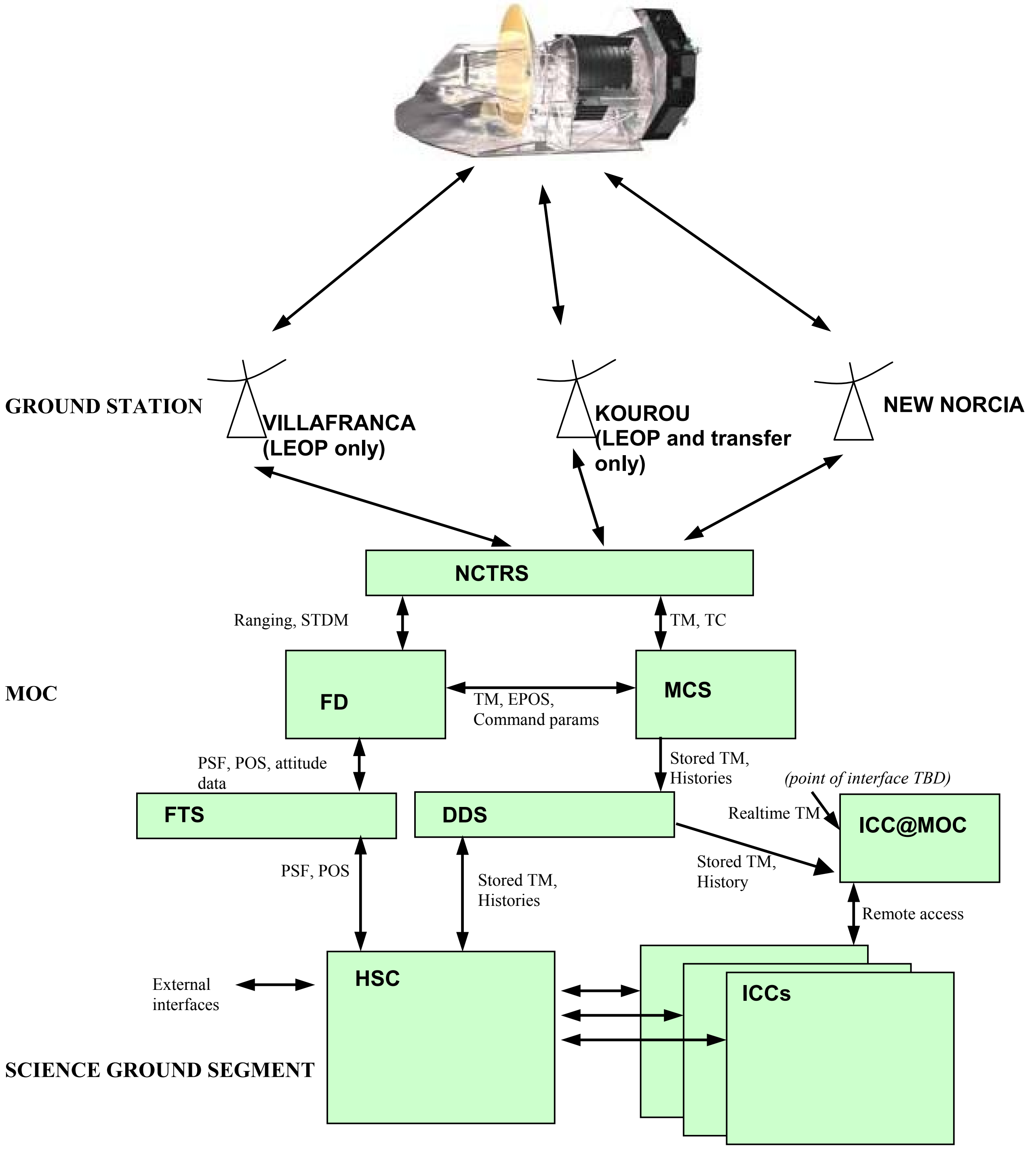

Figure 1, Ground segment overview

2.4 Key Mission Planning Aspects

2.4.1 NON-REAL-TIME MISSION

Herschel is allocated 3 hours of ground coverage every 24 hours. Consequently operations run autonomously from a Mission Time Line (MTL). Telemetry is stored onboard and downloaded during the pass.

Pass activities, and in particular the MTL, are pre-planned in advance of the DTCP. No changes are possible during a DTCP, except in the case of pre-defined contingencies where a recovery procedure exists. The MTL cannot be re-planned within a DTCP.

2.4.2 ATTITUDE CONSTRAINTS

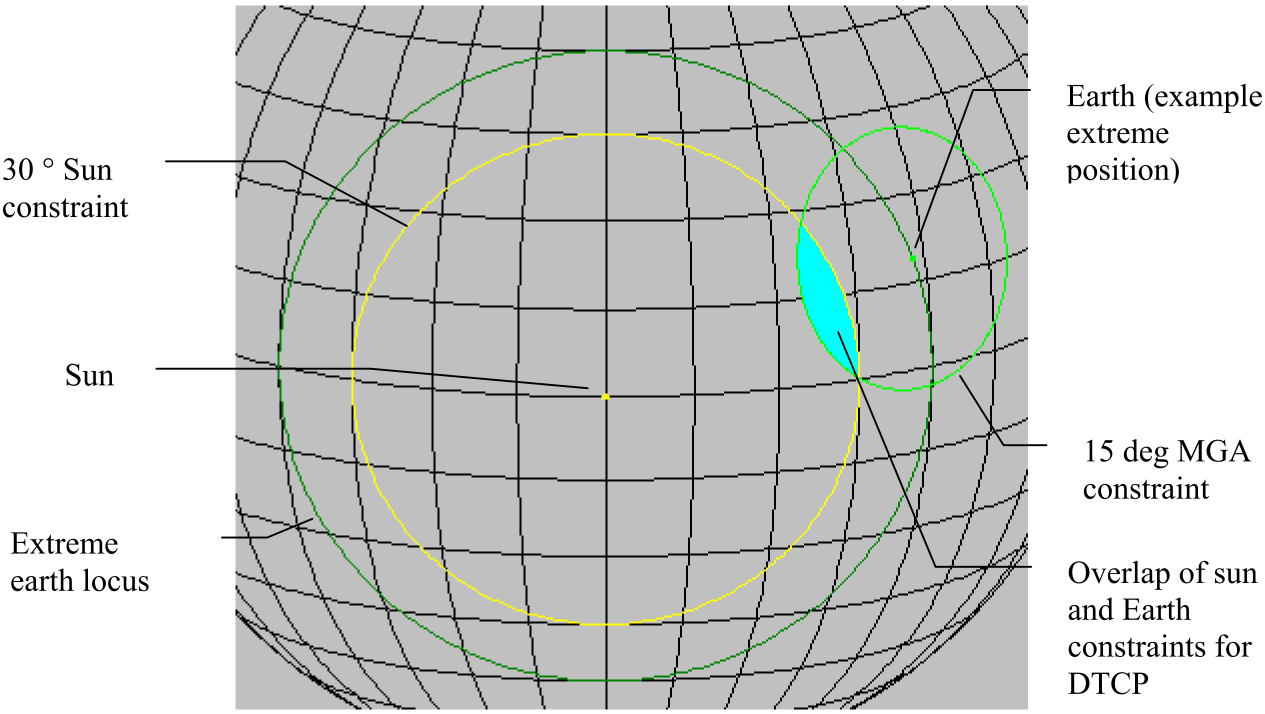

Figure 2, Attitude constraints

Figure 2 shows an overview of the attitude constraints. This is illustrative for background to the mission planning. Formal definition of the constraints may be found in [SRS] and in the ACMS design documentation. Orbit evolution is described in more detail in [CREMA].
The constraints are shown viewed from the spacecraft and projected onto the celestial sphere.
There is a 30° cone around the sun position, representing the SAA constraint.
The Earth lies within a cone 40° round the sun (since the L2 orbit is selected such that sun-sc-earth angle is always < 40°). There is a 15° cone around the earth position representing the Medium Gain Antenna (MGA) constraint. The boresight of the MGA is aligned with the +Z axis.

The +Z axis (also the peak power direction) of the spacecraft is placed anywhere within the sun constraint. This allows the telescope (+X axis) to image in the region of SAA [60°,120°]. Small parts of this imaging domain may be disallowed for extreme earth/moon positions due to additional constraints on the +X-earth and +X-moon angles (>23° and >13° respectively).

For the DTCP the spacecraft must be manoeuvred into the region where SAA and MGA constraints are both satisfied, represented by the cyan region (the lighter region on BW copies) in Figure 2. Scientific observations can still take place during the DTCP, within the more restrictive constraints.

2.4.3 TYPICAL DTCP SCHEDULE

Table 1 shows the breakdown of time allocation for TM during a DTCP. See [STORE] for a more detailed account.

	Duration	Cumulative total
AOS	0	0
Ranging	5 min	5 min
Configure station and switch to high TM rate	3 min	8 min
Dumps of onboard data 24hrs at 150 kbps[1] (stored) 2h26m24s plus 1hr at 120 kbps[2] (RT science) -this data is also stored 4m54s Downloaded at 1470 kbps (full rate minus real time VC0/4) plus 3mins total switching between dumps 3m	2hrs35m	2hrs43m
Configure station and switch to medium TM rate	3 min	2hrs46m
Ranging	5 min	2hrs51m

Table 1, DTCP schedule

MTL uplink is assumed at 30 minutes duration (for a nominal 24 hours MTL duration). This is equivalent to ~ three thousand commands of maximum length. (The maximum size of the MTL is 1.5 Mbytes.) This MTL estimate was made for Herschel for the Mission Reference Mission Scenario. The MTL uplink and the packet store dumps are assumed to operate in parallel, MTL uplink being started following the switch to high rate. No dump of the uploaded MTL is envisaged. The increase in VC0 traffic due to TC verification during the MTL uplink is negligible.

[1] Based on 130 kbps Instruments (all instrument TM), 9 kbps SVM HK TM, 11 kbps SVM non-HK TM)
[2] 130 kbps less ~10 kbps instrument HK, event, TC verification

3 MISSION PLANNING CONCEPT

3.1 Overview

The basic tasks of the any Mission Planning System are to

- Generate the onboard command sequence from science inputs.
- Manage resources.

For Herschel the resources are the onboard mass memory and the downlink duration. (Reaction wheel momentum management is internal to FD and will be part of their mission planning process.) The mass memory is adequate for 48 hours of TM (EOL), making the downlink duration the more significant constraint. The approach taken is to apply a quota on TM production rather than to actively manage TM via the mission planning system. Margin in the TM budget is the primary way of handling missed passes or TM overproduction, see [STORE]. Continuous overproduction of TM or recurrent station problems will result in lost data.

Instrument constraints (e.g. instrument internal cooler recycling) are managed by the HSC.

Mission planning management of battery charge is not foreseen. Where high power modes do exist it is considered safer and simpler to handle them through fixed constraints on observing plannning - e.g. no more than X minutes of high power instrument mode A within any OD, no more than Y hours of rastering within an OD, etc. - rather than attempting to actively predict and track power consumption through the mission planning system.

3.2 Dataflow

In the discussion of dataflow below generally only a single file has been referred to at each stage, e.g. POS, EPOS, PSOF. In general these may be implemented as multiple files. For example it is usual ESOC practise to separate commands and command parameters into two associated files, e.g. EPOS + Attitude Parameters File (APF) etc. Moreover most flight dynamics products will be delivered as a separate file per OD. I.e. a single nominal (weekly) PSF or EPOS delivery consists of seven separate PSF or EPOS files, one per OD. Ideally the POS would also follow this structure.

The short-term orbit file is a prediction of the orbit for at least 4 weeks into the future (more if it is produced less often than weekly). The orbit information is taken by the scheduling office and merged with equivalent data from other missions based on agreed scheduling rules. The Ground Station Schedule (GSS) is then generated containing the schedule of DTCPs. The GSS is created weekly, for 4 weeks into the future. This is a new requirement on the scheduling office, and should apply for all ESA deep space antennas (i.e. Cebreros as well). The GSS is not particularly sensitive to minor orbit errors, and can be created on the basis of earlier orbit knowledge.

The GSS is passed to Flight Dynamics who incorporate this information into the Planning Skeleton File (PSF). This file also contains windows for other spacecraft activities which impact on the science planning - for example windows for orbit manoeuvres which block out scientific pointings.

(The generation of PSFs for long-term planning, timescale of a year, is TBD. Given that the MOC cannot predict the times of DTCPs accurately in advance, the HSC may be able to generate their own dummy PSFs for long-term planning simply by assuming 3 hours for a DTCP.)

Both the short term orbit file and the PSF are then used by HSC to generate the planned observations for the next period. HSC produce the Planned Observation Sequence file (POS) which contains the data provided by the PSF, interspersed with instrument commanding and attitude requests.

The POS is passed to MOC and processed by Flight Dynamics to expand attitude-related Event Designators (EDs) where necessary. Attitude / orbit related windows from the PSF are populated where appropriate. At this point the Reaction wheel momentum management commands will also be provided by FD. The resulting file is the Enhanced Planned Observation Sequence file (EPOS). In addition to the expanded attitude commands this file still contains the PSF information and instrument commanding contained in the POS.

The EPOS is passed to the Flight Control Team. It is processed to translate both instrument and attitude EDs to commands or sequences. The processing at this stage also includes instrument-level checks/processing, for example onboard SSMM storage predictions will be made[3]. These checks provide a double check of the validity of the POS, and in the case of the SSMM predictions allow the duration of some DTCP activities (MTL load and later data dumps) to be estimated in advance. EPOS processing results in the Planned Spacecraft Operations File (PSOF).

In the last stage the final products of mission planning system are generated. These are
- The MTL for uplink
- A manual stack of commands for some of the DTCP handling
- A station scheduling file, which may be used for automated commanding of the ground station
- A ground station mission events file which is passed back to the scheduling office.
- A spacon activity summary which is a printable text file of activities and their timings occurring within the DTCP
- The spacon summary as a script for on-line execution to provide event information messages during the DTCP, e.g. start/stop of real-time science, start/stop of packet store dumps

Since multiple ODs are covered by a single mission planning cycle, multiple sets of these final products are created, one for each DTCP. In the nominal cycle seven sets of products are created.

[3] This will be done by the HSC populating instrument TM rate fields in the POS using data supplied by the ICCs.

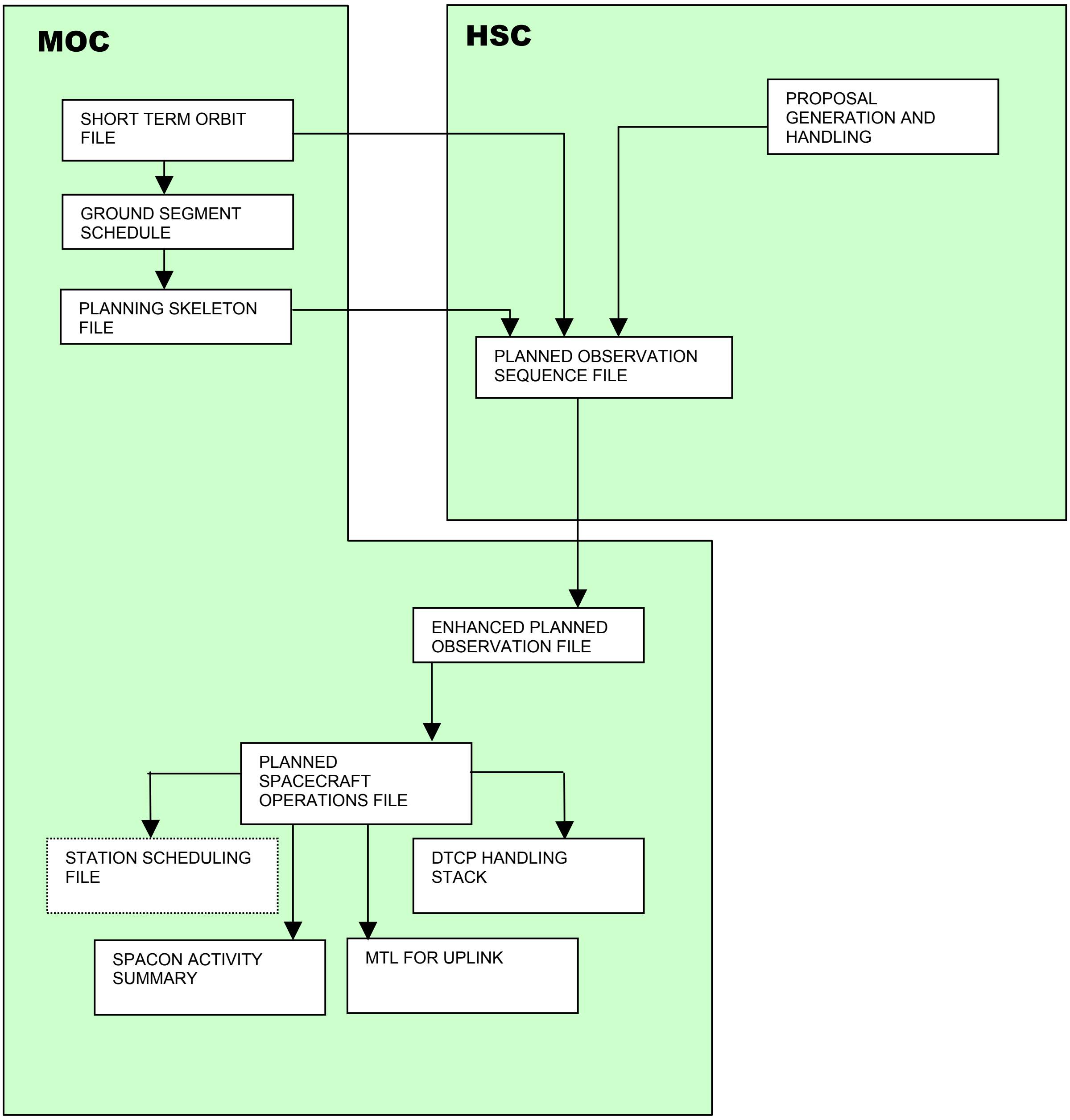

Figure 3, Mission planning overview

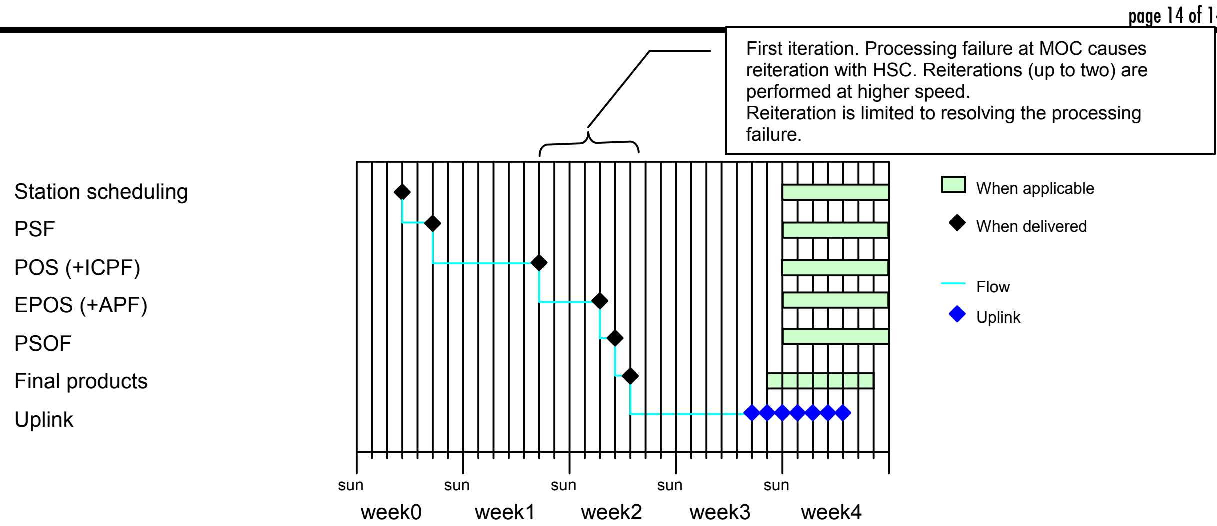

Figure 4, Suggested timings for mission planning

Herschel mission planning may be regarded as occurring in 3 phases.

Phase	Involving	Cycle rate	Completed
1	Station scheduling and production of PSF	Weekly	15 working days prior to uplink
2	Production of POS	Weekly	10 working days prior to uplink
3	Production of final products	Weekly	6 working days prior to uplink, nominal

Table 2, Mision planning phases

3.2.1 SPAN OF THE UPLINKED MTL

Nominally the uplinked MTL covers the period approximately 24 to 48 hours into the future. This is so that in the event of a missed DTCP, the spacecraft is able to continue observations until the subsequent DTCP. The observation planning unit, the OD, is defined as running from the start of one DTCP to the start of the next. This is as defined in [SCEN] and is a convenient span for scientific mission planning.

However this division is not appropriate for the MTL uplink, since a missed DTCP leads to the onboard MTL running out at the moment of next nominal AOS, i.e. well before the new MTL uplink is initiated. Rather than change the span of the OD, it is proposed to handle within the MOC system a timeshift between the OD definition and the MTL uplink. The MTL uplink will span from the end of a DTCP to the end of the next DTCP.

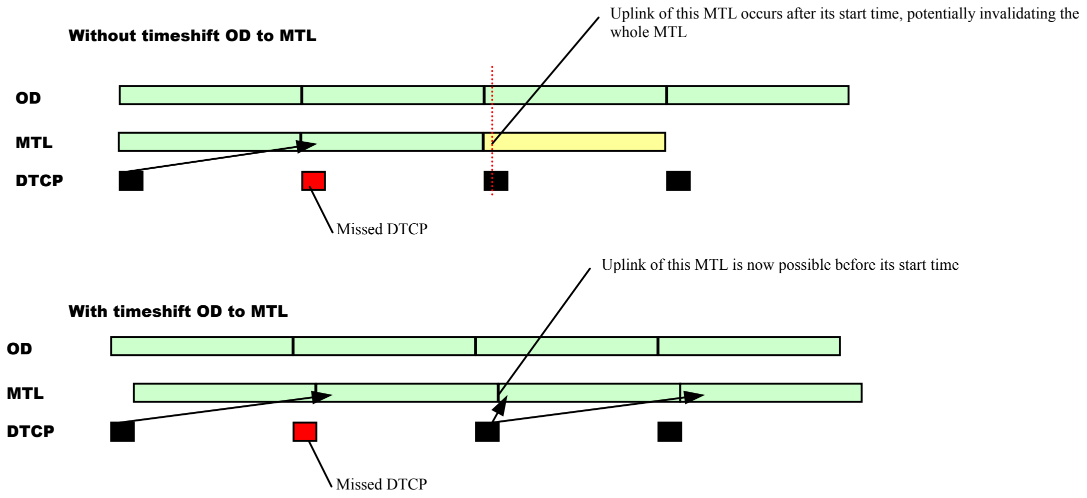

Figure 5, Consequences of missed DTCP on MTL upload

A consequence of this is that the majority of the last OD (i.e. the part beyond the DTCP end) contained in a given POS is held back at MOC, and incorporated into the first MTL generated from processing the next POS. This is the reason for the timeshift apparent on the final products in Figure 4.

Similar considerations apply to a restart of the MTL following a break. For example a serious contingency has occurred which has taken a week to diagnose and recover. The original planned sequence of observations has been abandoned, and a new sequence is generated at HSC starting from a specified future DTCP. A period following the start of the new OD (i.e. the start of the DTCP) must be allowed to establish the new MTL onboard. In the new POS no instrument commanding is allowed within this period for the first OD. As preliminary figure we take 38 minutes (the time to complete nominal ranging, switch to high rate, and upload 24 hrs of MTL). A more stringent restriction on pointing requests is likely. For these the preliminary figure is the whole of the DTCP, i.e. no pointing request would be allowed in the POS for the first 3 hours of the first OD of a new POS following "restart" of the MTL.

3.2.2 SPAN OF DOWNLINKED DATA

Packet store data downlinked during the DTCP will not align exactly with the OD boundary. This is because packet store dumps are initiated sequentially through the DTCP using the default packet store dump command.

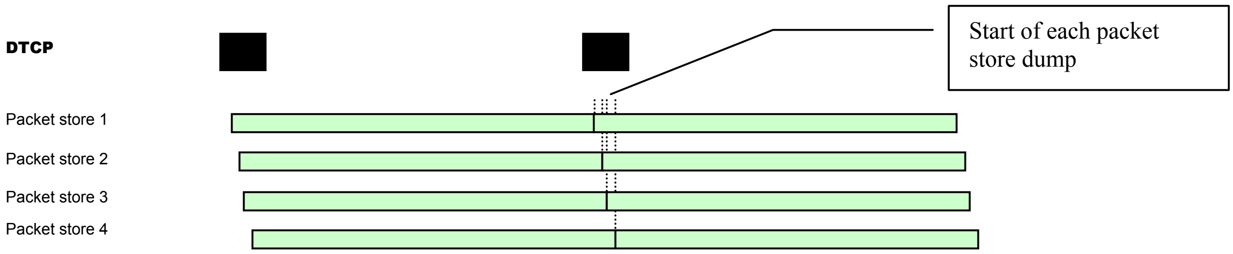

Figure 6, Span of downlink of packet stores

3.2.3 COMMISSIONING AND PV

Early comm/PV will be manually commanded in realtime according to defined commissioning procedures. Some activities may also involve manually commanding into the onboard MTL for non-realtime operation.

Later stages of comm/PV may begin to use the mission planning system.

Whilst there may be interleaving of periods of manual commanding and mission planning operation there is limited scope for a gradual transition from one type of operation to the other. In order to facilitate some limited flexibility here the system at MOC will be designed to allow an option of directing the mission-planned MTL to a manual stack, for step-by-step realtime operation. This is an alternative to defining windows within the PSF as reserved for manual activities, and then running commanding from FOP procedures.

The following differences between comm/PV and the routine mission phase are noted-

- Much of this phase of the mission will involve tight planning times more in keeping with the contingency processing times than with the nominal cycle.
- Files may be applicable to shorter periods than in the nominal cycle.
- The instrument modes and operation may not reflect the nominal routine-ops configuration.
- Ground station passes of longer than 3 hours may be utilised.
- Other stations beside New Norcia may be used.

Naturally instrument commands/sequences specific to comm/PV need to be specified within the scope of designing the mission planning interfaces, if the MPS is to handle them.

3.3 Use of onboard packet stores.

Packet store usage is now reported in [STORE].

3.4 Use of Sub-schedules

For the intended operational usage of sub-schedules see [SCHED].

3.5 Tasks identified for the DTCP

The following activities cannot be conducted outside of the DTCP

- Ranging
- Packet store dumps
- MTL uplink
- Real-time downlink of Science data
- Time correlation

The following activities have been identified as desirable to schedule within the DTCP.

- Momentum biasing
- PACS / SPIRE cooler recycling
- PACS cold readout electronics ON

[4] Routine requirement to be clarified - potential impact on mission planning and TM budget.

- HIFI hot blackbody ON
- HIFI change local oscillator band

For the majority of these the desirability for DTCP scheduling derives from observability concerns or the fact that the limited attitude domain during DTCP makes it an appropriate time to perform instrument set-up commanding. This latter point also combines well with the plan to give whole ODs to a specific instrument.
For boresight calibration DTCP scheduling is potentially advantageous to decrease turn around time on the calibration by up to 24 hours.
The last five items are essentially transparent to MOC, these activities being planned by HSC and encoded within the POS. Polling table updates will be limited to a (small) number of predefined configurations.

It would also be desirable to schedule orbit manoeuvres with the DTCP for observability, but it cannot be guaranteed that the manoeuvre attitude is within the DTCP constraint.

3.6 Manual commanding

Some pass activities are envisaged to be performed manually, and so are not included in the uploaded MTL (note they might however be manually time-tagged and so end up in the onboard MTL). The list of currently envisaged manual commanded pass activities are

- Start/end ranging at start of pass
- Switch to high rate
- All dump initialisations
- Switch to low rate and start/end ranging at end of pass

The intention of this manual commanding is to retain some flexibility in the event of contingencies. For example if the switch to high rate at the station is made late it is considered better to avoid missing the start of the dump.

This division of manually commanded vs. automatically scheduled events represents the current best-guess trade off of automation against flexibility. However it is clear that the division may be revised in the light of operational experience. The mission planning system needs to be flexible in this respect.

3.7 Station scheduling

The mission planning system will produce a station activity file compatible with the existing mechanisms for automated station control.

However the baseline is that this station control mechanism will not be used. This is because operating the ground station through a preplanned schedule severely restricts our ability to respond to contingencies. The time taken to override a running station schedule and replace it could knock a significant hole in the DTCP.

Instead the nominal station control mechanism is for the Spacon to request ground station configurations through Network. The mission planning system shall include the nominal ground station timings from the station scheduling file in the Spacon Activity Summary. A flag in the

[5] Note that simultaneous burst mode and realtime science would exceed the 150 kbps allocation for realtime data.

mission control system shall indicate if the station scheduling file is not being used, and will cause insertion of extra lines within the Spacon Activity Summary for making request to Network.

It is believed that no active control of the SLE service instances is required as part of the mission planning system, since a standard set of services will be used for all passes (TBC).

3.8 Orbit manoeuvres and momentum biasing

Orbit manoeuvres occur once a month. For Herschel they require a specific orientation and therefore exclude observations during an appropriate window, though, it is possible that instrument configuration operations can take place. This also means that in general it is not possible to schedule orbit manoeuvres to occur during the DTCP. The orbit manoeuvre window is identified within the PSF. This window includes slew time to and from the manoeuvre attitude. Worst case slew times are assumed since the attitude of the manoeuvre is unlikely to be known at the time the PSF is produced.

Momentum biasing is performed once per OD (TBC). These are also windowed within the PSF. Biasing will normally be scheduled within the DTCP.

The timing of the biasing within the DTCP is TBD. The normal FD approach is to place it as near as is reasonable to the start of the pass. It is highly recommended that there are no slews in the DTCP before the reaction wheel biasing. This would introduce a no-slew period to the beginning of every DTCP. In the event of a missed DTCP the biasing, being part of the MTL uplinked at the previous pass, would still go ahead but without ground visibility.

It is currently assumed that there is no requirement to choose attitude during momentum biasing to control the parasitic effect on the orbit.

4 REMAINING ISSUES

4.1 Prepass activities

For the DTCP the s/c transponder will need to be switched on and this involves a warm-up time. However, the warm-up of the TWT may be de-coupled from the switch-on of the transmitter itself, therefore giving no interference until the switch-on at the start of the DTCP. It is still to be confirmed (during the PV phase) whether or not the transponder interferes with scientific observations (specifically HIFI). To achieve the DTCP attitude the s/c may have to slew for upto 30mins or it may not have to slew at all. Excluding the possiblity of the SPIRE Serendipity mode an instrument will not be collecting science data during a s/c slew to the DTCP attitude.

The clarification of these points will lead to the constraints governing the scheduling of the transponder switch on at the end of each OD.

4.2 Movement in DTCP time

Thus far the discussions assume that the DTCPs recur at 24 hour intervals. In reality this is unlikely to be the case. There is a gradual shift in visibiltiy window, but sudden jumps for scheduling reasons are also a possibility. For example, to accommodate critical Mars Express or

Rosetta operations. It is also possible to envisage an approx. 3 hour shift occurring if Herschel and Planck "cross over" in terms of ecliptic longitude and it becomes better to swap the order of the DTCPs for the two spacecraft.

A three hour jump in the timing of a DTCP leading to a 27 hour OD would mean that at the budgeted TM rates not all of the data could be downloaded within a standard DTCP. Given current TM budgets, [STORE], the backlog would be recovered by the end of the subsequent DTCP however.

The Planck possibility of identifying "long" ODs at PSF creation and scaling the DTCP duration up within the PSF appropriately (subject to station availiability) is probably less appropriate to Herschel. Planck has stable TM rates such that a longer OD invariably leads to increased TM to downlink, this may not be true for Herschel.

4.3 Further instruments

Herschel also contains two non-astronomy instruments. The Visual Monitoring Camera (VMC) and the Standard Radiation Environment Monitor (SREM).
The VMC will acquire 15 consecutive frames starting at separation from the launcher. It then waits in Standby mode for the download of the frames to the data pool and then to the SSMM in the form of TM source packets. Once the frames are transferred to the CDMU, the VMC is turned off. It has no impact on operational mission planning.

SREM is assumed to generate data continuously in orbit. Cyclic acquisition of SREM data is left running (using TC(8,4,4,1)). This transparently transfers SREM data into a specified packet store. SREM is also assumed to require no routine commanding, and to have no impact on mission planning, other the need to allow for its data downlink in the DTCP. The SREM accumulation time is assumed to remain static in the routine phase. If necessary an interface whereby the accumulation time is updated may be implemented - this would be through the equivalent of a faxed instrument procedure request as implemented for Planck ([PMPC], figure 3), which assumes non time critical update of the parameter manually during next available DTCP.

4.4 Boresight calibration

Periodic boresight calibrations will be required for Herschel, though a full calibration takes too long for weekly use. These calibrations necessarily require the participation of MOC and ICCs and are complicated by the potential influence of spacecraft thermo-elastic distortion. This means that it is inadvisable to perform one after a big slew, e.g. when returning to a DTCP. [CAL] has been produced by Project on this issue. However the precise final form of the boresight calibrations, and their impact on mission planning is not yet certain.***Recovery from anomalies***

It is too early to be able to define specific contingency recovery procedures, however there are some areas where clarification of the general philosophy would be helpful, since it potentially affects the use of subschedules and the mission planning approach.

There are two classes of anomalies for which the approach is clear.

1. Minor anomalies, understood, easily diagnosed and recovered from. In general these may be recovered within a DTCP.

2. Major anomalies, not understood, difficult to diagnose / recover from. In general these will take many ODs to recover. Caution overrides the desire for rapid recovery.

Once at the start of a DTCP and an anomaly has been identified, the following must be considered in the case of:

- Instrument anomaly
  - Is it to be operated in the next OD?
    - if not, then have time to analyse and recover, continue the MTL,
    - if yes, when is the next point in the MTL when operations can be restarted?
  - When is the instrument next planned as PRIME?
  - Is it a known anomaly and straight-forward recovery?
    - if not, perform contingency replanning to remove the instrument from the short-term plan?
  - The ACMS will continue to follow its sequence of slews and pointings. Therefore, recovery of position would not be an issue.
- SM anomaly (ACMS/CDMS/…)
  - When is the next point in the MTL where operations can be restarted?
  - Is it a known anomaly and straight-forward recovery?
- Bus anomaly. Bus on redundant unit. SC safe but diagnosis and recovery unclear.
  - Alert project and halt observations?

This leads us to the topic of restarting the MTL following an anomaly that has caused suspension of some or all of the MTL.

4.5.1 RESTARTING THE MTL

Naturally it is advantageous to rejoin the already available MTL at an appropriate point rather than waiting on a replanning cycle of the mission planning. However this is not necessarily trivial -

- The planned slew path and momentum profile must be rejoined if it has been left. The slew that would be used to perform the rejoin is not part of the planned path / profile and would require additional processing by FD.
- Upcoming observations may assume that the instrument is in a configuration from a previous observation or configuration setting which did not occur.

Whilst in principal known simple anomalies could be recovered within the DTCP, it is not clear that the MTL rejoin can also be completed within the same DTCP, which means that the MTL rejoin would be delayed ~24 hours to the subsequent DTCP[6]. This is certainly likely for anomalies that have caused suspension of the slew path. It may be the case also for instrument-suspending anomalies.

Example situations that could lead to the need to perform a restart are:

- Unplanned maintenance requirement, e.g. patching of CDMU/ACC[7].
- Pre-defined contingencies[8].

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[6] Using extended / emergency ground station coverage may allow completion of the MTL rejoin outside of the nominal DTCP. However extended coverage cannot be guaranteed. Extended coverage is less likely to help for the case where the slew path has been left since strictly this would require recomputation of a new slew path over the observations left in the reduced observing period. This would probably result in little end gain over waiting for the next nominal pass.

[7] Non-urgent patching may be scheduled via the four week mission planning process. Urgent patching would involve either an interruption to planned MTL operations, or a contingency-speed replan with a SOPS window for the patching activities in the new PSF.

It may be possible to design the DTCP to facilitate "fast" rejoin of the MTL. However this will mean adding constraints to the nominal DTCP activities, and the current assumption is that this is not required.

In order to facilitate rejoin of the MTL (at any timescale) instrument commanding should have a granularity at which it is "self-consistent", i.e. at which the commanding makes no assumption about the initial state of the instrument[9]. As a minimum this should be at the level of the OD, such that an OD of observations may be performed in isolation. However this would mean that a delay to the next DTCP for MTL rejoin would always be required, unless an instrument command-free "recovery window" is introduced to the start of each DTCP. This "recovery window" approach is probably impractical - a window large enough to realistically accommodate recovery and MTL rejoin, will likely be too large to allow nominal DTCP operations.

In principle making each individual observation self-consistent offers more opportunity to rejoin the MTL, but it is appreciated that this may not be desirable from a scientific mission planning perspective.

A hybrid approach is also possible whereby the top-level configuration to a particular observing mode (that works from *any* instrument start state) is procedurised in the FOP, and the observing mode of each observation is labelled in the POS. Then only the low level observing mode configuration needs to be self-consistent. This approach makes for fewer commands in the MTL, but slower rejoin of the MTL following anomaly.

See Appendix 1 for an illustration of a scheme for restart options once per OD. The instruments are assumed to have a granularity of 1 OD. Contingency restart actions are routinely uplinked along with the nominal MTL but are contained in (nominally) disabled sub-schedules. These contingency actions can be, for example, a cooler recycling, or a slew to rejoin the abandoned path, or commands to re-activate a suspended MTL. Once the anomaly has been recovered (either by the end of the DTCP or by the end of the extended coverage period), the contingency sub-schedules are activated to bring the spacecraft/instrument into a configuration compatible with the rejoin the MTL by the start of the next OD/DTCP.
Two points make this slightly more difficult:

- It is assumed that some instrument initial configuring will tend to occur in the DTCP. This is unhelpful for recovery and restart, since the configuring may be lost in the DTCP whilst the anomaly is diagnosed and recovered.
- Some activities (e.g. cooler recycling for SPIRE and PACS) run on a longer cycle.

This approach would not apply for

[8] This means contingencies where a diagnosis and recovery procedure has been defined. This includes both contingencies defined at launch and contingencies discovered in flight and where recovery is subsequently procedurised.
[9] There are a few specific constraints that *must* be assumed. For example that the instrument is ON, also probably cooler recycling - it is probably not desirable to repeat cooler recycling merely for the sake of self consistency within the OD. Providing the number of such additional constraints is small and adequately documented then this is acceptable.

- Major anomalies / anomalies without an identified recovery procedure - the recovery time for these will be comparable with the time to perform a replan. This probably includes any level 4 alarm.[10]
- Anomalies leading to a loss of data, but not a break in the MTL.
- Instrument anomalies - In general instruments have requested that they be left running (exception for specific SPIRE events).

4.5.1.1 Requirements on mission planning interfaces

Schemes that aim to restart an existing MTL would require:

- Knowledge of instrument commanding consistency points (either by convention, e.g. every observation, or by an identifying field in the POS).
- The ability to receive a nominally disabled block of commanding within the POS/EPOS to allow insertion of the contingency subschedules into the MTL. These would be used to cover the aspects not covered by the instrument commanding consistency.

4.5.1.2 Limitations and variations

With the minimum restart capability (once per OD) as assumed above there is a 24 hour granularity in the restart points. This means that even relatively trivial breaks in the MTL may lead to significant losses of science. If the original MTL suspension is due to an anomaly out of coverage, then potentially more time is lost.

The position of the restart point within the observing period is largely arbitrary. An earlier restart point (e.g. soon after the DTCP where the anomaly has been detected) is advantageous for situations where recovery is trivial and can be comfortably performed within the DTCP, but is less helpful for situations where recovery is more involved and extended coverage is needed.

It is, of course, possible to increase the number of restart points thus lowering the granularity. This increases the overhead on mission planning in terms of extra contingency subschedules (especially if a contingency slew is to be calculated for every rejoin point). Furthermore it is difficult to foresee the typical time necessary to bring the spacecraft to the position where it is ready to be restarted - this depends both on the complexity of the recovery, and (potentially) on the availability of unplanned ground station coverage. Once in an OD seems therefore to be a reasonable initial compromise.

Another possibility, requiring just instrument/platform consistency by OD without the need for contingency subschedules, would be to rely on manual identification and commanding of cooler recycling, and on-call flight dynamics support for the slew determination followed by manual commanding. This seems much more dependent on the availability of extra station coverage, and if this were not available it could easily increase the rejoin time to 48 hours.

A crude estimate for a contingency replanning cycle is 72 hours - 1 day identification of replan start time and POS generation, 1 day EPOS/PSOF generation, 1 day DTCP uplink granularity.

[10] Note however that restart points may still be useful if, for example, problem diagnosis and recovery is originally expected to take 5 days say, and then slips to 6 days. It is still possible to make use of the majority of first replan.

4.6 Notes on constraint checking

Constraint checking occurs at at least 3 different locations.

- At HSC when producing the POS
- At MOC when generating the EPOS
- On the spacecraft at command execution.

Constraint checking will be influenced by

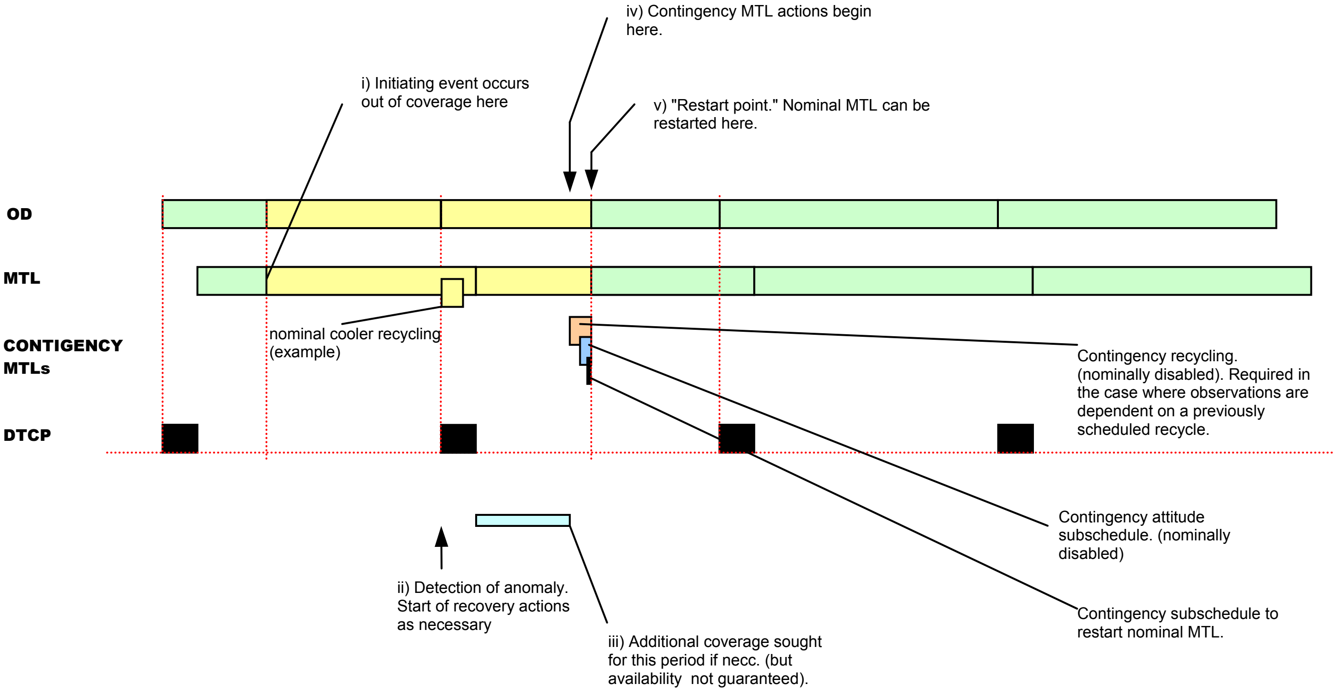
- changes in the knowledge of the orbit, HSC to MOC[11]
- accuracy of the onboard inertial sun position, MOC to SC

It is therefore possible that a pointing that passed constraint checking at HSC would then fail constraint checking at MOC, or equivalently might pass at MOC but fail onboard.

Given the impact on mission planning that this could have it is recommended that different constraints be applied onboard, at MOC, and at HSC. This will shrink the effective operational domain, but the effect should be small, and it protects against the disruption of failed planning cycles, or onboard command rejection. The strictest constraints would apply at the level of HSC planning, the least strict constraints would be those onboard the spacecraft.

[11] I.e. the orbit is predicted further into the future for the stage of HSC planning, and is therefore less well known.. Processing at MOC occurs closer to the execution time, and consequently the orbit errors at this stage are less.

APPENDIX 1: RESTART OF THE MTL



ODs numbered 0,1,2,3
DTCPs enumerated A, B, C
MTL uplinks enumerated A, B, C
Anomaly and recovery / restart actions numbered i, ii, iii, iv, v
"Recovery" - is the process of resolving the anomaly that has caused the MTL suspension.
"Restart" - is the process of correctly re-entering the nominal MTL.

At ii) the anomaly is detected. If recovery is not complete by the end of the DTCP then extended coverage may be sought into period iii) to complete the recovery[12]. Once recovery is complete the appropriate recovery subschedules may be enabled, these are used to ensure the correct configuration of any part of the MTL not covered by the instrument commanding self-consistency at the restart point. Once these contingency subschedules are active then station coverage is no longer required. This minimises the dependency on extended coverage - if recovery is complete within the DTCP no extended coverage is required.

The contingency subschedules shown are purely illustrative. The actual contingency actions required depend on the limits of the instrument commanding consistency and on the type of anomaly being protected against.
Recycling - This covers the case that nominal recycling for the OD is lost due to the ongoing recovery. Naturally this would only be required for a OD containing an earlier nominal recycling.
Attitude - This would bring the spacecraft back onto the nominal slew/momentum path. It is only required if the slew path part of the MTL has been suspended, e.g. CDMU level 3 alarm.
Restart - The sole purpose of this subschedule is to restart the nominal MTL subschedules at the restart point, without the need for ground coverage.

[12] Note that New Norcia is a shared resource and extended availability is not guaranteed. Note also that if the slew path is continuing (which is advantageous for rejoin) then TM/TC will most likely need to be through the LGA.