Solar Orbiter
Science Operations Planning Concept
& Onboard Data Management

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On behalf of the Solar Orbiter SOC Team, ESA/ESAC
Outline

- Solar Orbiter Science Operations Planning Concept
  - Science Ground Segment (SGS)
    - SOC Functional blocks
    - Instrument Team’s responsibilities
  - Science Operations Planning Cycles
    - For each cycle: the actions required by each player (MOC, SOC, SOWG, SWT)
  - Key aspects of SoIO Mission Planning Concept

- Onboard Data Management
  - Low-Latency Science Data
  - Selective Science Data
Science Operations Planning Concept
Science Ground Segment

Overview

US PIs
- HIS/SWA
- SoloHI

European PIs
- SWA
- EUI
- PHI
- RPW
- METIS
- MAG
- STIX
- EPD
- SPICE

Science Operations Centre (SOC)

ESAC

Mission Operations Centre (MOC)

ESTRACK

Science Ground Segment (SGS)

(Single point of contact between each PI team and the SOC)

Non-Routine, Engineering, Anomalies
SGS system functionalities:

- Science Planning & preparation of Payload Operation Requests (POR) + Pointing Requests (PTR)
- Low-Latency science data visualisation
- Science data processing
- Auxiliary data processing
- Data Archiving and Retrieval facilities
- Data Distribution to scientific community
**Science Ground Segment**

**Functional blocks and interfaces**

### SGS system functionalities:
- **Science Planning** & preparation of Payload Operation Requests (POR) + Pointing Requests (PTR)
- Low-Latency science data visualisation
- **Science data processing**
- Auxiliary data processing
- Data Archiving and Retrieval facilities
- Data Distribution to scientific community
Instrument teams’ responsibilities

- Participate in SWT and SOWG establishing overall science priorities and plans.
- **Plan instrument operations** along the lines agreed at SWT and SOWG.
- Plan instrument operations to maintain **instrument calibration and characterization**.
- Deliver **Instrument Operations Requests** (IORs) to the SOC.
- Retrieve instrument TM from the DDS at MOC or from the SOC.
- **Process science** and non-science telemetry into housekeeping, engineering, calibrated, higher level data products (data levels 1, 2, 3+).
- Monitor **instrument health**.
- Monitor **science data quality**.
- Maintain **instrument flight software**.
- If applicable, any data selection on-board, based on Low-Latency data provided by SOC.
- **Deliver software** to process selected **Low-Latency TM** into Quick-Look data at the SOC.
- Support LL software maintenance at the SOC.
- Retrieve from the SOC the LL and auxiliary data required for instrument operations planning.
- Deliver pipeline and data analysis software to the Solar Orbiter Archive at the SOC.
- **Deliver all data products to the Solar Orbiter Archive** at the SOC.
- Provide support to the science community on using the instruments’ observations.
Science Operations Planning Cycles

- **Top Level Planning** - Scope: the entire mission.
  - Assign SoLO science objectives to certain orbits: **Science Activity Plan (SAP)**
  - TM return analysis to assess the feasibility of the SAP.
- **Long Term Planning** - Scope: orbit \( n \) (planned during orbit \( n-2 \))
  - Main S/C manoeuvres & ground station passes are known
  - SAP orbit plan broken into set of **SOOPs**. Pointing type defined.
- **Medium Term Planning** - Scope: orbit \( n \) ops timeline (planned during orbit \( n-1 \))
  - SOOPs converted into **Instrument Operations Requests (IORs)**
  - Resource envelops are frozen.
- **Short Term Planning** - Scope: 1 week or 1 RS window (planned ~2w before)
  - IORs refined, first uplink of instrument commanding to the S/C.
- **Very Short Term Planning** - Scope: Evaluate & refine the S/C pointing daily during RS window with tracking of solar targets (**only!**)
  - SoLO-specific! Pointing adjustments based on LL data. Daily **PTR** uplink possible.
  - Shortest turn-around time ~3 days
## Science Operations Planning Concept

<table>
<thead>
<tr>
<th>Planning cycle</th>
<th>SWT</th>
<th>SOWG</th>
<th>Instrument Teams</th>
<th>SOC</th>
<th>MOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission level</td>
<td>SAP</td>
<td></td>
<td></td>
<td>SAP Feasibility (TM return analysis)</td>
<td></td>
</tr>
<tr>
<td>LTP</td>
<td>SAP</td>
<td>Coordinated SOOPs</td>
<td>Individual SOOPs</td>
<td>IOR placeholders &amp; feasibility</td>
<td></td>
</tr>
<tr>
<td>MTP</td>
<td>Coordinated SOOPs</td>
<td>Instrument Operations Requests (IORs)</td>
<td>PORs, PTRs &amp; feasibility</td>
<td>Constraint checks</td>
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<td></td>
</tr>
<tr>
<td>VSTP</td>
<td></td>
<td></td>
<td>updated PTRs, based on LL data</td>
<td>Constraint checks &amp; uplink to S/C</td>
<td></td>
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</tbody>
</table>
Mission (top) level planning

- Mission level - Scope: the entire mission
  - SWT allocates specific orbits to specific mission science objectives & determines best locations for the RS windows. **Type** of pointing determined.
  - Iteration with OGS on RS window location, given mission constraints.
  - SWT/SOWG produce draft **Science Activity Plan**.
  - SOC with the support of Instrument Teams uses **instrument models** to determine what level of resources (data, power, pointing) are required & **instrumental constraints** to explore incompatibilities.
  - SOC executes **data return analysis** and GS pass optimization to identify periods where additional GS passes are of critical importance to meet data return requirements. These typically span multiple orbits.
  - SOC feeds back resource estimates and GS requests to SWT/SOWG and OGS.
  - **Iterative process** until level of planning detail is enough to determine S/C and GS resources, and requested and available resources converge.
  - The output is the mission **Science Activity Plan**.
Long Term Planning

- Long Term planning - Scope: Orbit \(n\) - Takes place during orbit \(n-2\)
  - Roughly matches OGS station-scheduling exercise (2x/year) but not completely.
    - SGS input to the OGS will consist of plans coming from two adjacent orbits
  - LTP kicks off with schedule of main S/C manoeuvres & ground contacts.
  - SWT updates SAP, refining the science activities for the orbit & any implications for the rest of the mission.
  - SOWG translates the SAP plans into a set of SOOPs, covering whole orbit and all payload. The Instrument Teams detail their instrument operations in the SOOPs.
  - SOC integrates all instrument operation plans and checks against mission rules, constraints and resource estimates, using high-level instrument models.
  - SOC feeds back planning information into SOWG and Instrument Teams.
  - Output is a set of both coordinated & individual SOOPs covering the orbit.
SOOPs are operations plans dedicated to certain science goal or purpose (detailed in header). They are generic enough to be re-used. There are two types of SOOPs:

- **Coordinated SOOP**: Several instruments involved, coordinated operations over part of the orbit, coordinator tracks acquisition of scientifically useful dataset. ~SoHO JOP

- **Individual SOOP**: One instrument only. Fills rest of the orbit with individual instrument timelines. No coordinator needed beyond SOWG agreement.

Set of SOOPs will be sent to SOC for constraint checking and TM return analysis.

> **Today, a draft SOOP template has been sent to all ITs!**
Medium Term Planning

- **Medium Term planning - Scope: Orbit \( n \), detailing science operations within RS windows and IS operations in between - Takes place during orbit \( n-1 \)**
  - **SOWG** updates and refines the SOOPs if necessary, based on outcome of LTP exercise.
  - **Instrument Teams** translate operations from SOOPs into Instrument Operations Requests (**IORs**) and send to SOC.
  - **SOC** provides feedback to ITs after power, SSMM & TM modelling.
  - **SOC** provides week-long PORs and PTRs to **MOC** ~4 weeks before start of the orbit, for validation (pointing & dynamics, resource validation, pass schedule, ... )
  - At end of MTP planning cycle, **all resource allocations will be fixed**!
  - Type of pointing is known, but details on **off-pointing/fine-pointing** will be determined later, either in the STP or VSTP, depending on the nature of the observations.
  - Output is **Payload Operations Request** and **Pointing requests**, to be sent to MOC for constraint checks.
Short Term Planning

- Short Term planning - Scope: Planning of min 1 week of operations. Typically RS windows are planned in one go - Takes place ~2 weeks before.

- **Instrument Teams** update their instrument operations **within the resource envelope defined at MTP** and send updated IORs to SOC.

- SOC runs detailed instrument models, refines the SSMM modelling and provides feedback to ITs.

- SOC provides week-long PORs and PTRs to OGS ~1 week in advance for re-validation of system constraints and resource usage.

- **MOC** generates instrument commands for upload to S/C.
Very-Short Term Planning

- **Scope:** Refinement of pointing within RS windows with target-tracking
  - **SOC** processes Low-Latency Science data into QL images to
    1) define - supported by SOWG scientist - a target based on precursor data, OR
    2) evaluate the pointing and define an updated pointing profile if necessary
  - **SOC** can send updated PTRs to OGS **every day**, for validation and upload
  - **MOC** generates updated S/C pointing commands for uplink, after ~48hours
  - Daily upload is restricted to PTRs. **Exceptions** are not completely ruled out (calibration) BUT need to be discussed case-by-case. Limitations apply!
Key aspects of SoIO Mission Planning

Concept

- Due to limited TM and associated long latencies on data return, science operations planning for different orbits cannot be assessed in isolation. There has to be a global plan on mission level, to be updated in response to TM under/over productions.

- Resource envelopes and constraints will be fixed in orbit-long Medium Term Plan (fixed >1month before start of the orbit).

- During VSTP, only S/C pointing can be changed. Instrument commands (PORs) are uplinked as part of weekly STP. Last-minute instrument TC not part of baseline!

- VSTP cycle (during RS windows) requires daily (7d/week) quick-turn-around time operations of SOC and OGS.

- In order to make the VSTP and STP cycles work, we need appropriate precursor data & Low-Latency science data for planning purposes:
  - Low-latency/Low-volume – overview of yesterday’s data, returned at start of each pass.
  - Detailed & panoramic – to support tracking and re-targeting.
Solar Orbiter
Onboard Data Management

Which types of Data Products reside onboard?
Data types

- **Instrument HK data**: always comes down first, after the platform HK data (max 500 kb/s)

- **Low-latency science**: Subset of science data that is brought to ground promptly, ideally next day. (max 1MB per day)

- **Bulk science data**: will all get downlinked, but probably with long latency, depending on the phase of the mission

- **Selective science**: Subset of science data where only some of the data generated onboard is ultimately downlinked to ground, and the remainder is deliberately abandoned (overwritten or deleted).

- These data types will be marked each with a specific APID. They will also be routed to a dedicated packet store in the SSMM. (1 PS could contain different APIDs though)
Low-Latency science data

- Is the subset of science data that is brought to ground promptly
- Fulfills three functions:
  - Allows crude checks of instrument performance and science data quality (i.e. avoids up to 6 month delay in “seeing” what the instrument did).
  - Allows to make the selective decision for some instruments that use selective data.
  - Allows improvement of pointing profile and/or re-targeting when tracking solar features (baseline: EUI and PHI full disk images).
- Basic test of data-content appropriateness
  - The low-latency data has to (potentially) trigger some sort of planning update on ground. Otherwise the data doesn’t belong here.

- Volume
  - 1 MB/day limit per instrument (exceptions to be agreed with compelling justification).
  - Restriction because we want to be able to downlink this data daily in the worst-case communication situations and still retain significant margin (e.g. for pass contingencies, conjunctions, flexibility in station planning etc.).
## METIS proposal for LL data

<table>
<thead>
<tr>
<th>Instr.</th>
<th>Data product</th>
<th>Data Vol (kB/product)</th>
<th>Cadence (mins)</th>
<th>TM Vol (kB/day)</th>
<th>Usage</th>
<th>Data type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>METIS</td>
<td>Low-latency data</td>
<td>562.5</td>
<td>1440</td>
<td>563</td>
<td>x</td>
<td>Science</td>
<td>Evaluation of state/evolution of corona, in order to adjust observations + could be used for 3D modelling of corona &amp; linking RS with IS observations.</td>
</tr>
<tr>
<td></td>
<td>Low-resolution science images: 4 VL for p8 (bin4x4) + 1 UV (bin2x2)</td>
<td>228.84</td>
<td>1440</td>
<td>229</td>
<td>x</td>
<td>Science</td>
<td>Selective Data Decision set. This set is only needed in case of CME watch program but will be multiplied by number of detected CMEs/day!</td>
</tr>
<tr>
<td></td>
<td>Snapshot data of CME events: 8 lightcurves (32bit/min over 120min) + 1VL (2x2bin) + 1UV (no bin) image reduced angular FOV</td>
<td>987.5</td>
<td>1440</td>
<td>988</td>
<td>x</td>
<td>Science</td>
<td>For assessment of scattered light + quantitative calibration + monitoring of LCVR performance (any resulting action??). Only in case of no CME watch.</td>
</tr>
<tr>
<td>Total low-latency data rate</td>
<td>791.34 kB/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LL data in case of CME watch (type1+2), and only 1 CME</td>
</tr>
</tbody>
</table>

### Comments:

- LL data will be dependent on METIS CME watch trigger being on or off.
- In case of no CME watch, proposed volume is still too high, but data types 1 and 3 are very similar: can they be merged?
- In case of CME watch, the number of buffered CME events should be controlled!
- Data package headers not yet taken into account.
Selective science data (1)

- Some instruments want to generate more science than they ultimately downlink
  - Generate the data onboard
  - Decide on-ground what parts of this data are worth downlinking
  - Organise the downlink of only the chosen parts (and abandon the non-chosen parts)

  N.b. the downlink of the chosen parts is not necessarily faster than normal science (this is a detail of the implementation).

- Problems:
  - Although discussed in vague terms with some instruments in the past, attempts to form an operational concept started only this year. Concept has to fit the existing design.
  - SSMM volume. The flight baseline SSMM volume is marginal in the periods of bad comms (using the EID-A TM allocations). Selective data is effectively making the SSMM situation worse by allowing instruments to write data at higher rates than the allocated downlink rate.
  - There can be some tricks to try to bridge the gap between higher TM generation and the fact that the SSMM allocation is the same as before. However we can expect that these tricks don’t work in all conditions.
Selective decision

- This is the process by which the instrument-team on ground decides which parts of the selective data are worth downlinking. (…Obviously the scheme does not work if the only way to know which parts of the data you want to downlink is to downlink all the data first).

- Some instrument-teams put a specific science product into low-latency data to inform their selective decision.
Payload data return analysis has been started, based on EID-B’s & operation concept documents

Goal of instrument models:
*Predict at any time the power usage and data volume associated with the payload operations, for comparison with onboard resources, and total data return analysis over the mission.*

Use case:
*Validate planning against power restrictions, total data return model & SSMM usage.*
Will be based on the typical observing modes & parameters to be set.

Duration & cadence in each mode gives expected data rate.

Power profiles will be used to assess power consumption in each mode.
METIS questions to SOC?