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DOCUMENT

Solar Orbiter METIS/SOLO-HI Cross-like Straylight calibration TN

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APPROVAL

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CHANGE LOG

Reason for change	Issue	Revision	Date
• Correction of typo in table 2. Adds 1 hour to total time.	0	3	

Reason for change	Issue	Revision	Date
Updates based on comments from ITs • Includes widening of the METIS constraint in section 2	0	2	

CHANGE RECORD

Issue 0	Revision 3		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

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1 INTRODUCTION

METIS and SOLO-HI both require a straylight calibration consisting of a cruciate series of offpoints, which move across the disk on two orthogonal lines. This document defines a single shared pattern that can be used by both instruments together.

This note is written for calibrations within Cruise Phase and NMP. There is a straylight calibration for METIS also expected within NECP. In principle this same approach can be used for this.

This note defines the calibration pattern but does not record in detail when instances of this calibration are scheduled. Instead scheduling information is found:

- For ITs, in the first instance, on the SOC-public science planning pages
  https://issues.cosmos.esa.int/solarorbiterwiki/pages/viewpage.action?pageId=34047195
- Later, for FD, in the pre-LTP TN from SOC
- Later still, for ITs, in the EFECS and SOOP-kitchen plan

1.1 Overview of desired calibration patterns

1.1.1 METIS

Summary of METIS foreseen calibration approach according to their UM:

- o Calibration is investigating the intrusion of sunlight around/through the occulter system of the instrument
- o Prefer pattern based on fixed number of steps
- o Pattern is scaled to bring the ends to either the limb, or a limit derived from the METIS beta_max constraint (defined in section 2), depending on whichever is smaller.
- o Dwell at each point 1 min (TBC depending on "double" integrations parallel or sequential)

1.1.2 SOLO-HI

Summary of SOLO-HI foreseen calibration approach according to their UM:

- o Calibration is investigating the straylight, mainly that coming from the edge of the heatshield
- o Prefer pattern with fixed step size
  - 2 arcmin, which leads to a very long patterns when close to the sun
  - Possibility of smaller steps across some special area
- o Dwell at each point 5 min (later revised up to 10 minutes in discussion).

1.1.3 Agreed common pattern

At the SOWG-14 METIS and SOLO-HI teams have agreed on a pattern that can be used by both instruments in parallel. This follows the METIS pattern ("N=5" variant) but with an extended dwell time at each point to satisfy SOLO-HI needs. This is the basis of the calibration in this document. SOLO-HI is expected to actively acquire during only a subset of these dwell positions, but this is under SOLO-HI control and these details can be decided later.

The approach will be used in RSCW-1, even though only METIS will actively use this calibration instance[1]. This is to provide commonality with later calibrations, the first truly combined instance occurring in later in Cruise.

1.2 Reference Documents

[METIS_UM] "METIS Instrument User Manual", METIS-ATI-MA-001, July 2018, v9_0
[SOLOHI_UM] "SOLOHI Instrument User Manual", SSD-DOC-SOLOHI-013, April 2018, Rev F

1.3 Acronyms

APE	Attitude Pointing Error
CP	Cruise Phase
EFECS	Enhanced Flight Events and Communication Skeleton *Also called planning skeleton. This is a SOC-extended version of the FECS+PTEL that comes from MOC which details the spacecraft events*
FD	Flight Dynamics *Team at ESOC*
FIFO	First-In, First Out
HK	Housekeeping telemetry
IS	In-Situ
LLD	Low-Latency Data *That "thin-slice" of science data that can always be downlinked promptly to ground*
LTP	Long-Term Planning
MOC	Mission Operations Centre. *For Solar Orbiter this is ESOC in Darmstadt.*
MTL	Mission TimeLine *The onboard time-tagged queue from which nominal operations execute*
MTP	Medium-Term Planning
NMP	Nominal Mission Phase
PTEL	Planning Timeline Events *The planning skeleton produced by Flight Dynamics*
PTR	PoinTing Request *Routine phase RSW mechanism for SOC to request pointings to FD*
RPE	Relative Pointing Error
RS	Remote Sensing
RSCW	Remote-Sensing Checkout Window *The checkout windows for RS-instruments in cruise phase*
RSW	Remote-Sensing Window
SOC	Science Operations Centre *For Solar Orbiter this is ESAC near Madrid*
SOOP	Solar Orbiter Observing Plan
SOOP kitchen	The software tool used for collaborative science planning at LTP
SSMM	Solid State Mass Memory
STP	Short-Term Planning
TAC	Turn-Around Calibration *Complements LLD as prompt science link to ground. Because a "fatter slice" of science can come through this (compared to LLD) it is normally OFF, and only enabled for specific activities that need*

[1] The SOLO-HI lid is still closed at this time

	it (those where there is a mandatory tight space->ground->space loop needed), and then only when the downlink can support it.
TBA	To Be Agreed
TMC	TeleMetry Corridor
TMC-M	TMC-Measured *TMC plus Measured data of actual write rates seen at the SSMM*
VSTP	Very Short Term Planning

2 OVERVIEW OF THE CALIBRATION

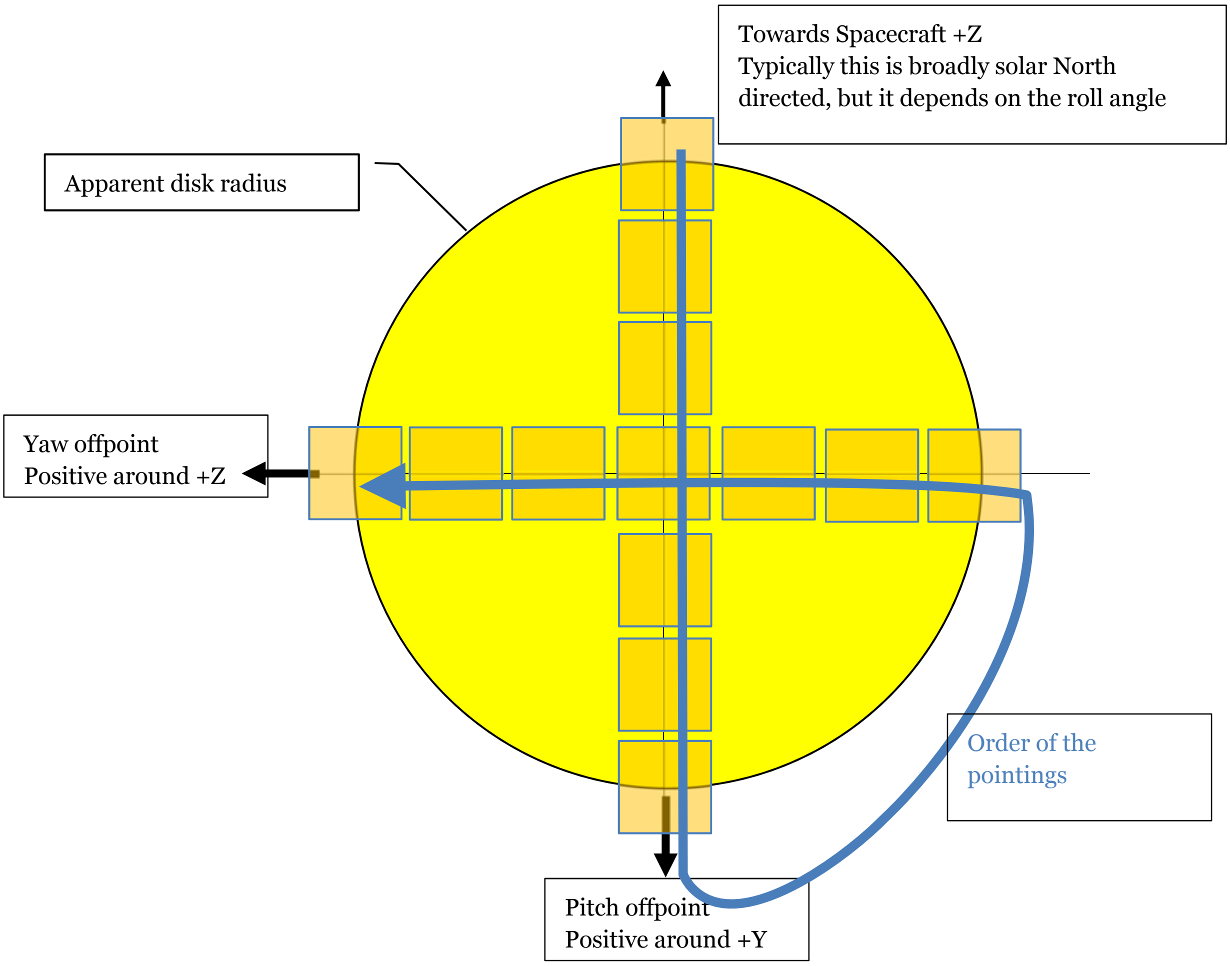

Figure 1, crude off-point diagram of SOLO-HI/METIS cross-like straylight pointing pattern (with three pointings per arm as illustration)

Figure 1 illustrates the general scheme.

- Figure shows small FoVs at each pointing for illustration, but these are of course not representative for SOLO-HI or METIS
- Disk centre position is acquired twice
- The order of pointings is not critical but needs to be known in advance. It is therefore defined here as first ascending rotations around SC Y, then ascending rotations around SC Z. The blue line illustrates the ordering of the various points (but not the precise slew path followed).
- The illustrated number of pointings **in the figure** corresponds to N=3 in the METIS nomenclature, where N is the number on each "arm" and the total number of pointings is 2.(2N+1). **The actual pattern uses N=5**.
- In the figure, the spacing of the steps is arranged to scale to the disk size. I.e. the ends of each arm correspond to a limb-pointing

- In reality the scaling of the end of the arms is to the limb, or to the METIS constraint βmax plus 7 arcmin[2], whichever is smaller. Below about 0.46 AU the METIS constraint is driving.
- Since the METIS constraint βmax is given by the expression,

  $$\beta max[arcmin] = 61.1 - 15.9/dist[AU]$$

  the alternate to the limb is

  $$\mathbf{limit[arcmin] = 68.1 - 15.9/dist[AU]}$$

  where βmax is the angular distance from the disk centre that avoids sun impingement on internal optical elements not designed for direct exposure, limit is angular distance that guarantees sun impingement, and dist is the SC-sun distance

The N=5 choice leads to **twenty two** pointings in total including the disk centre. Dwell time at each point would be **10 minutes**. It is the **spacecraft +X axis** being pointed.

Table 1 shows these off-points numerically. All off-points are defined as a fraction of the limiting off-disk-centre angle (either the angular disk radius or METIS constraint)[3].

Point number	Fraction of max off-point of the pattern (either the limb or the METIS constraint) in yaw	Fraction of max off-point of the pattern (either the limb or the METIS constraint) in pitch
1	0	-1
2	0	-0.8
3	0	-0.6
4	0	-0.4
5	0	-0.2
6	0	0
7	0	0.2
8	0	0.4
9	0	0.6
10	0	0.8
11	0	1
12	-1	0
13	-0.8	0
14	-0.6	0
15	-0.4	0
16	-0.2	0
17	0	0
18	0.2	0

[2] The additional 7 arcmin corresponds to two times the APE. It arises because the Beta_max constraint is conservative wrt sun-intrusion and the APE. This makes sense, in normal observations we want to avoid sun intrusion. However in the straylight calibration we want to provoke sun intrusion at the extremes of the arms (when geometry allows), so we have to remove the original APE correction and then apply it in the opposite sense.

[3] Practically this limiting angle would probably be calculated at a single point in time (e.g. the start or the midpoint of the pattern, or the closest approach to the Sun representing the tighter constraint).

19	**0.4**	**0**
20	**0.6**	**0**
21	**0.8**	**0**
22	**1**	**0**

Table 1, numeric values for offpoints (bold)

2.1 Duration

Table 2 shows the timing of the pattern. This timing includes pre- and post- slews.

	Duration (mins)	Start time within pattern (hh:mm)
Slew to 1	5	00:00
Dwell at 1	10	00:05
Slew to 2	5	00:15
Dwell at 2	10	00:20
Slew to 3	5	00:30
Dwell at 3	10	00:35
Slew to 4	5	00:45
Dwell at 4	10	00:50
Slew to 5	5	01:00
Dwell at 5	10	01:05
Slew to 6	5	01:15
Dwell at 6	10	01:20
Slew to 7	5	01:30
Dwell at 7	10	01:35
Slew to 8	5	01:45
Dwell at 8	10	01:50
Slew to 9	5	02:00
Dwell at 9	10	02:05
Slew to 10	5	02:15
Dwell at 10	10	02:20
Slew to 11	5	02:30
Dwell at 11	10	02:35
Slew to 12	5	02:45
Dwell at 12	10	02:50
Slew to 13	5	03:00
Dwell at 13	10	03:05
Slew to 14	5	03:15
Dwell at 14	10	03:20
Slew to 15	5	03:30
Dwell at 15	10	03:35
Slew to 16	5	03:45
Dwell at 16	10	03:50
Slew to 17	5	04:00
Dwell at 17	10	04:05
Slew to 18	5	04:15
Dwell at 18	10	04:20
Slew to 19	5	04:30
Dwell at 19	10	04:35
Slew to 20	5	04:45
Dwell at 20	10	04:50
Slew to 21	5	05:00
Dwell at 21	10	05:05
Slew to 22	5	05:15
Dwell at 22	10	05:20
Slew to default	5	05:30
End	-	*05:35*

Table 2, timeline for offpoints

2.2 Placement of the pattern

In Cruise Phase SOC will request the day that the pattern be implemented and FD will place the pattern avoiding

- Passes
- Incompatible platform modes and disturbance events such as wheel-offloadings, appendage movements etc.

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As far as possible the entire pattern should be placed in a contiguous block.
The position of the pattern shall be communicated to SOC within the PTEL.
SOC will then expand the pattern to component events within the EFECS such that instrument teams can see the individual dwell times.

2.2.1 Slew time

Solar Orbiter routine planning assumes a fixed worst-case duration for slews. This worst case value is currently assumed to be 5 mins (as visible in Table 2). Any change to this value, e.g. arising during NECP, needs to be communicated from MOC to SOC to ensure that SOC can correctly expand the component parts of the calibration in planning.

2.2.2 Quiescence time

The AOCS includes a flexure filter on the wheel torque demands. If this works correctly then reaction wheel controlled slews will require no quiescence time, so that further overhead (besides slewing) in completing the overall pattern can be avoided. The actual performance of this approach will need to be seen in NECP. As with the previous point, any change in this needs to be communicated MOC to SOC.

2.2.3 As reported in PTEL

PTEL is the planning skeleton that comes to SOC from Flight Dynamics.

Naming of this calibration event is CALIB_OFFPOI_STRAYLIGHT
The duration of the calibration event in the PTEL would reflect the duration of the pattern according to Table 2.

2.2.4 As reported in SOOP Kitchen and EFECS pointing enumerations

SOC products to instrument teams will expand the calibration into component POINT_ events etc. The current plan for the enumeration of these is that

- All pointings are POINT_PATTERN events
  - The intention is to add a new enumeration to the patternType attribute of "METIS_SOLOHI_straylight_cal"

3 SIDE ISSUES

The following issues are highlighted to instrument teams for completeness, but are understood not to impact the calibration pattern approach.

3.1 Downlink latency

The scheduling of the pointing pattern does in itself prioritise the science associated to the pattern. By default the science flows through the bulk science store in the normal FIFO way, which may involve significant latency.

In the Cruise Phase for the RSCW-1 the closure of the TM corridor flexibility at the end of the LTP-1 period is expected sufficient to ensure that data comes down adequately before RSCW-2. The later RSCWs of the cruise phase are closer spaced and may require more care. A particular concern here is:

- LTP simulation can be used to establish latency in the modelled scenario. This provides an opportunity to check that data downlink needs prior to next RSCW are met (based on the modelled LTP scenario).
- Subsequently the TM corridors expose flexibility on the TM generation but this flexibility comes at the price of unmodelled increased latency.

In routine phase it is expected that data arising from these calibrations will follow the normal bulk science latency.

In routine the TAC store may be used to "jump the queue" for "turn-around calibrations" but this is not applicable here.

- the calibration is not expected to lead directly to instrument commanding updates
- TAC is subject to significant constraints on when and how it is used. Not least amongst these, the currently foreseen volumes of data on this calibration exceed the baseline sizing of the TAC store.

3.2 APE, RPE etc.

The SC will not succeed to point exactly to where it is commanded, and subsequent knowledge of where it actually went will not be perfect either. This will complicate the analysis of the calibration. Numbers for the specified performance of the spacecraft can be found in the EID-A.

3.3 Aberration

In Cruise phase[4] the calibration is expected to be implemented without correction for aberration. Aberration magnitude in cruise will be similar to that seen from Earth, i.e. ~20 arcsec.

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[4] More precisely, whenever the calibration is implemented outside of the PTR mechanism for requesting pointings, which covers the CP, but may also occur in NMP if calibrations are implemented away from RSWs.

3.4 Apparent roll[5] under off-pointing

Apparent roll is **not** expected on this calibration because pitch and yaw movements are independent.

[5] Apparent roll is the name given to the (very small) instrument ALOS rotations that can occur within off-pointings.