Refresher on Solar Orbiter science planning constraints & process

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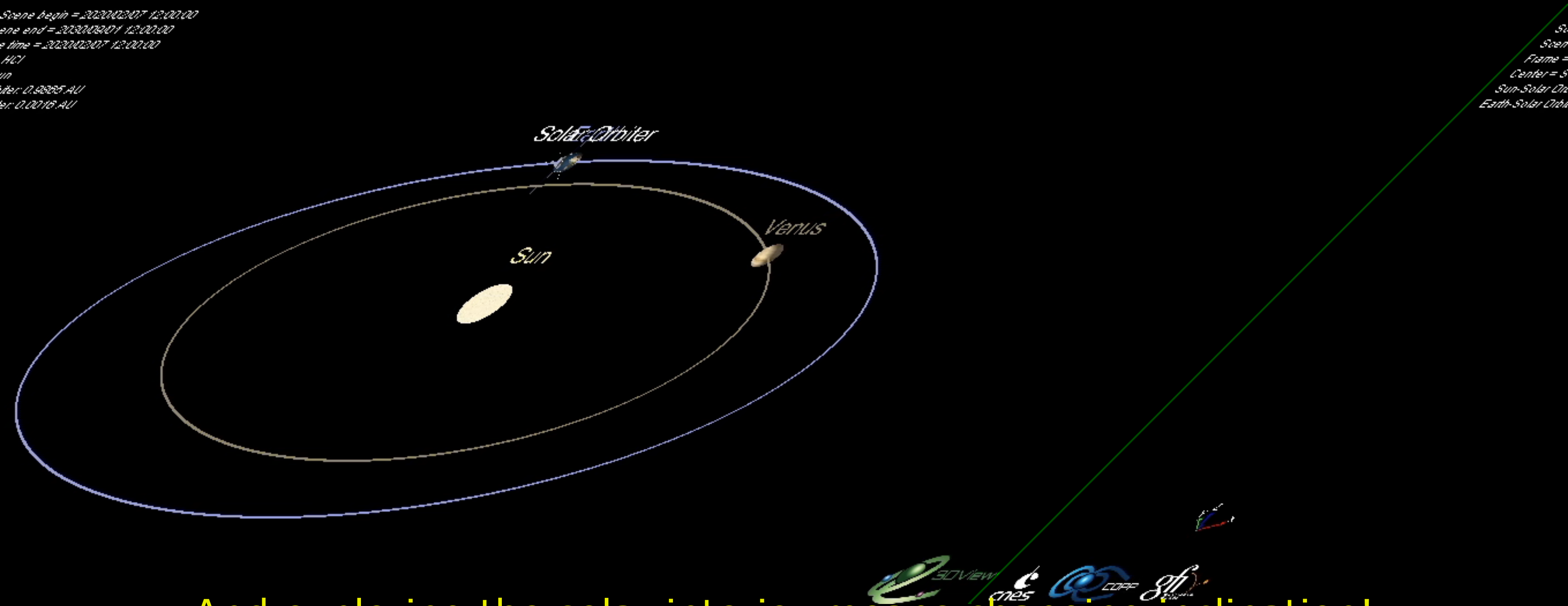
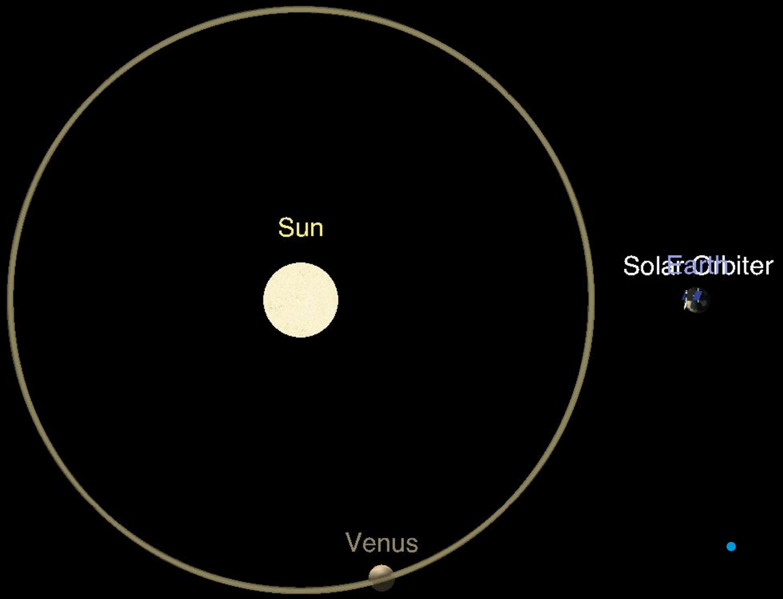
Exploring the Heliosphere means going far from Earth



And exploring the solar interior means changing inclination!

February 2020 launch

Effects of Solar Orbiter’s trajectory: geometry



February 2020 launch

- Non-Earth-synchronised orbit means *many* different observation opportunities
  - Geometric alignments with Sun-Earth line (conjunctions)
    - Quadrature with Earth view
    - Parker-spiral alignments with Earth
  - Alignments with *Parker Solar Probe*
  - Other opportunities you can think of…
- Increasing inclination means some opportunities are only available early / later in the mission

Effects of Solar Orbiter's trajectory: data rates

- Massively varying distances to Earth mean highly variable downlink rates
- But the Sun sets its own timescales, which set sampling rates and durations.
- **How to manage this?**

1. Compression:
   - We can do a lot, but eventually we hit limits
2. Selectivity:
   - restricting the sampling frequency
   - carefully selecting observation ranges in the wavelength / frequency domain
   - Constraining the duration of observations / high-cadence "burst" periods
3. On-board data storage (SSMM)
   - This lets us sample enough of the Sun and solar wind that we can make the right observations
   - It also means we **have to *wait*** for data to come to ground.

Downlink Constraints

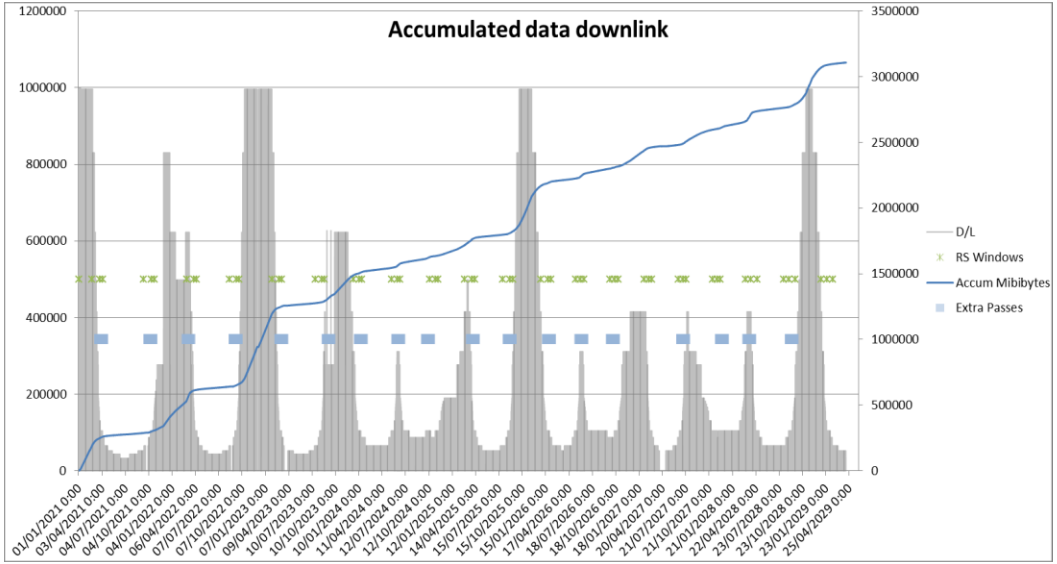
Downlink fluctuates over the mission

Data can stay on board for a long time

Peaks where data is downlinked

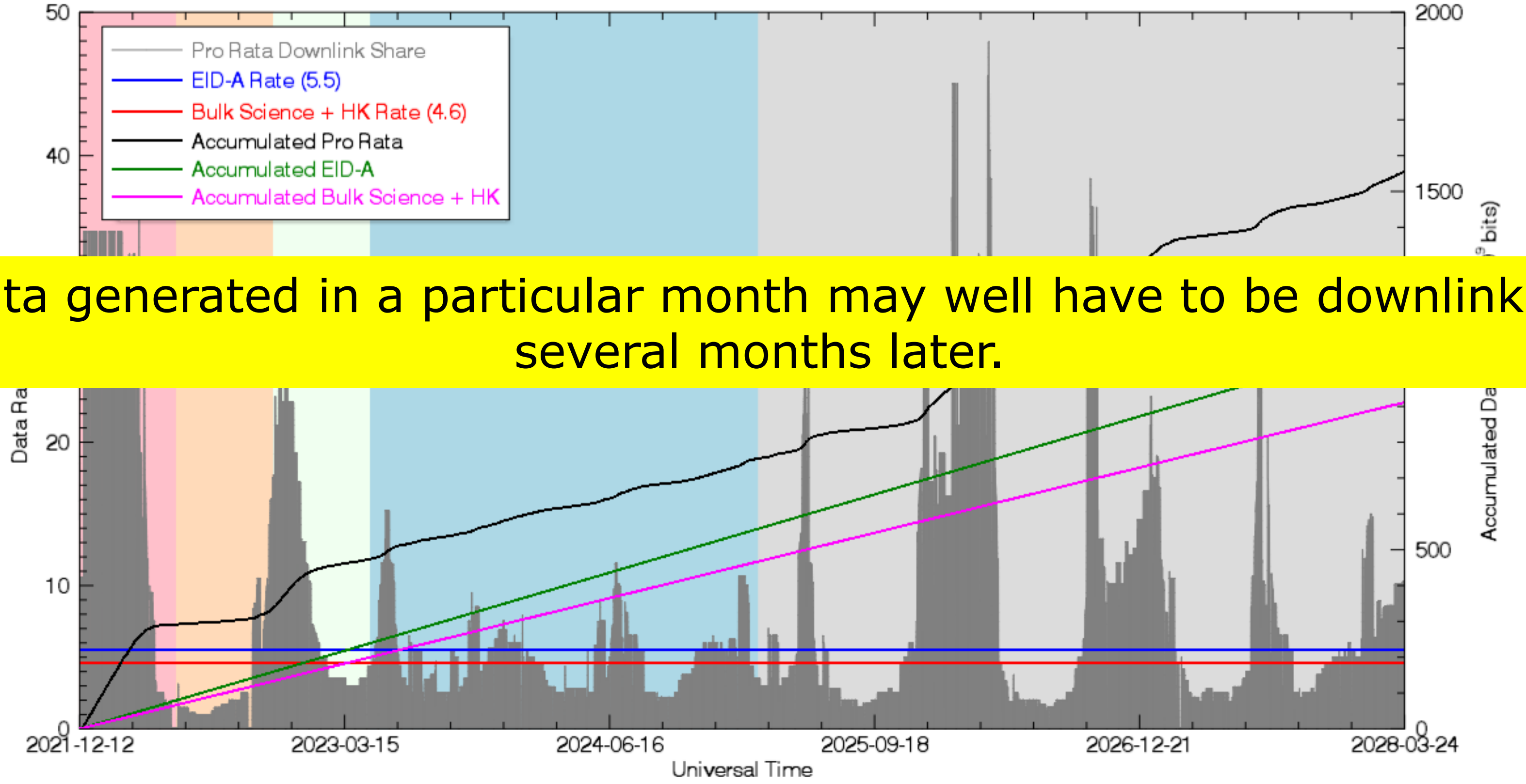
Periods where data builds up on board

High Latency and full/near-full stores



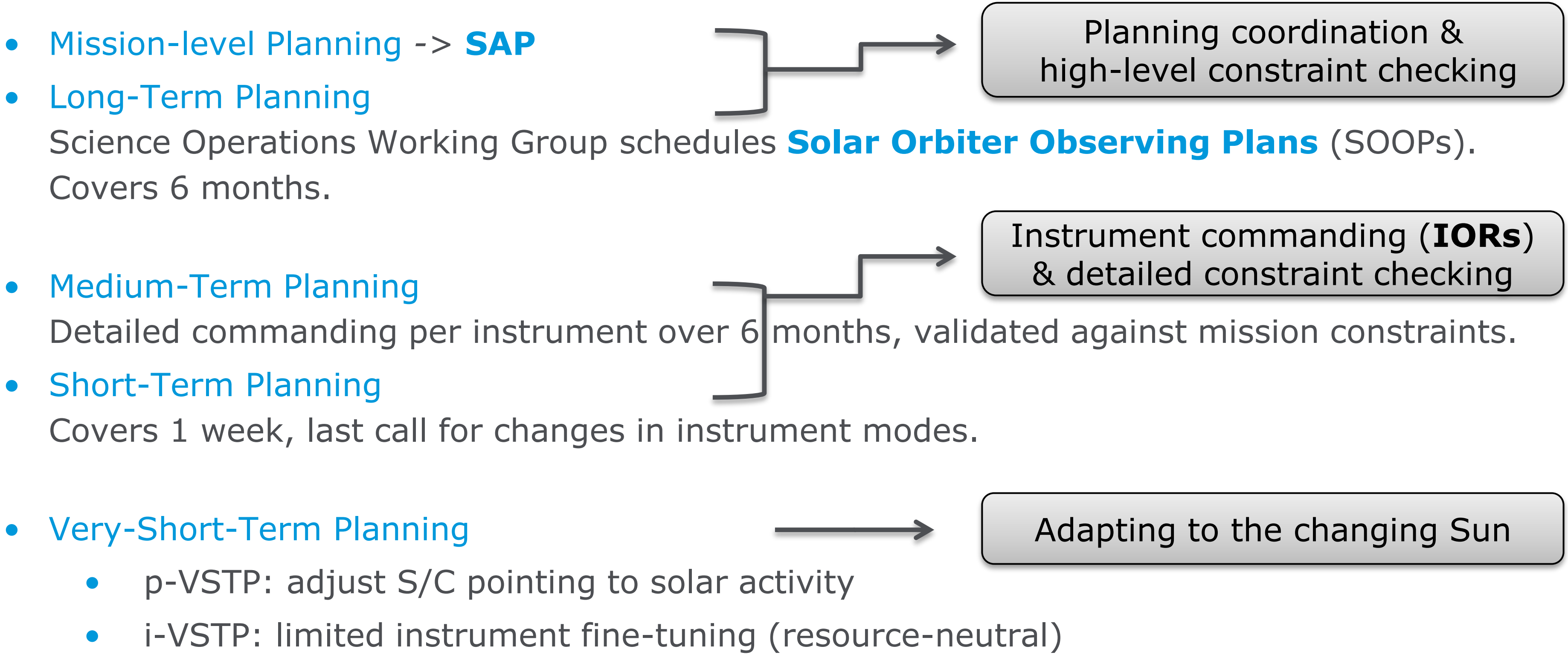
⇒ SOC needs to
manage Storage and Downlink Priorities
provide guidelines on production
have transparency on data production

Example downlink rate profile



Data generated in a particular month may well have to be downlinked several months later.

Solar Orbiter’s Planning Cycles



- Mission-level Planning -> **SAP**
- Long-Term Planning
  Science Operations Working Group schedules **Solar Orbiter Observing Plans** (SOOPs). Covers 6 months.

Planning coordination & high-level constraint checking

- Medium-Term Planning
  Detailed commanding per instrument over 6 months, validated against mission constraints.
- Short-Term Planning
  Covers 1 week, last call for changes in instrument modes.

Instrument commanding (**IORs**) & detailed constraint checking

- Very-Short-Term Planning
  - p-VSTP: adjust S/C pointing to solar activity
  - i-VSTP: limited instrument fine-tuning (resource-neutral)

Adapting to the changing Sun

Mission characteristics driving these planning cycles

Non-continuous observing

RS observations concentrated on RS windows.

Need to be chosen wisely, especially since orbits vary.

Coordinated observations

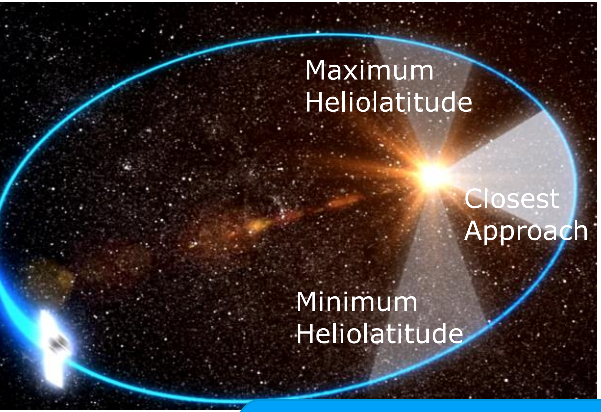
Science requires coordinated observations RS+IS.

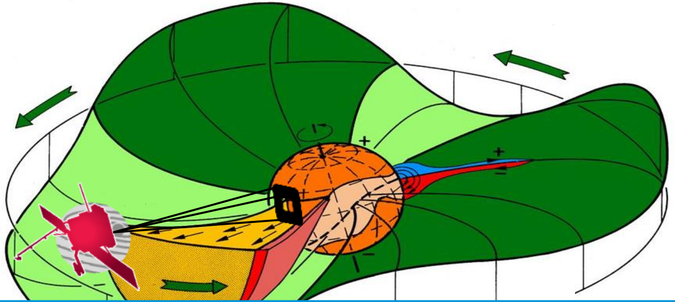
Connectivity also needs situational awareness.

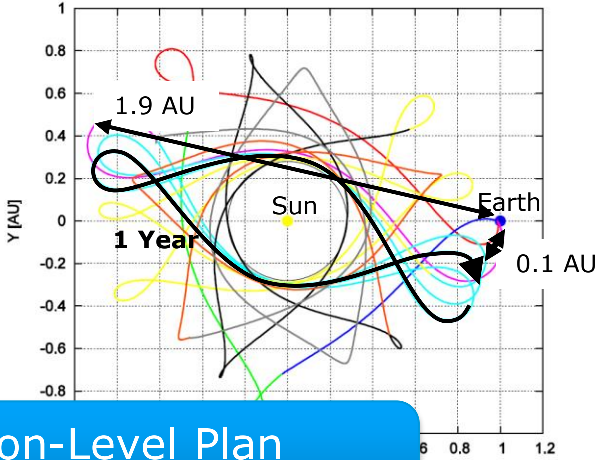
Data downlink constraints

23:1 ratio good to bad downlink, not in line with science value.

-> creates dependency between planning periods!

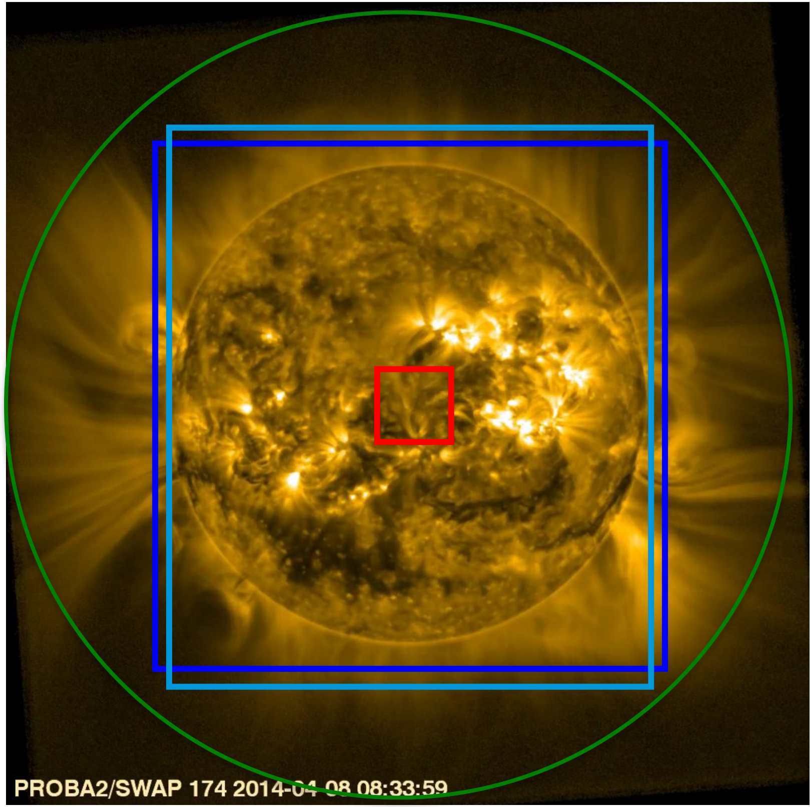


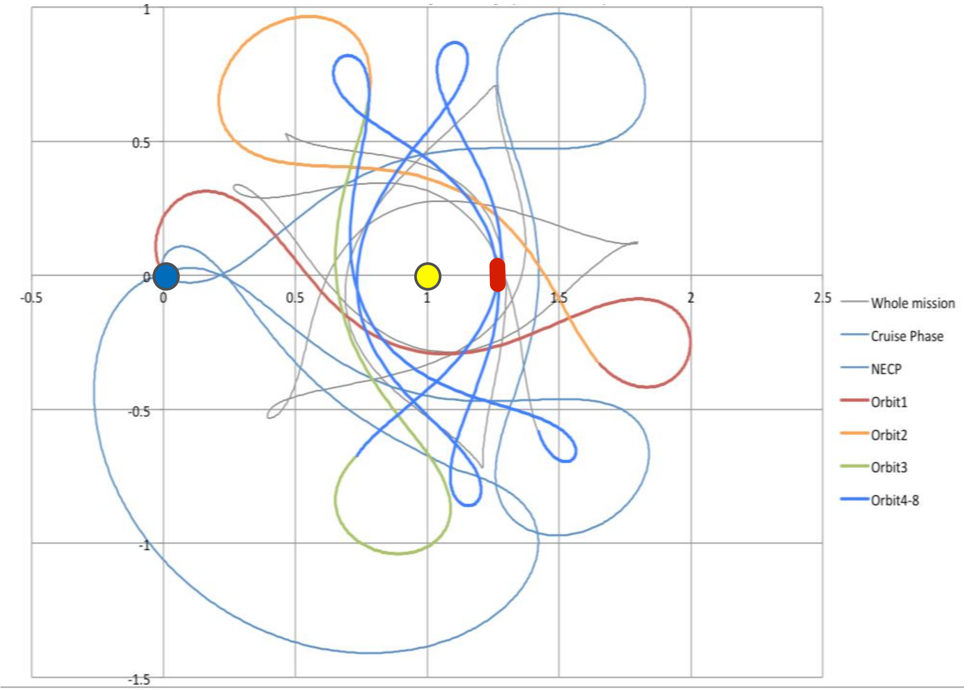




These constraints drive the need for a Mission-Level Plan & proper resource-checking at Long-Term Planning

Very Short Term Plan: Reacting to variable Sun





High-res FOV are small and all share same pointing. You cannot always rely on Earth context for target selection!

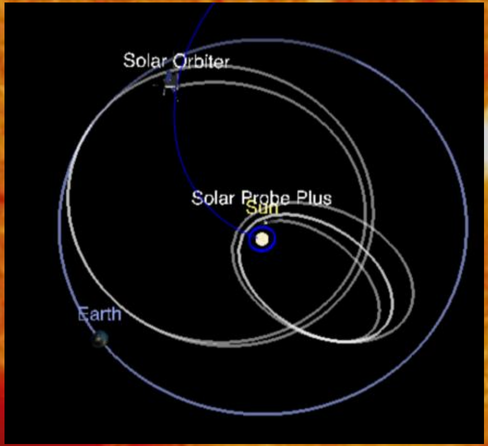
Clear need for mission long science plan!

First step: **Science planning strategy** to address all science goals

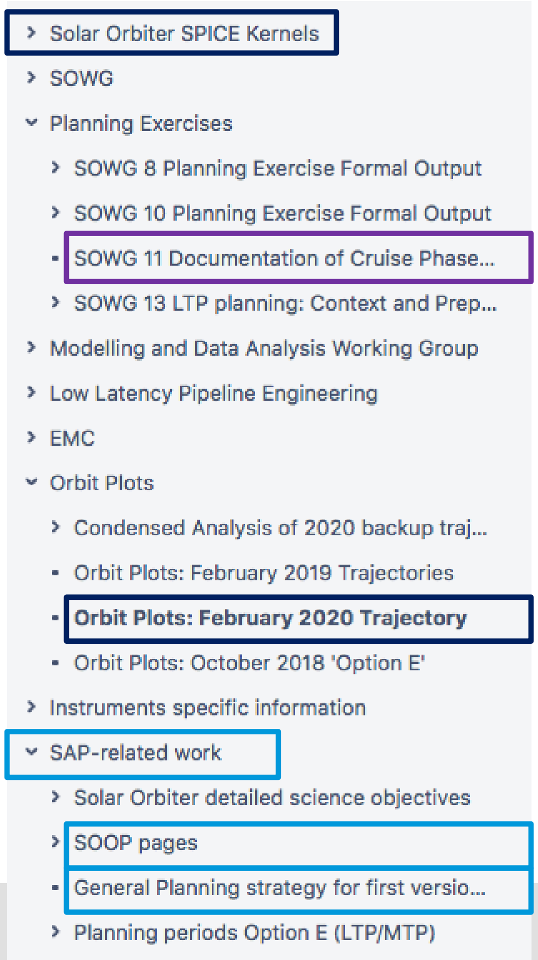
Detailed Science Objectives → Solar Orbiter Observation Plans =SOOPs + SOOP scheduling strategy → Science Activity Plan (SAP)

Which ones need similar coordinated observations?

Best opportunities for each SOOP and its objectives (incl. PSP & Earth!)

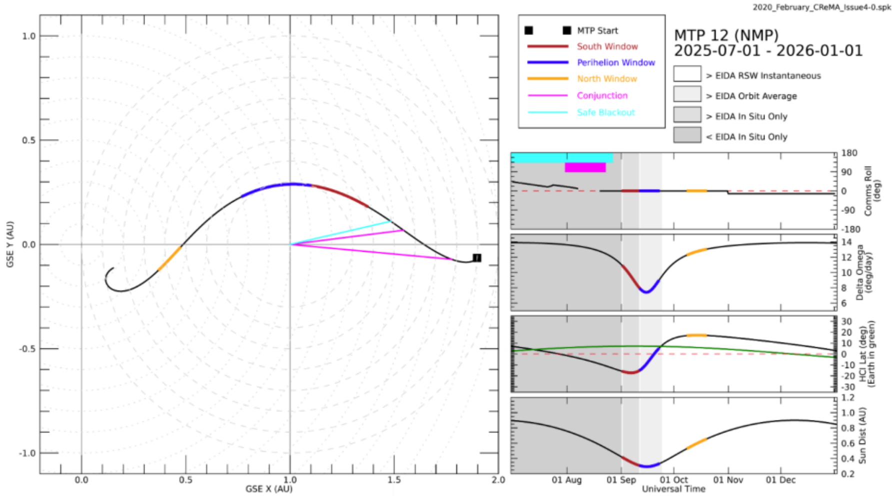


Solar Orbiter’s Science Activity Plan - Status

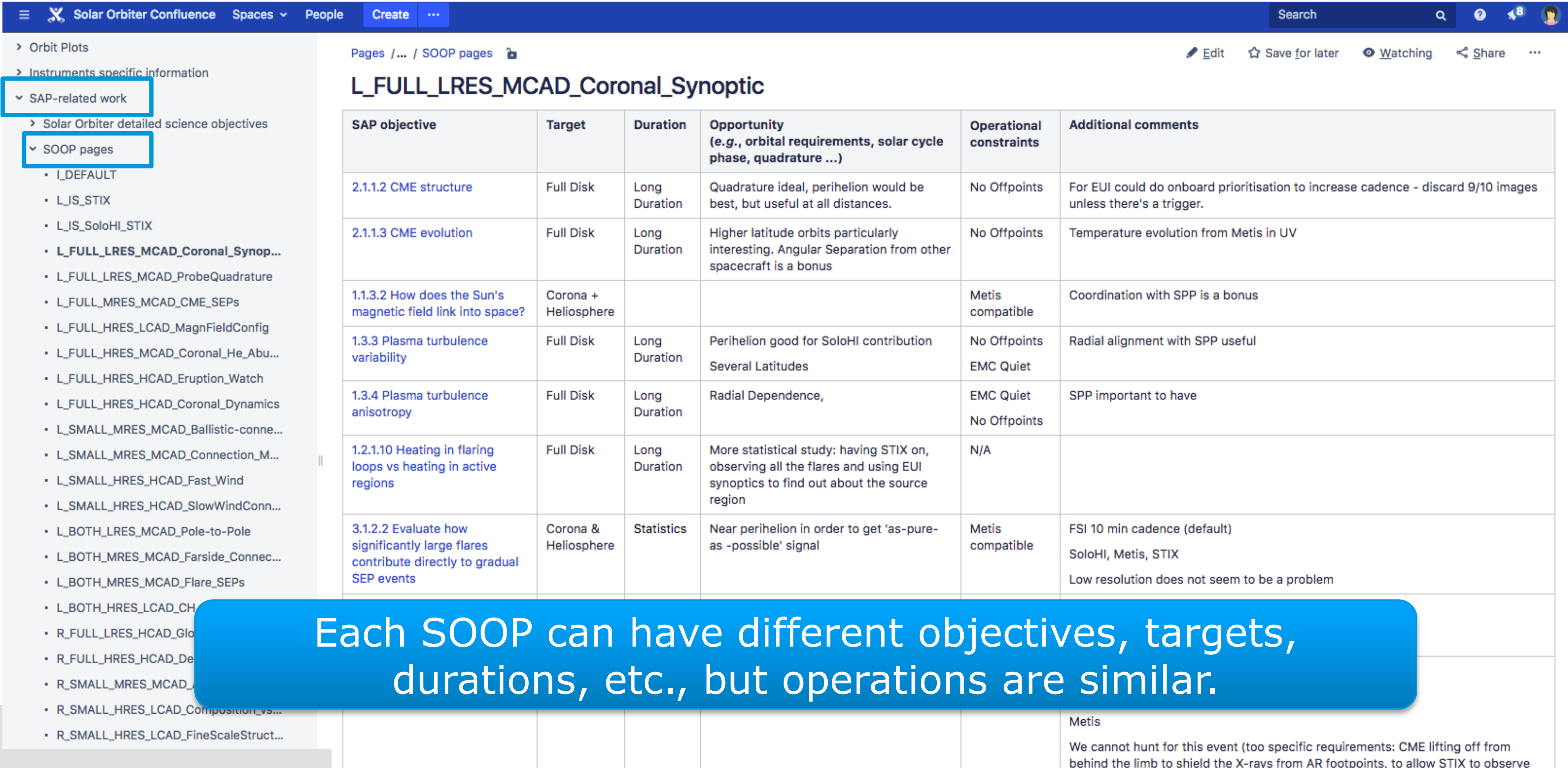


- › Solar Orbiter SPICE Kernels
- › SOWG
- ˅ Planning Exercises
  - › SOWG 8 Planning Exercise Formal Output
  - › SOWG 10 Planning Exercise Formal Output
  - ▪ SOWG 11 Documentation of Cruise Phase...
  - › SOWG 13 LTP planning: Context and Prep...
- › Modelling and Data Analysis Working Group
- › Low Latency Pipeline Engineering
- › EMC
- ˅ Orbit Plots
  - › Condensed Analysis of 2020 backup traj...
  - ▪ Orbit Plots: February 2019 Trajectories
  - ▪ **Orbit Plots: February 2020 Trajectory**
  - ▪ Orbit Plots: October 2018 'Option E'
- › Instruments specific information
- ˅ SAP-related work
  - › Solar Orbiter detailed science objectives
  - › SOOP pages
  - ▪ General Planning strategy for first versio...
  - › Planning periods Option E (LTP/MTP)

- SAP v0 for NMP has been written and reviewed by SWT.
  - First set of SOOPs
  - Preliminary SOOP scheduling strategy
- Cruise Phase SAP has been drafted (SO only)
- Planning context: orbit plots & SPICE kernels



Solar Orbiter SOOPs



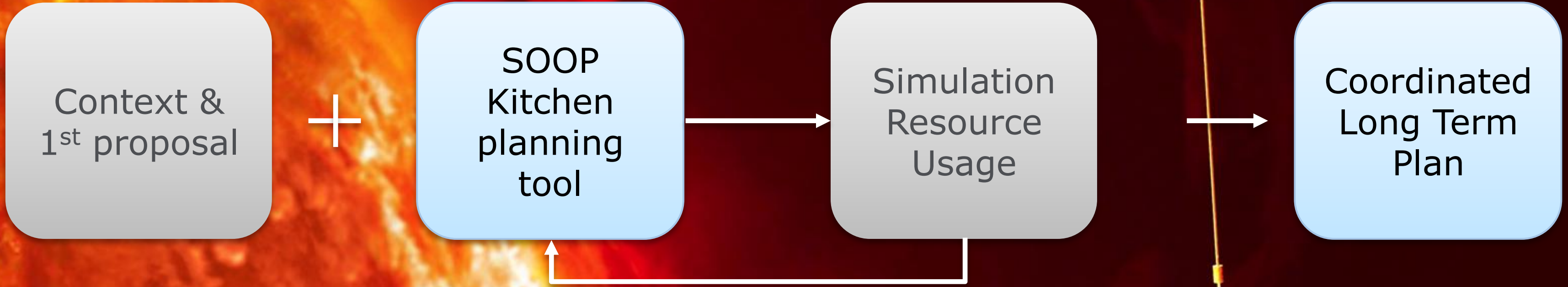
- Orbit Plots
- Instruments specific information
- SAP-related work
  - Solar Orbiter detailed science objectives
  - SOOP pages
    - L_DEFAULT
    - L_IS_STIX
    - L_IS_SoloHI_STIX
    - **L_FULL_LRES_MCAD_Coronal_Synop...**
    - L_FULL_LRES_MCAD_ProbeQuadrature
    - L_FULL_MRES_MCAD_CME_SEPs
    - L_FULL_HRES_LCAD_MagnFieldConfig
    - L_FULL_HRES_MCAD_Coronal_He_Abu...
    - L_FULL_HRES_HCAD_Eruption_Watch
    - L_FULL_HRES_HCAD_Coronal_Dynamics
    - L_SMALL_MRES_MCAD_Ballistic-conne...
    - L_SMALL_MRES_MCAD_Connection_M...
    - L_SMALL_HRES_HCAD_Fast_Wind
    - L_SMALL_HRES_HCAD_SlowWindConn...
    - L_BOTH_LRES_MCAD_Pole-to-Pole
    - L_BOTH_MRES_MCAD_Farside_Connec...
    - L_BOTH_MRES_MCAD_Flare_SEPs
    - L_BOTH_HRES_LCAD_CH
    - R_FULL_LRES_HCAD_Glo
    - R_FULL_HRES_HCAD_De
    - R_SMALL_MRES_MCAD_
    - R_SMALL_HRES_LCAD_Composition_vs...
    - R_SMALL_HRES_LCAD_FineScaleStruct...

L_FULL_LRES_MCAD_Coronal_Synoptic

SAP objective	Target	Duration	Opportunity (*e.g.*, orbital requirements, solar cycle phase, quadrature ...)	Operational constraints	Additional comments
2.1.1.2 CME structure	Full Disk	Long Duration	Quadrature ideal, perihelion would be best, but useful at all distances.	No Offpoints	For EUI could do onboard prioritisation to increase cadence - discard 9/10 images unless there's a trigger.
2.1.1.3 CME evolution	Full Disk	Long Duration	Higher latitude orbits particularly interesting. Angular Separation from other spacecraft is a bonus	No Offpoints	Temperature evolution from Metis in UV
1.1.3.2 How does the Sun's magnetic field link into space?	Corona + Heliosphere			Metis compatible	Coordination with SPP is a bonus
1.3.3 Plasma turbulence variability	Full Disk	Long Duration	Perihelion good for SoloHI contribution Several Latitudes	No Offpoints EMC Quiet	Radial alignment with SPP useful
1.3.4 Plasma turbulence anisotropy	Full Disk	Long Duration	Radial Dependence,	EMC Quiet No Offpoints	SPP important to have
1.2.1.10 Heating in flaring loops vs heating in active regions	Full Disk	Long Duration	More statistical study: having STIX on, observing all the flares and using EUI synoptics to find out about the source region	N/A	
3.1.2.2 Evaluate how significantly large flares contribute directly to gradual SEP events	Corona & Heliosphere	Statistics	Near perihelion in order to get 'as-pure-as -possible' signal	Metis compatible	FSI 10 min cadence (default) SoloHI, Metis, STIX Low resolution does not seem to be a problem
					Metis We cannot hunt for this event (too specific requirements: CME lifting off from behind the limb to shield the X-rays from AR footpoints, to allow STIX to observe

Each SOOP can have different objectives, targets, durations, etc., but operations are similar.

Long Term Planning: No automatic scheduling but **concurrent observations planning**

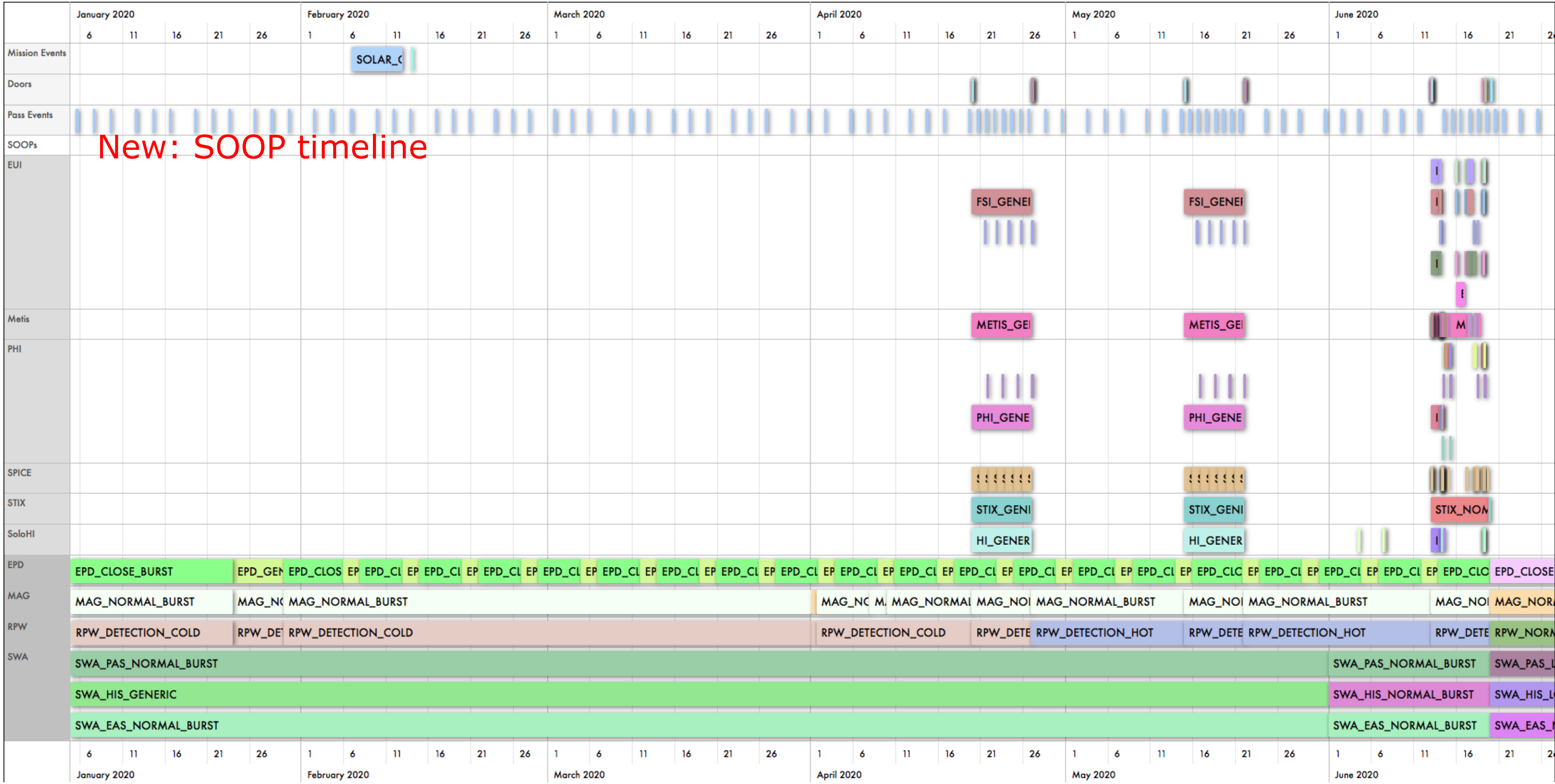


>50 scientists in meeting,
web-based planning tool,
multiple users,
coordinated planning.

SOOP Kitchen: Multi-user, long term planning tool

Events

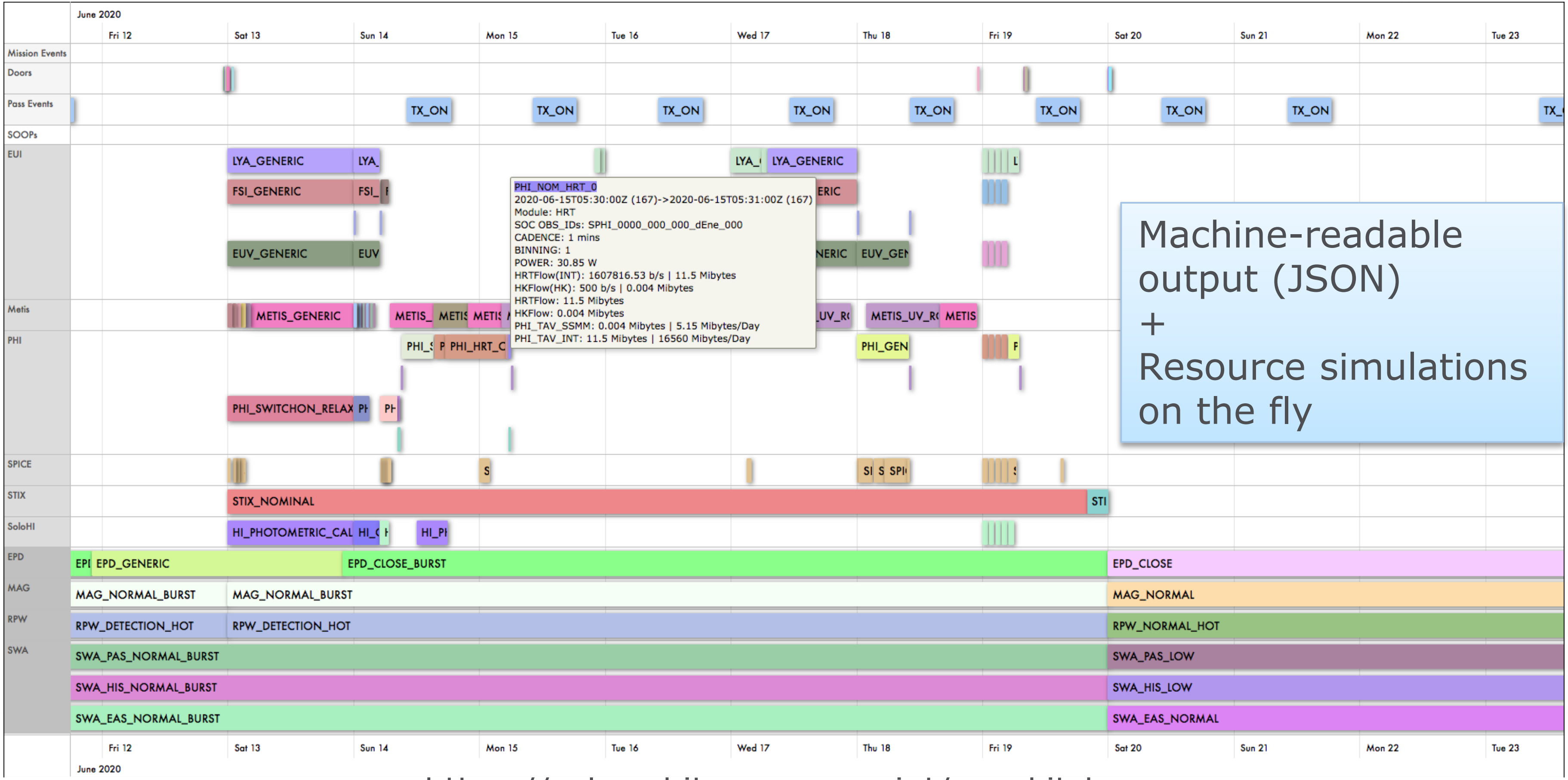
Instrument timelines



New: SOOP timeline

6 months

SOOP Kitchen: Multi-user, long term planning tool



```
PHI_NOM_HRT_0
2020-06-15T05:30:00Z (167)->2020-06-15T05:31:00Z (167)
Module: HRT
SOC OBS_IDs: SPHI_0000_000_000_dEne_000
CADENCE: 1 mins
BINNING: 1
POWER: 30.85 W
HRTFlow(INT): 1607816.53 b/s | 11.5 Mibytes
HKFlow(HK): 500 b/s | 0.004 Mibytes
HRTFlow: 11.5 Mibytes
HKFlow: 0.004 Mibytes
PHI_TAV_SSMM: 0.004 Mibytes | 5.15 Mibytes/Day
PHI_TAV_INT: 11.5 Mibytes | 16560 Mibytes/Day
```

Machine-readable output (JSON)
+
Resource simulations on the fly

https://solarorbiter.esac.esa.int/soopkitchen

LTP output

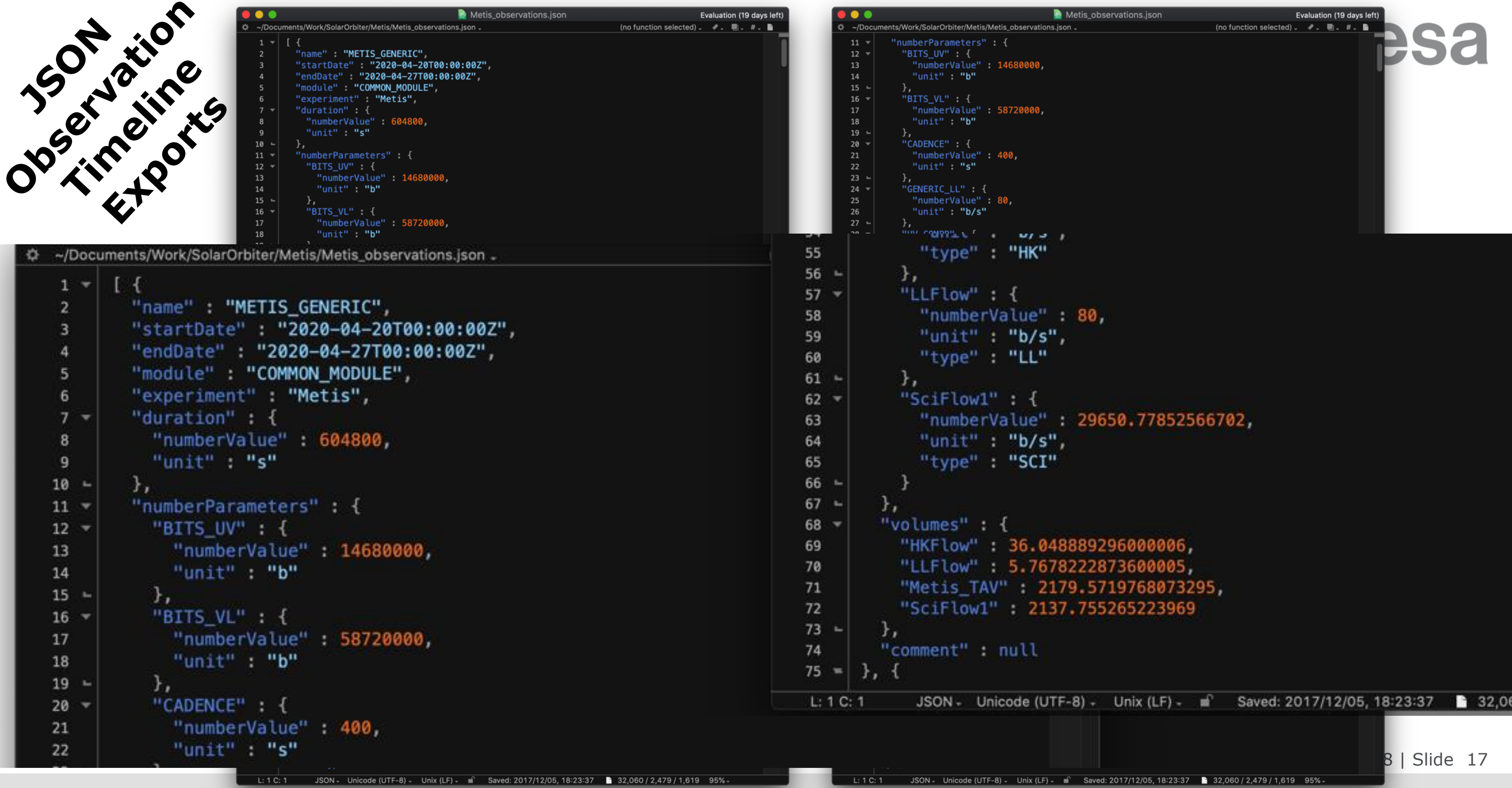
SOOP Kitchen output:

- Visualisation of the coordinated plan, both at SOOP level and instrument level
- Machine-readable instrument observation timeline exports (JSON), including observation IDs (link to SOOPs)
- E-FECS: platform events (passes, disturbances, pointing events, …) + scientific relevant context information
- Summary of resource usage per instrument

Extra:

- TM corridors: give flexibility in instrument data generation
- High-level downlink simulation (SSMM fill states)
- SOWG minutes

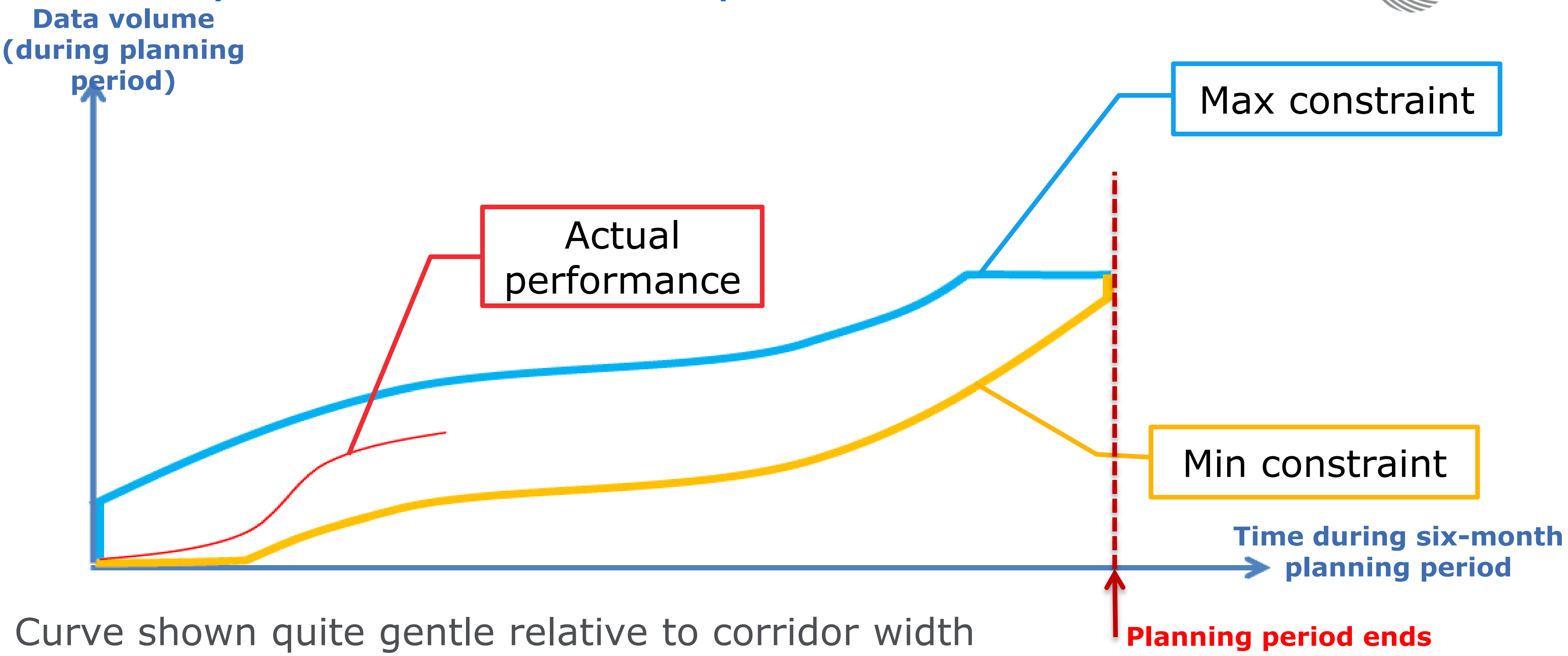
JSON Observation Timeline Exports



```
[ {
  "name" : "METIS_GENERIC",
  "startDate" : "2020-04-20T00:00:00Z",
  "endDate" : "2020-04-27T00:00:00Z",
  "module" : "COMMON_MODULE",
  "experiment" : "Metis",
  "duration" : {
    "numberValue" : 604800,
    "unit" : "s"
  },
  "numberParameters" : {
    "BITS_UV" : {
      "numberValue" : 14680000,
      "unit" : "b"
    },
    "BITS_VL" : {
      "numberValue" : 58720000,
      "unit" : "b"
    },
    "CADENCE" : {
      "numberValue" : 400,
      "unit" : "s"
    },
    "GENERIC_LL" : {
      "numberValue" : 80,
      "unit" : "b/s"
    },
```

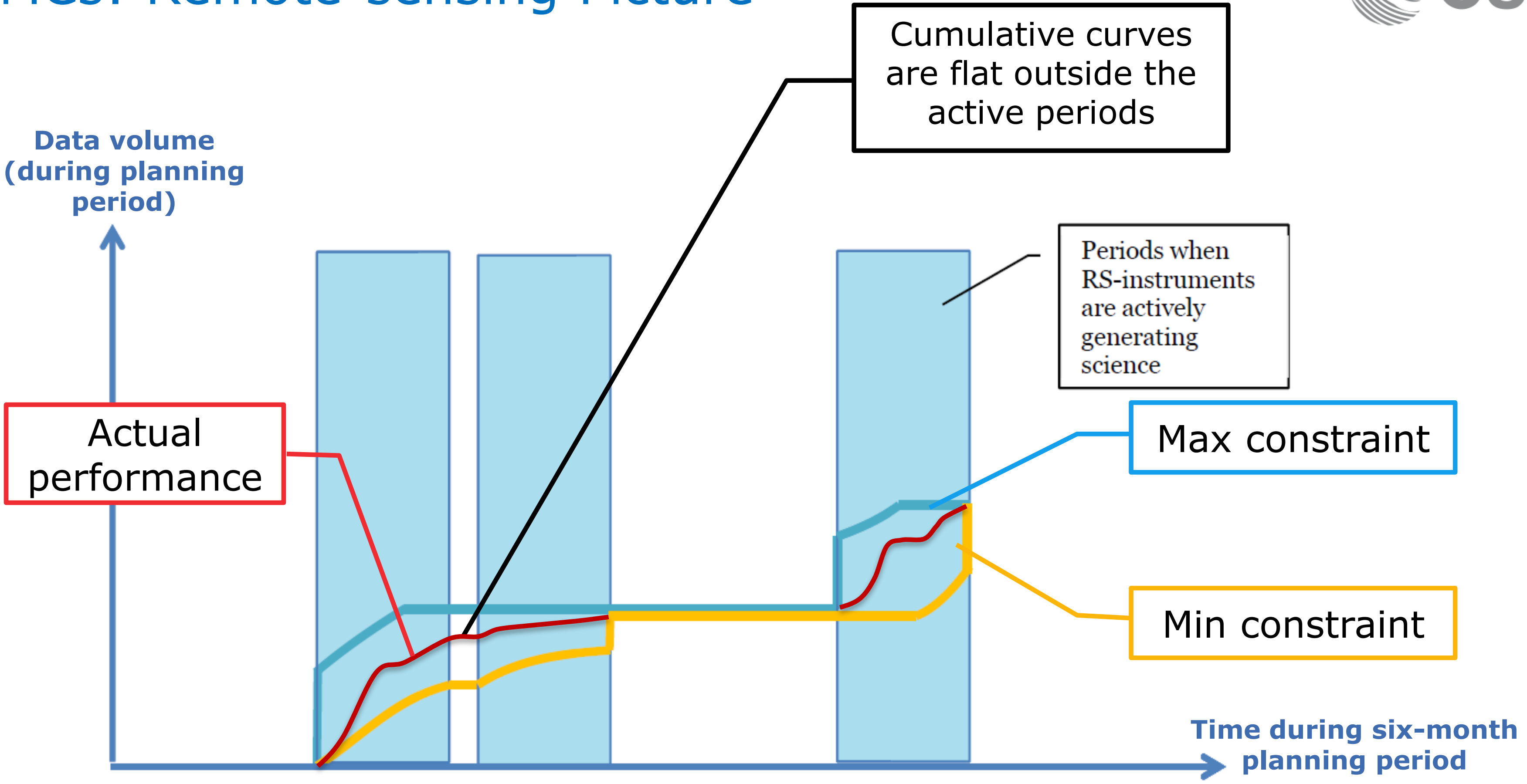
```
      "type" : "HK"
    },
    "LLFlow" : {
      "numberValue" : 80,
      "unit" : "b/s",
      "type" : "LL"
    },
    "SciFlow1" : {
      "numberValue" : 29650.77852566702,
      "unit" : "b/s",
      "type" : "SCI"
    }
  },
  "volumes" : {
    "HKFlow" : 36.048889296000006,
    "LLFlow" : 5.7678222873600005,
    "Metis_TAV" : 2179.5719768073295,
    "SciFlow1" : 2137.755265223969
  },
  "comment" : null
}, {
```

Telemetry corridors: In-situ picture



- Curve shown quite gentle relative to corridor width
  - Real behaviour can sometime be more severe. Consequence of the strong changes in downlink capability

TMCs: Remote-sensing Picture



Following steps in planning

Long Term Plan (6–12 months ahead)

= coordinated observation plan,
incl. flexibility at instrument level

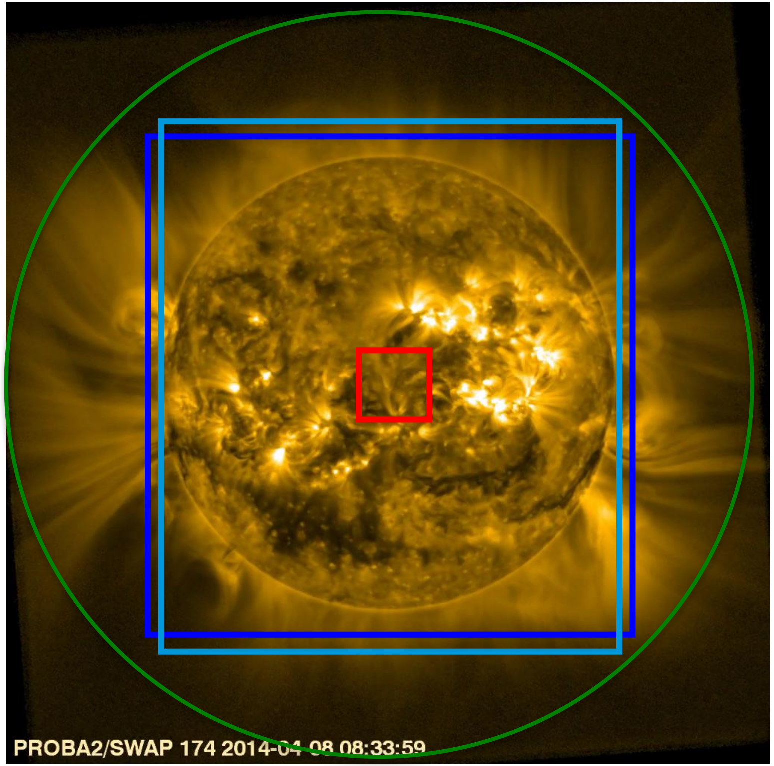
Medium-Term (1–6 months) **/**
Short-Term Planning (1–2 weeks)

-> individual Instrument Operations Requests
-> detailed constraint checking

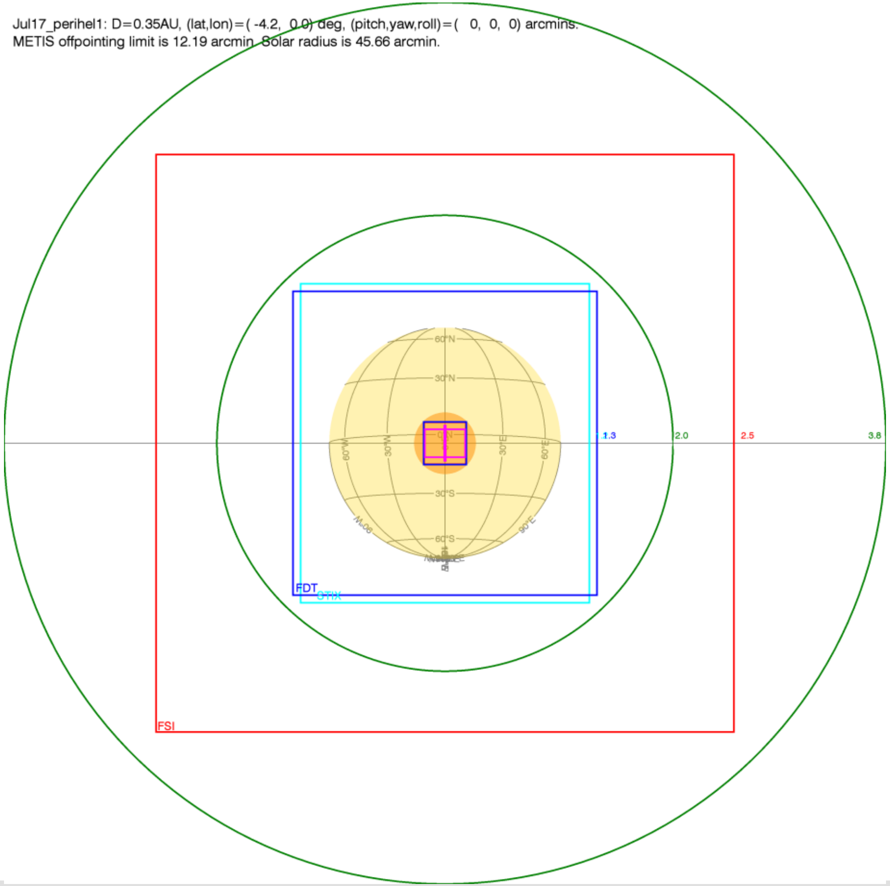
Very Short Term Planning (~3 days ahead)

Spacecraft Pointing can be updated to few days in advance of actual operations

Instruments can tweak few (calibration) settings

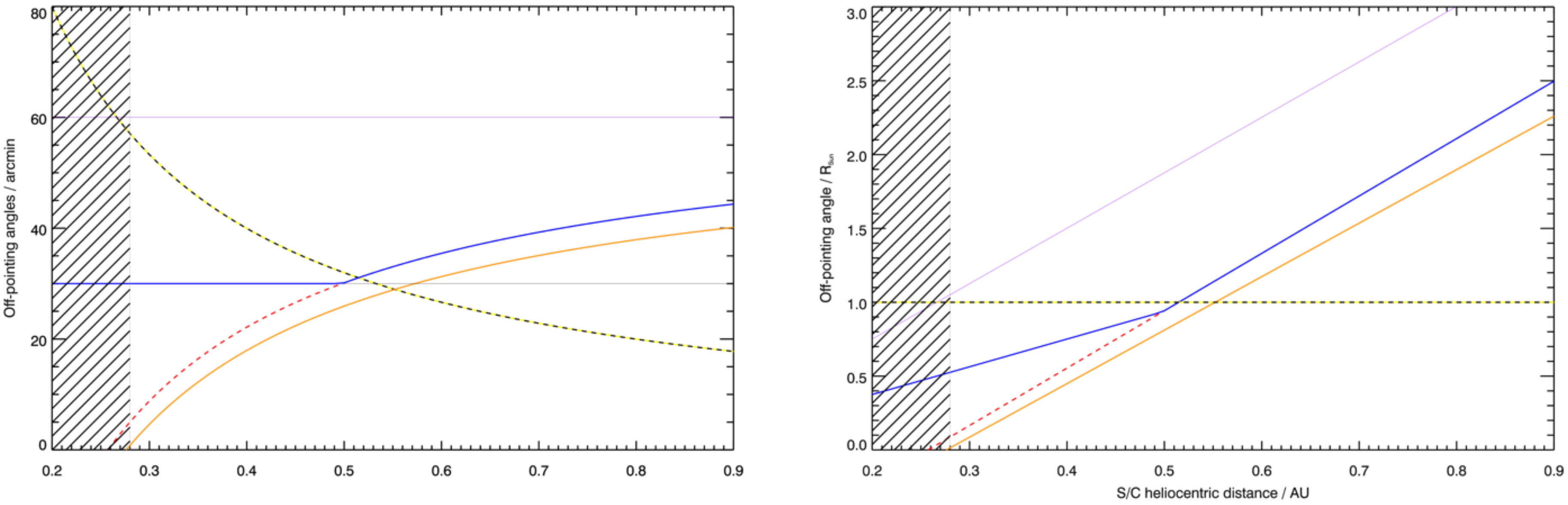


Off-pointing constraints


Jul17_perihel1: D=0.35AU, (lat,lon)=(-4.2, 0.0) deg, (pitch,yaw,roll)=(0, 0, 0) arcmins.
METIS offpointing limit is 12.19 arcmin. Solar radius is 45.66 arcmin.

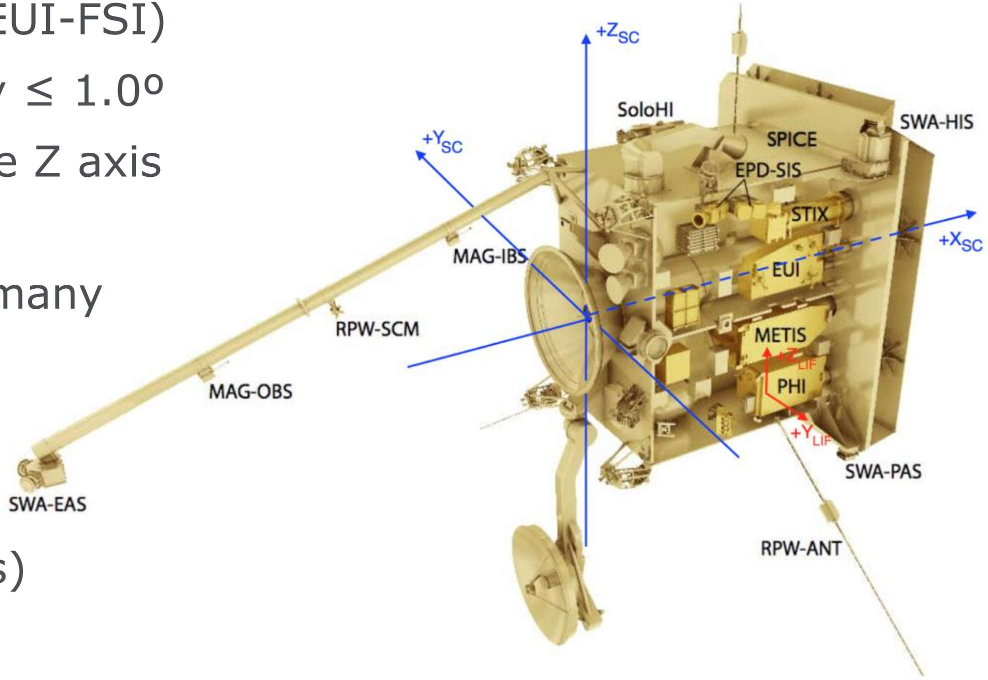
- The allowable angular separation between Metis' FoV centre and the centre of the solar disc is a function of distance from the Sun.
    - stray-light performance
    - safety constraint
- If this is needed for a certain time, Metis door *can* be closed, but some science is then not possible.

Metis off-pointing angles

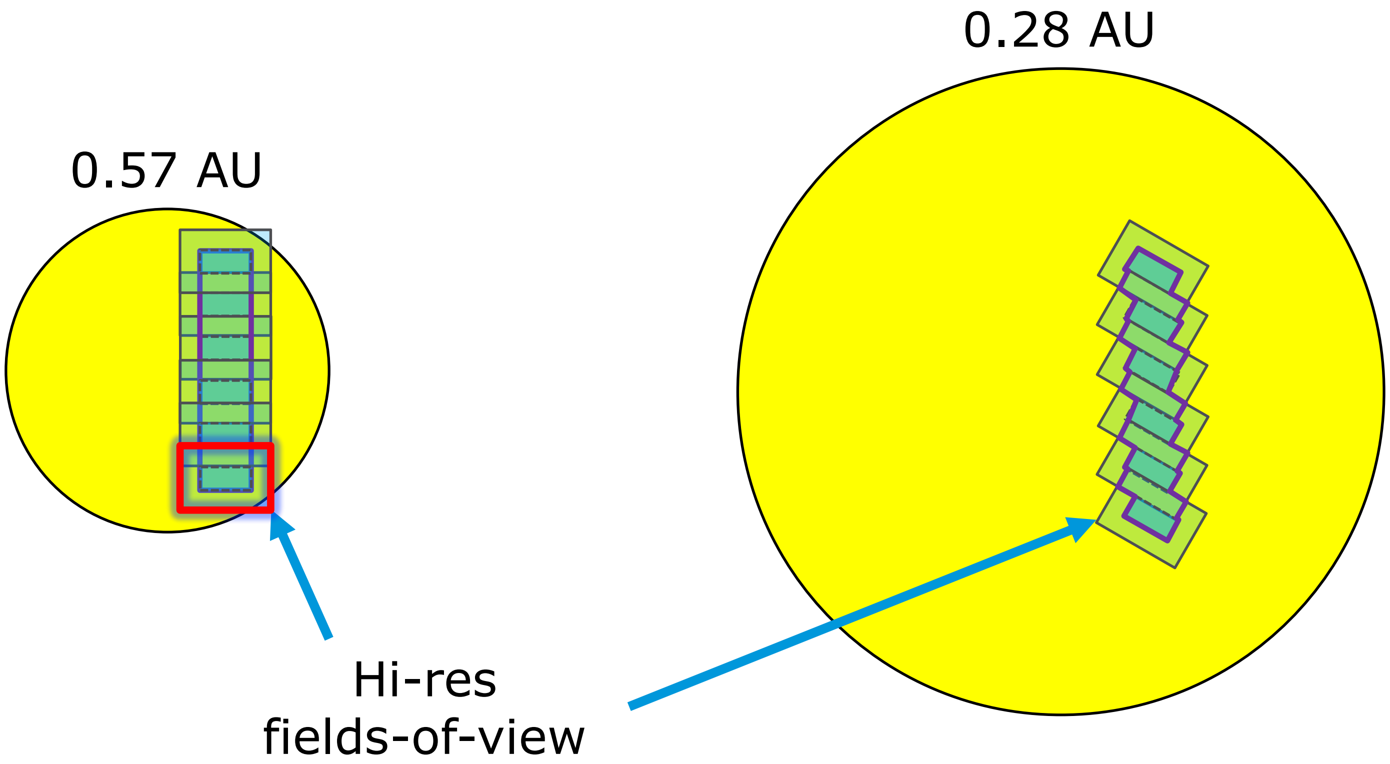


Pointing & roll constraints

- Default **pointing** is disc centre
  - (best for PHI-FDT, STIX, Metis, EUI-FSI)
  - Can off-point from disc centre by ≤ 1.0º
  - Can rotate (track/slew) about the Z axis by ≤ 0.01º s^{-1}.
- **Attitude** – "which way is up?" – has many possibilities, *e.g.*:
  - Z is orbit-normal (reference)
  - Y is parallel to solar equator
  - rotating about X (calibration rolls)
    - ≤0.1º s^{-1}.



Mosaics let us map out larger regions



Medium Term Planning: From SOOPs to IORs

- Coordinated science campaigns (SOOPs) -> individual instrument timelines, covering 6 months
- TM Corridors give some flexibility in data production, guided by predictions at LTP
- IORs = timeline of command sequences, written by Instrument Teams, within the framework provided during LTP

- SOC interprets IORs with the help of instrument models :
    - simulating **resource** usage (power, data flows LL/HK/SCI, EMC)
    - checking **constraints**
    - simulating and optimizing **downlink and data latency**
- Once validated, PORs sent to ESOC for overall validation in SC ops plan

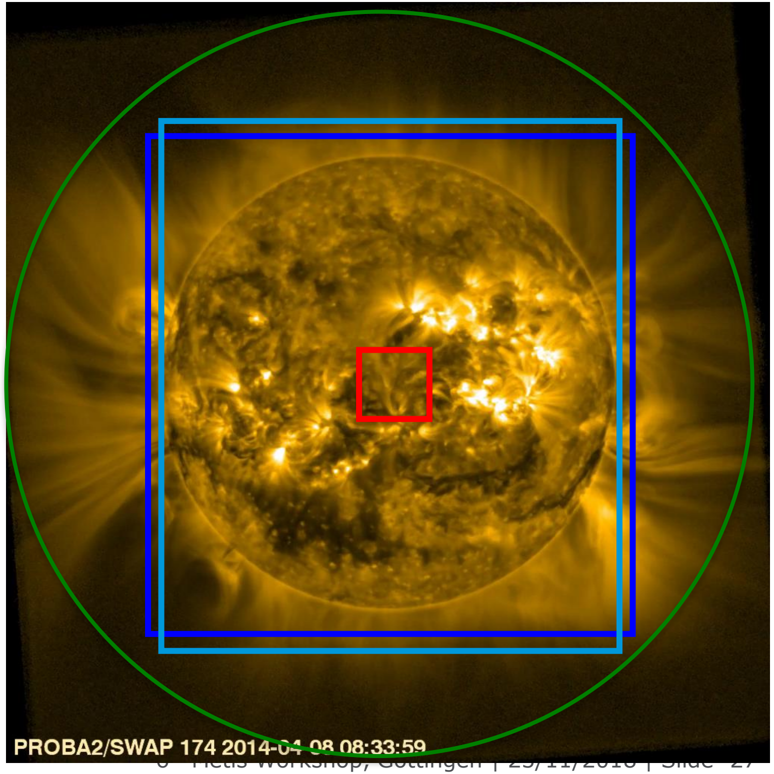
Short Term Planning: Refining IORs, upload to S/C

- Second round of refined IORs, covering 1 week
- Simulation at SOC for full payload, constraints checking
- Once validated, SOC sends PORs to MOC for validation at their side
- Commands get uploaded to S/C few days before 1st command executes

Very Short Term Plan: Reacting to variable Sun

Every day during RS window, Low-Latency data will be downloaded and inspected.

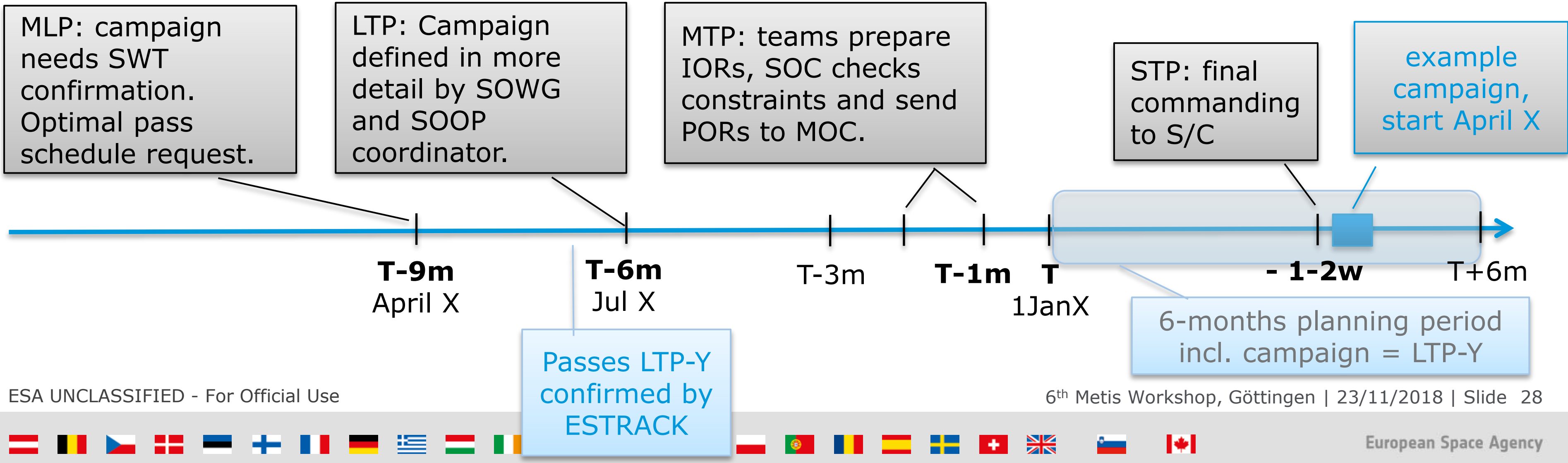
- Spacecraft Pointing can be updated if necessary: will take effect after 2-3 days.
- Instrument timeline (already onboard) can be complemented with few extra commands* to fine-tune instrument (calibration) settings



* Only a few *additional* commands are allowed: they must be resource-neutral, non-crucial for instrument safety!

Planning cycles on a timeline

- Mission-Level Planning *(before launch, reviewed every 6 months, last time 9-15 m ahead)*
- Long-Term Planning of 6-months period *(6-12m ahead)*
- Medium-Term Planning of 6-months period *(1-7m ahead)*
- Short-Term Planning of 1-week period *(1-2w ahead)*
- Very-Short-Term Planning *(2-3 days ahead)*



MLP: campaign needs SWT confirmation. Optimal pass schedule request.

LTP: Campaign defined in more detail by SOWG and SOOP coordinator.

MTP: teams prepare IORs, SOC checks constraints and send PORs to MOC.

STP: final commanding to S/C

example campaign, start April X

T-9m
April X

T-6m
Jul X

T-3m

T-1m

T
1JanX

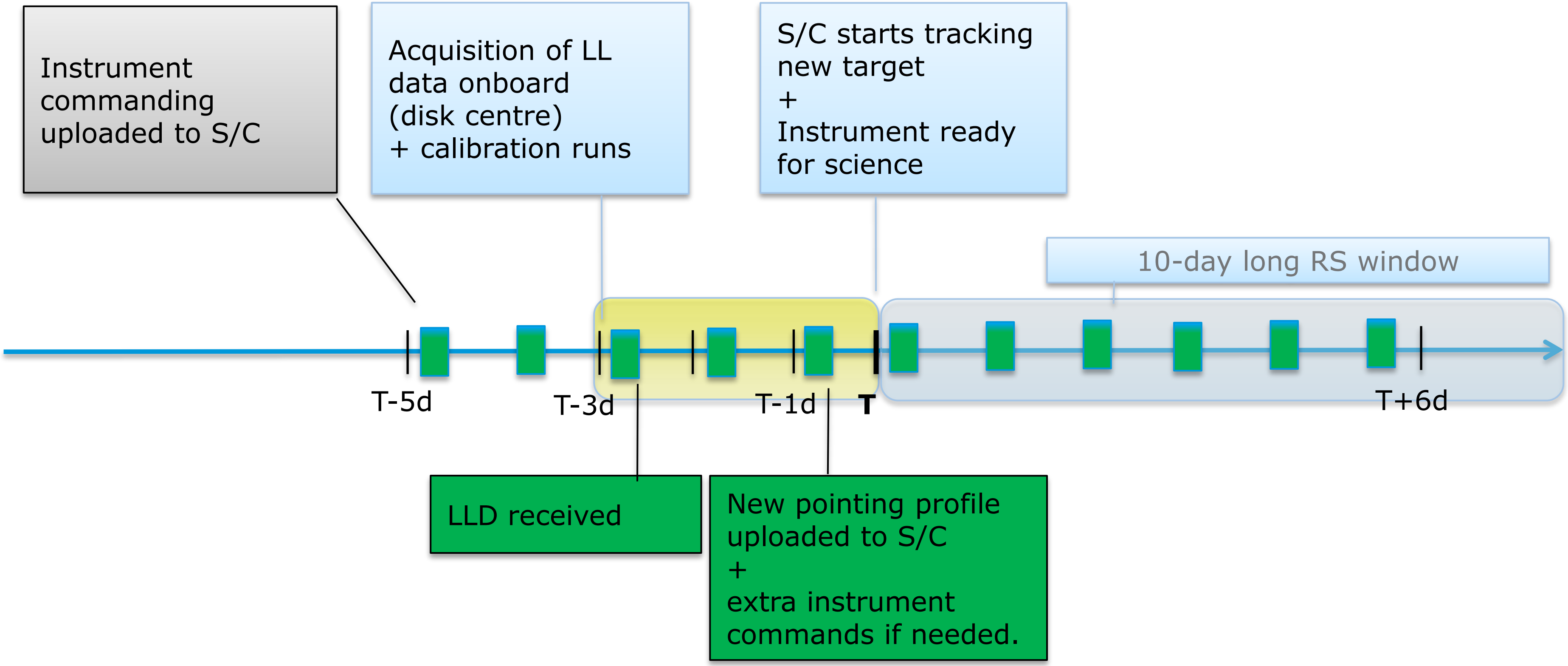
- 1-2w

T+6m

Passes LTP-Y confirmed by ESTRACK

6-months planning period incl. campaign = LTP-Y

Very Short Term Planning on a timeline



Instrument commanding uploaded to S/C

Acquisition of LL data onboard (disk centre)
+ calibration runs

S/C starts tracking new target
+
Instrument ready for science

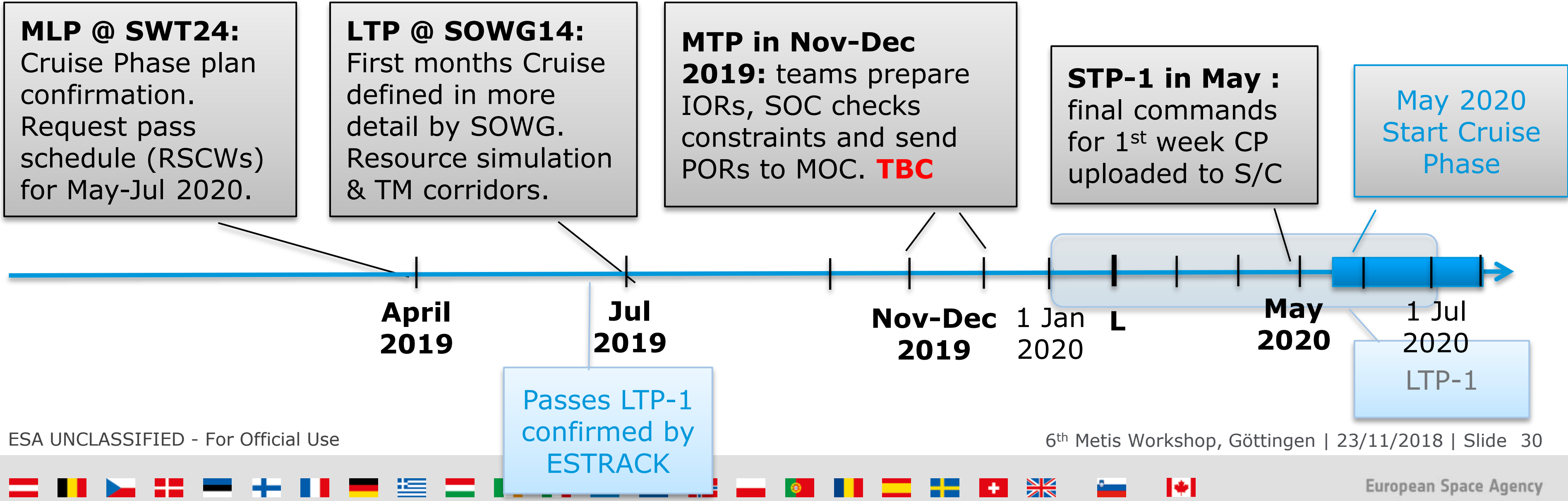
10-day long RS window

LLD received

New pointing profile uploaded to S/C
+
extra instrument commands if needed.

Feb 2020 launch: planning timeline

- For Feb 2020 launch, **real** planning process starts in spring 2019.
- Science operations start in Cruise Phase, at **T**=L+3months = mid May 2020.
- Part of 6-months planning period Jan-Jul 2020 = **LTP1**, so in theory we only plan for 1.5 months of science and checkout operations. However need full CP SAP.



MLP @ SWT24: Cruise Phase plan confirmation. Request pass schedule (RSCWs) for May-Jul 2020.

LTP @ SOWG14: First months Cruise defined in more detail by SOWG. Resource simulation & TM corridors.

MTP in Nov-Dec 2019: teams prepare IORs, SOC checks constraints and send PORs to MOC. **TBC**

STP-1 in May : final commands for 1st week CP uploaded to S/C

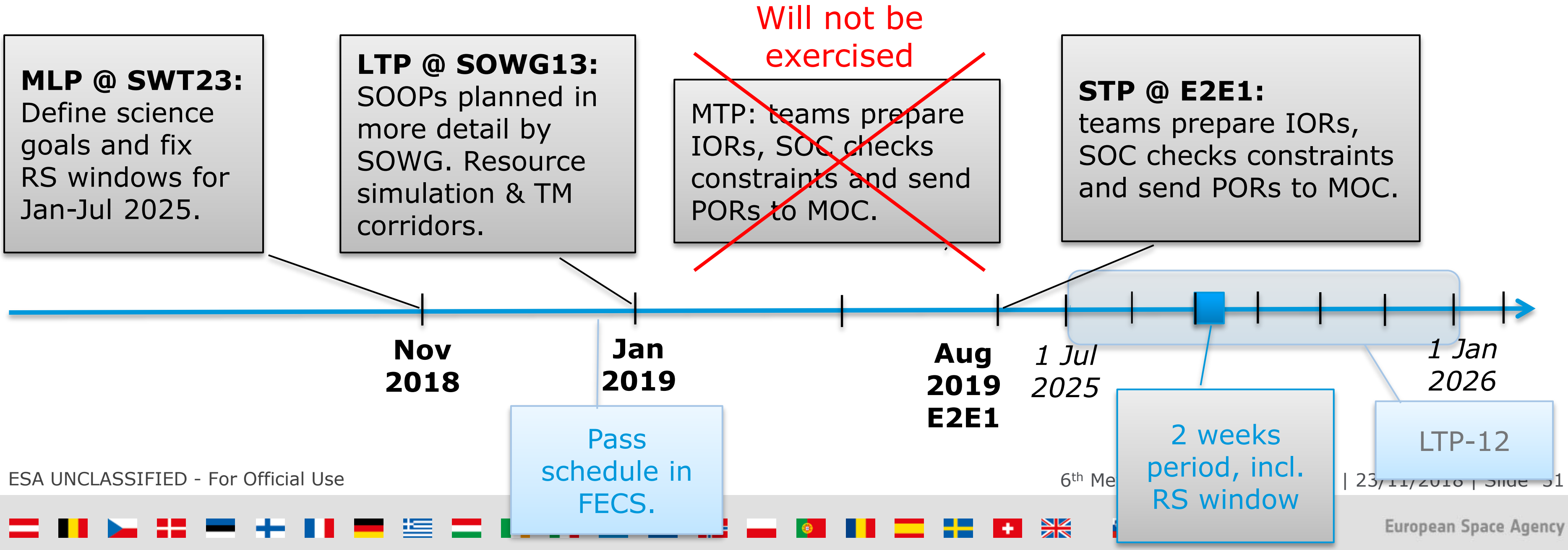
May 2020 Start Cruise Phase

LTP-1

Passes LTP-1 confirmed by ESTRACK

Last playing-around opportunity = NOW

- We will exercise full planning process one more time, between now and End-to-End-test 1 (summer 2019).
- Target of planning: NMP planning period LTP-12=MTP-12 (Jul-Dec 2025)



MLP @ SWT23: Define science goals and fix RS windows for Jan-Jul 2025.

LTP @ SOWG13: SOOPs planned in more detail by SOWG. Resource simulation & TM corridors.

Will not be exercised

~~MTP: teams prepare IORs, SOC checks constraints and send PORs to MOC.~~

STP @ E2E1: teams prepare IORs, SOC checks constraints and send PORs to MOC.

Pass schedule in FECS.

2 weeks period, incl. RS window

LTP-12

Upcoming planning activities: summary

Date	Meeting	Planning activity
Nov 2018=now	SWT23	*MLP(12) for E2E1*
Jan 2019	SOWG13	*LTP-12 (science phase orbit) for E2E1*
Apr 2019	SWT24	Cruise Phase MLP(1)
Jul 2019	SOWG14	Cruise Phase LTP-1= ~~Jan~~ May-Jun 2020
Jul-Aug 2019		*E2E1 = 2 STPs in LTP-12*
Oct 2019	SWT25	Cruise Phase MLP(2)
Nov 2019 TBC		Cruise Phase MTP-1 IORs
Jan 2020	SOWG15	Cruise Phase LTP-2=Jul-Dec 2020
Feb 2020	**LAUNCH**	
Apr 2020	SWT26	Cruise Phase MLP(3)
~1 May 2020		First STP for start Cruise

Placement of RS checkouts

Feb 2020 trajectory has an unusually short Cruise Phase of ~18 months.

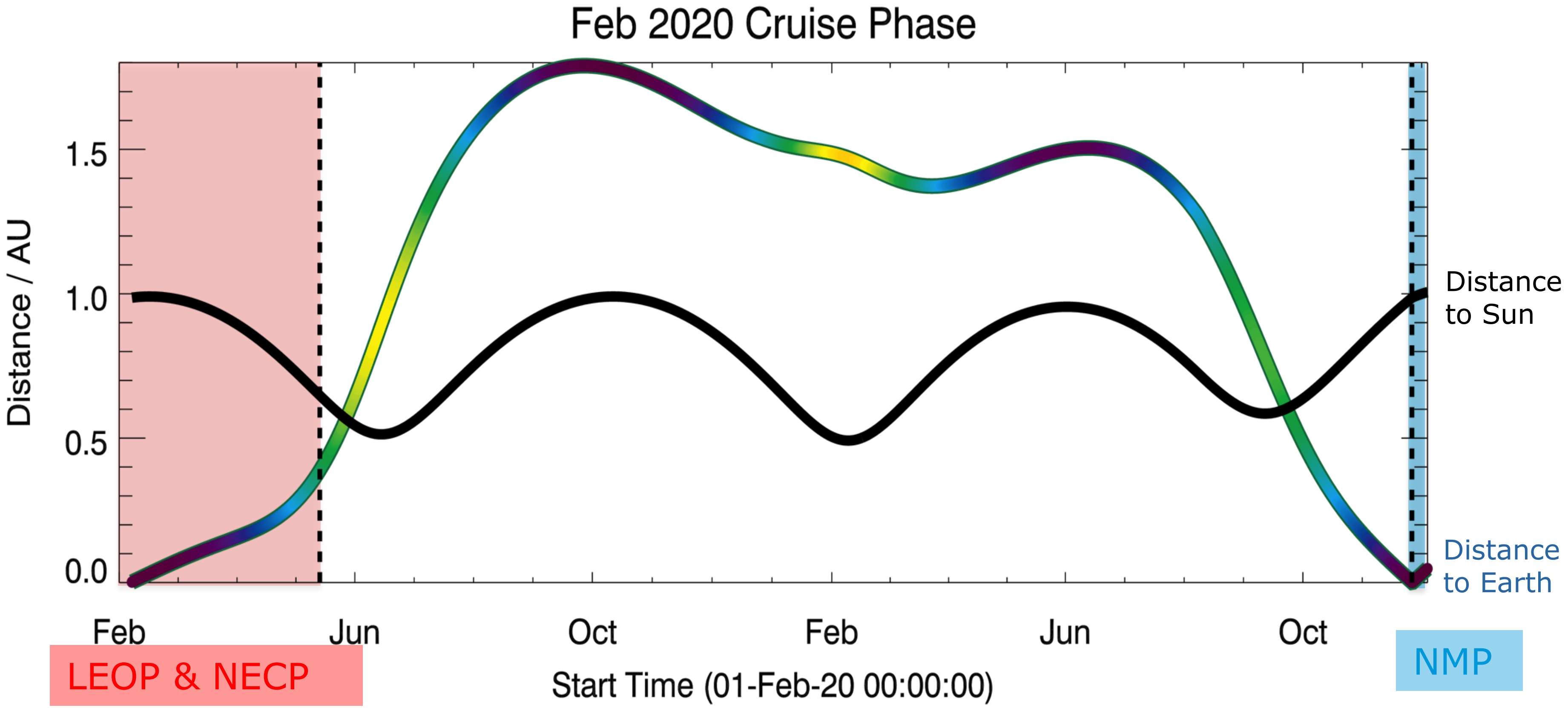
During Cruise, week-long RS payload checkout windows (RSCWs) are foreseen every 6 months, *i.e.*, 21 days in total.

- Aim of the RS checkouts = payload characterisation and calibration (incl. EMC)
- Operations have to be run off-line* (using IORs).
- Subject to agreement with MOC, there is **some** flexibility in the RSCW placement.

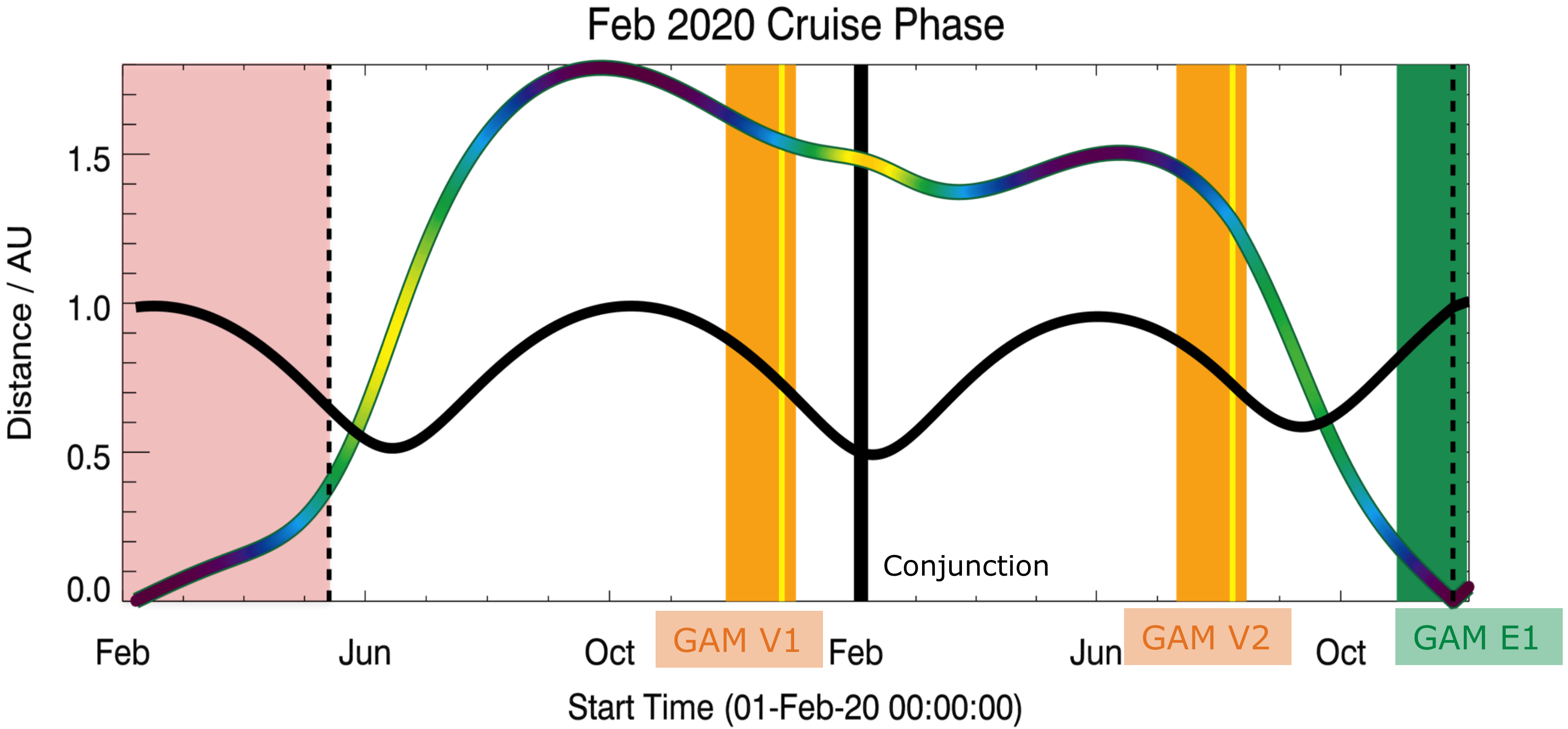
We needed to find the best opportunities during Cruise Phase, taking into account the restrictions posed by mission operations.

** Some exceptional campaigns, such as Metis stellar calibrations, can be run as engineering activities outside RSCWs.*

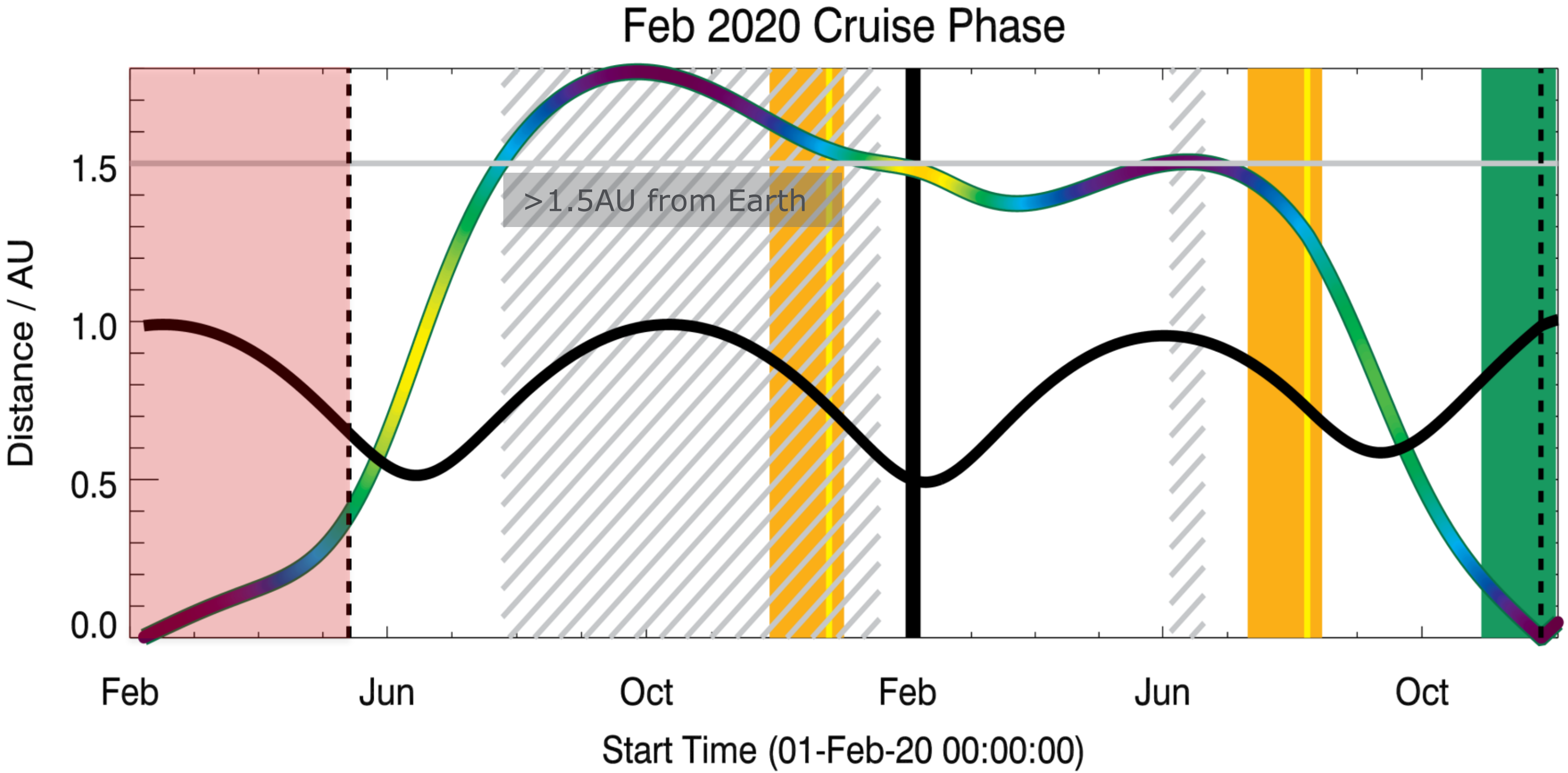
Placement of RS checkouts during Cruise



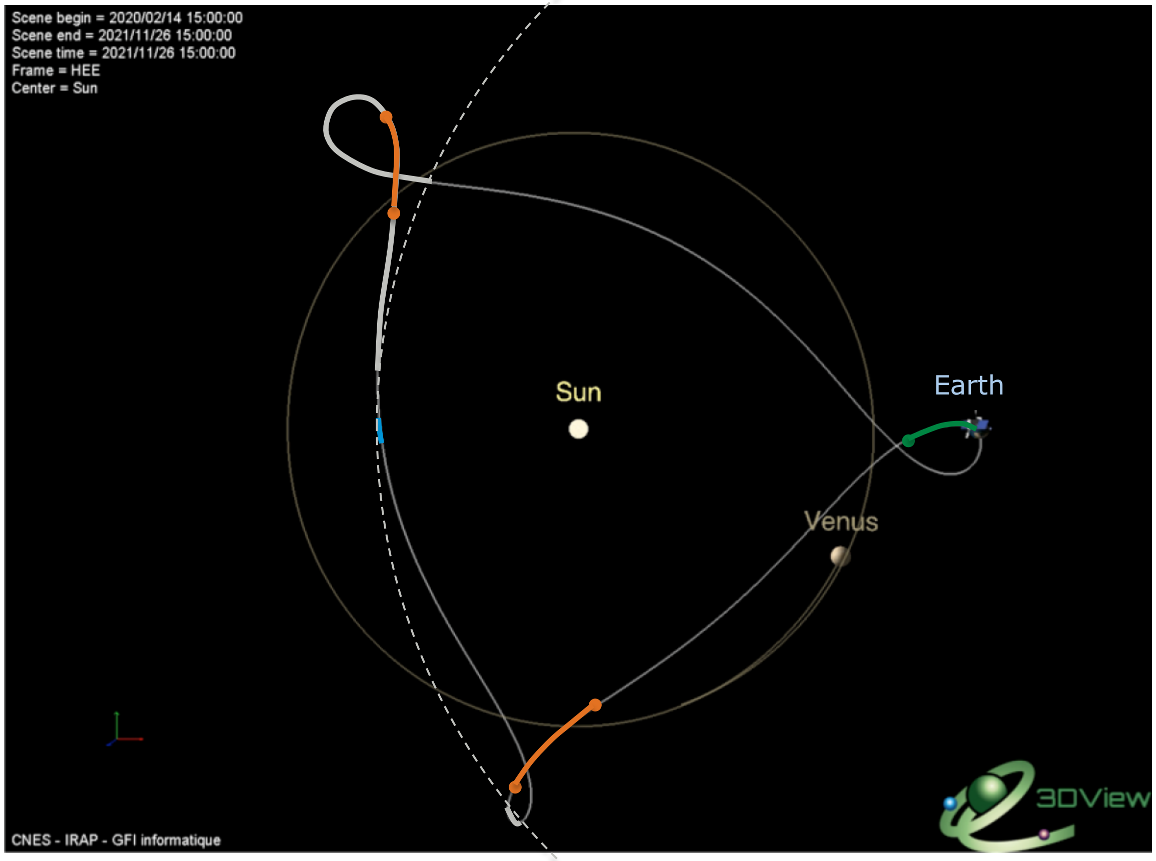
Placement of RS checkouts during Cruise



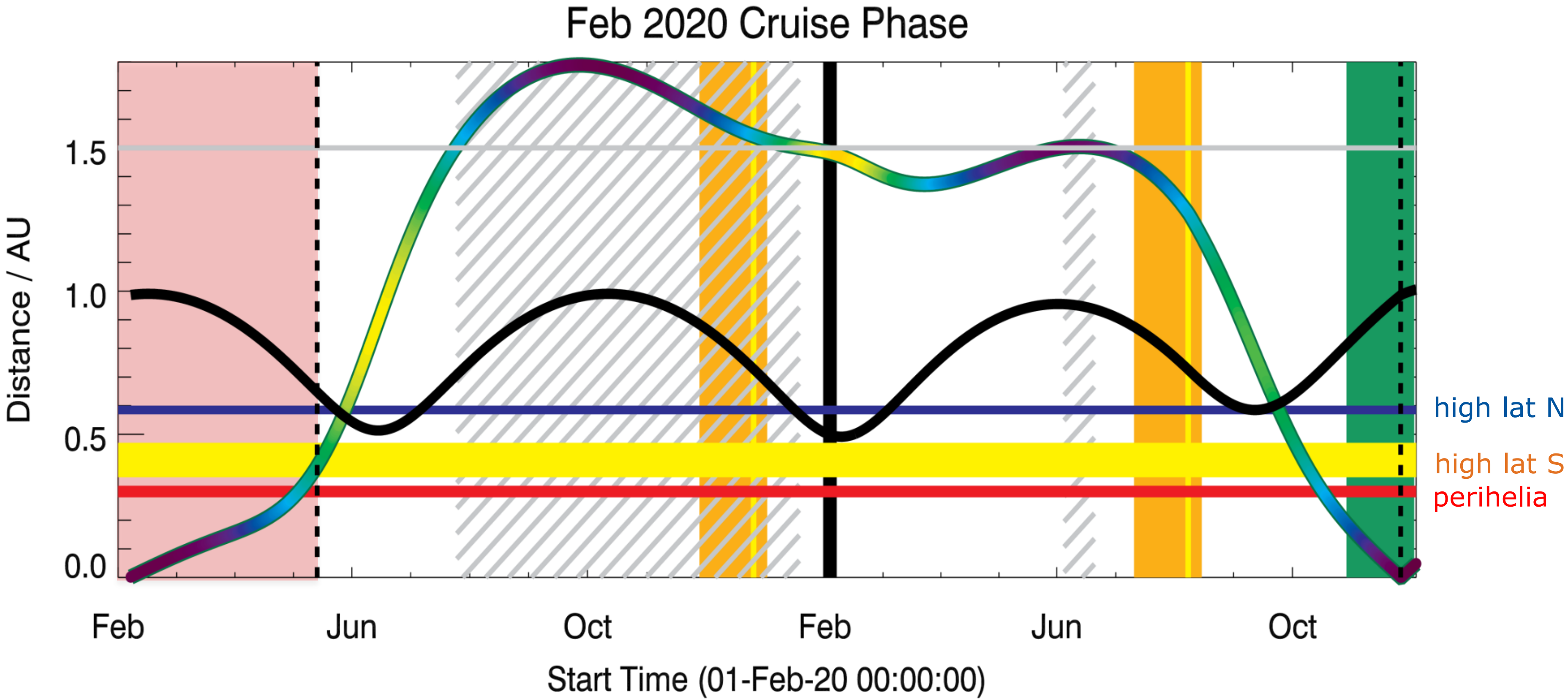
Placement of RS checkouts during Cruise



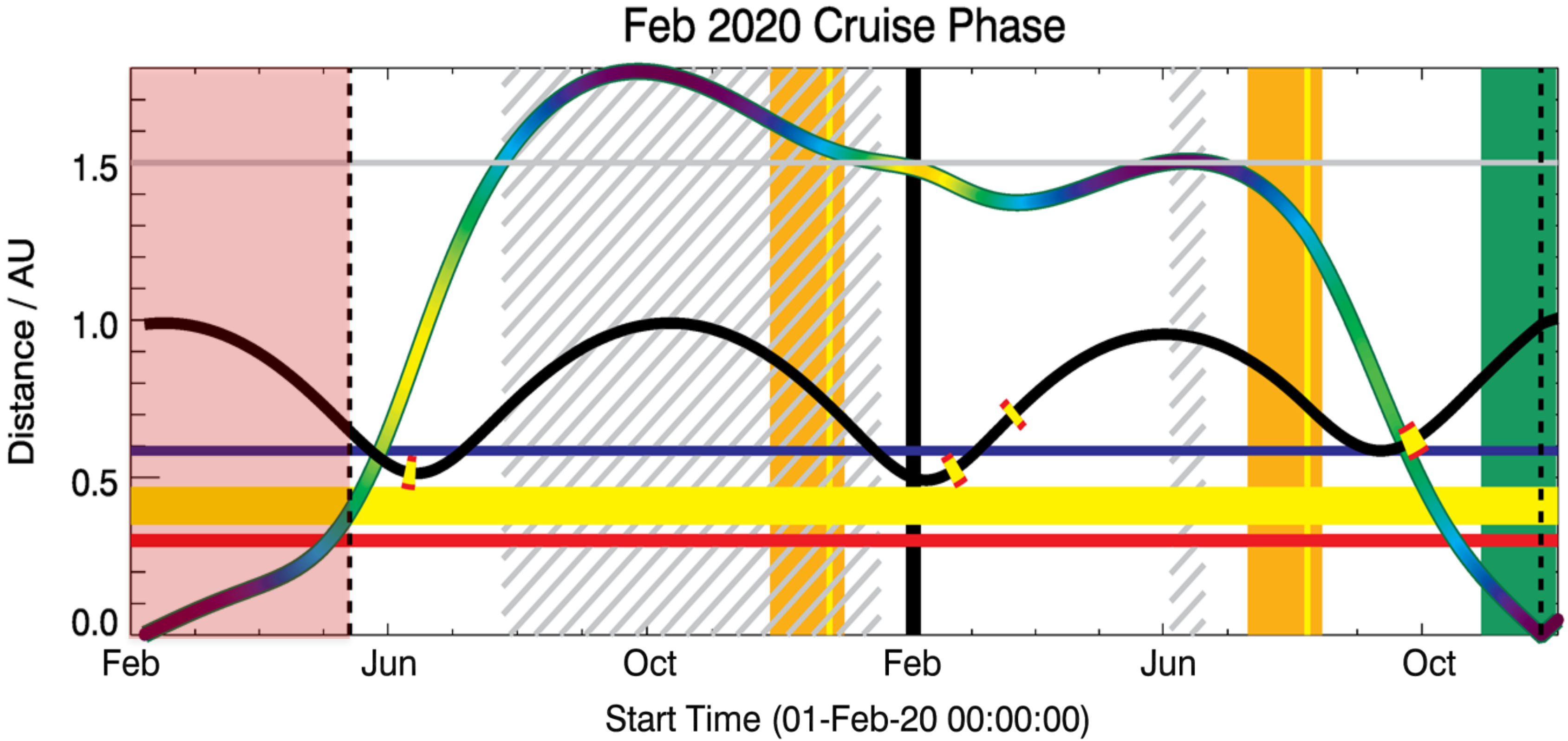
Step 1: Placement of RS checkouts



Placement of RS checkouts during Cruise



Placement of RS checkouts: decision



Placement of RS checkouts during Cruise

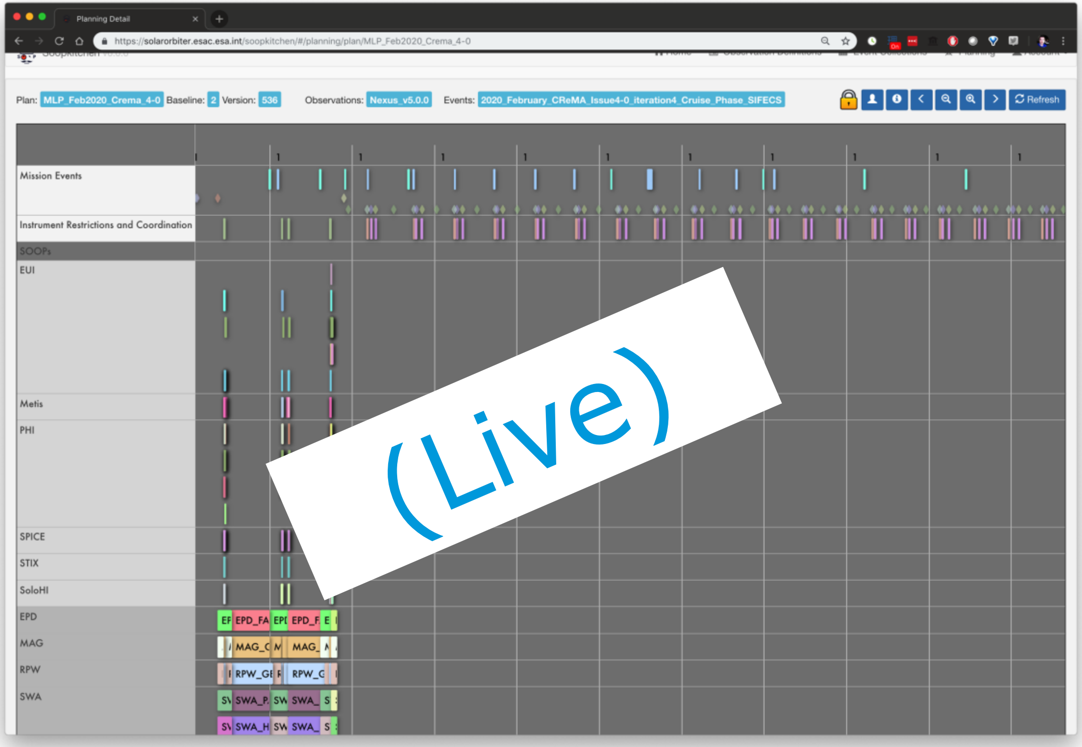
SOC's initial proposal was reviewed and a shift of the RS checkout windows were needed, considering:

- Orbital requirements for calibration/characterisation campaigns (especially different temperatures/distances)
- TM return needs
- Coordinated campaigns or inter-calibration
- Spread in time
- Reserving a slot for SSMM re-configuration for NMP, ideally before last checkout

Updated: **RSCW1:** 12–17 Jun 2020 **RSCW2:** 27 Feb–4 Mar 2021

RSCW3: 12–17 Sep 2021 **RSCW4:** 17–23 Oct 2021

SOOP Kitchen



Plan: MLP_Feb2020_Crema_4-0 Baseline: 2 Version: 536 Observations: Nexus_v5.0.0 Events: 2020_February_CReMA_Issue4-0_iteration4_Cruise_Phase_SIFECS

(Live)

Instrument commanding VSTP (i-VSTP)

CHRIS WATSON

ESAC

Background

- “VSTP” is used in two contexts
  - Pointing-VSTP (p-VSTP)
    Not the subject of this presentation
  - Instrument-commanding-VSTP (i-VSTP)
    The subject of this presentation

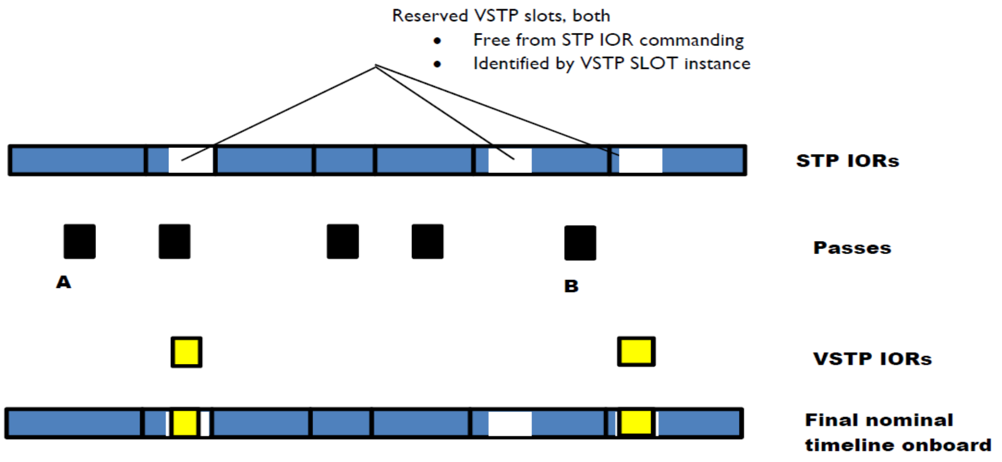
  The two are distinct. There is no synchronisation between the two

- This presentation is to highlight some updates on i-VSTP detailed in the IOR ICD

- Reminder: i-VSTP commanding is required to be
  - Pure addition of commands (no moves, no deletions)
  - Resource neutral
  - Non-critical / Non-safety-related
  - Belonging to whitelisted sequence call (agreement with MOC/SOC)

i-VSTP updates

- i-VSTP commanding is now agreed with MOC to be supported in any RSW
  - Not just “feature-tracking” RSWs, where the p-VSTP support is foreseen
- The windows for i-VSTP insertion have to be declared in advance within your STP IORs
- (and we recommend that you do this also in your MTP IORs).


Reserved VSTP slots, both
- Free from STP IOR commanding
- Identified by VSTP SLOT instance

i-VSTP updates

- Reserved slot to be free from all instrument commands at MTP/STP
    - 1 TC/second constraint => we don’t allow interleaving of VSTP commanding on top of STP commanding.
    - Plus a margin around the edges, 1 sec TBC (because the time correlation will shift slightly between the uplink of STP and i-VSTP)
    - …this needs to include the expansion to commands (not just the sequence calls explicit in the IOR). TBC details of how SOC will check this
- Max number of commands (for later insertion) declared as a parameter of each reserved slot
    - 150 TCs/day checked at MTP/STP is the sum of explicit commanding IOR, plus sum of VSTP reserved max TCs, plus one implicit command for each VSTP window (inserted by SOC, needed to “glue” the scheme together onboard)

- The i-VSTP IOR, when it comes, is checked at SOC for
  - Sequence calls belonging to whitelist
  - i-VSTP IOR fits (in time) inside its corresponding slot identified at STP
  - The number of commands is <= the declared max number of commands associated to the slot
- The i-VSTP IOR has to arrive at SOC 36 hours (TBC) before the start of the pass which completes prior to the start of the reserved slot