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# DOCUMENT

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## Solar Orbiter SPICE Operations Phase: Required Tasks

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## 1 INTRODUCTION

This document describes the tasks required to ensure the successful operation and allow scientific exploitation of the Solar Orbiter SPICE instrument. The document includes the required preparations, services and products to achieve these tasks.

The current SPICE instrument consortium is contractually responsible for the development of SPICE up to and including successful commissioning [1]. It is necessary, however, to set up an entity for the SPICE operations phase, hereafter called SPICE Operations Team, before launch so its members can participate in the instrument testing and commissioning activities to ensure a smooth operational phase following the successful commissioning of the instrument.

## 2 SCOPE OF WORK

As baseline, the remote-sensing instruments of Solar Orbiter, including SPICE, will acquire data during three 10-day remote-sensing windows per orbit (orbital period: 150-180 days) [1,2]. Due to the considerable variation of spacecraft (S/C)-Earth distances, the telemetry rate will vary by more than a factor 20 throughout the mission. As a result, the data latency will also vary strongly; the requirement is to receive data within one orbital period of acquisition. Given the size of the spacecraft's on-board mass memory, this in turn requires long-term science operations planning. At the same time, the inherent dynamics of the Sun require updates of the S/C fine-pointing with short turn-around times — down to a granularity of 24h during Very-Short-Term-Planning (VSTP) cycles — to ensure tracking of observational targets such as active regions [3,4].

To fulfil the Solar Orbiter mission's science objectives [2], operations support for the SPICE instrument has to be provided. This requires the following top-level tasks to be performed:

- Planning of SPICE operations and providing operational inputs to ESA, as well as providing support to the Science Working Team (SWT) and Science Operations Working Group (SOWG) so that operations of all Solar Orbiter instruments are carried in a coordinated fashion.
- Providing ESA with a data processing pipeline for the production of SPICE low latency data at the SOC so these data can be used for the planning of Solar Orbiter operations.
- Setting up and operating a data pipeline to process raw telemetry (TM) into calibrated data products and deliver these data products to ESA.
- Maintaining the SPICE instrument, including monitoring and troubleshooting instrument health and safety.
- Providing software and support to the scientific community to work with SPICE data.

The tasks cover two functional groups, the first related to the actual operation of the instrument, the second to allow scientific exploitation of the data by the scientific community. The required tasks can also be divided into provisioning of services and producing the software tools required to



provide those services. Below, tasks are labelled with the categories "services" (e.g. carrying out science planning activities) and "products" (e.g. software).

*All software products are to be provided to the ESA Science Operations Centre (SOC).*

The SPICE Operations Team shall operate the instrument through the nominal interfaces and planning products starting from the Cruise Phase (CP). As a consequence, part of the preparatory work shall be performed and the services/products tested well before the start of CP.

### **3 TASKS REQUIRED FOR THE SPICE PRE-LAUNCH PHASE**

The following tasks are required before launch in preparation of the SPICE Operations Phase.

#### **3.1 SPICE-to-Science Operations Centre (SOC) and SPICE-to-Mission Operations Centre (MOC) interfaces**

##### **3.1.1 *[Service] Support design and implementation of SPICE-to-SOC and SPICE-to-MOC interfaces for science planning***

The SPICE Operations Team shall support the design and implementation of SPICE-to-SOC and SPICE-to-MOC interfaces for science planning.

##### **3.1.2 *[Service] Support design and implementation of SPICE-to-SOC and SPICE-to-MOC interfaces for data retrieval and archiving***

The SPICE Operations Team shall support the design and implementation of SPICE-to-SOC and SPICE-to-MOC interfaces for data retrieval and archiving.

##### **3.1.3 *[Service] Support SOC in building and maintaining a SPICE instrument model***

The SPICE Operations Team shall support the SOC in building and maintaining a SPICE instrument model (in software). The SPICE instrument model shall describe and model instrument modes and associated resource usage, as well as instrumental constraints.

##### **3.1.4 *[Product] Instrument database (DB) and Flight Operations Plans (FOPs)***

The SPICE Operations Team shall deliver the instrument database (DB) and Flight Operations Plans (FOPs) to the MOC.

##### **3.1.5 *[Product] Instrument Operation Requests (IORs)***

The SPICE Operations Team shall deliver Instrument Operation Requests (IORs) to the SOC. Deliver representative IORs to SOC for testing of the SOC science operations planning system.



## **3.2 System-Level Pre-Launch Tests**

### **3.2.1 *[Service] Support pre-launch operational rehearsals, System Verification Tests (SVTs), System Operations Verification Tests (SOVTs) involving the Science Ground Segment***

The SPICE Operations Team shall support pre-launch operational rehearsals, System Verification Tests (SVTs), and System Operations Verification Tests (SOVTs) involving the Science Ground Segment.

## **3.3 SPICE User Manual**

### **3.3.1 *[Service] Update and maintain SPICE User Manual***

The SPICE Operations Team shall update and maintain the SPICE User Manual. The SPICE User Manual shall be maintained throughout all mission phases, starting pre-launch, including definition of data products and data formats, instrument's operational constraints, EMC aspects and data management.

## **4 TASKS REQUIRED FOR THE OPERATION OF SPICE**

These products/services, required for the operation of the instrument, shall be available in “pre-release” form 6 months prior to launch for testing with the instrument simulator. They must be available in full release form 3 months before the end of the NECP.

## **4.1 SPICE Science Operations Planning at Mission-Level**

### **4.1.1 *[Service] Support science operations planning by providing support to SWT and SOWG***

The SPICE Operations Team shall provide support to the Solar Orbiter Science Working Team (SWT) and Science Operations Working Group (SOWG) to establish mission-level science priorities and operations plans; establish instrument-level operations plans; coordinate joint operations with other instruments.

## **4.2 SPICE Observing Sequences**

### **4.2.1 *[Service] Define, design and test observing sequences***

The SPICE Operations Team shall define, design and test individual observing sequences (traditionally called ‘studies’). An initial set of studies, sufficient to cover the SAP during the first few 10-day remote-sensing windows, shall be prepared and tested on the instrument simulator well before the first remote-sensing window of the mission. Subsequent study modifications and new studies are to be generated as the mission progresses and are typically to be delivered before the Long Term Planning of the period in which the new studies will be used.

#### **4.2.2 [Product] Study generator**

The SPICE Operations Team shall provide and maintain a Study Generator tool. The Study Generator is a software tool to design studies, which will subsequently be run on the instrument. The output from this tool defines all required instrumental parameters (slit, spectral windows, spatial and spectral resolution, raster area, etc.) and is written into a study database. This tool shall be able to estimate the instrument performance and e.g. telemetry requirements for various exposure conditions (e.g. quiet Sun, active region, coronal hole, off limb, flare) to help the study designer choose the raster and/or study parameters. Although the tool itself will most likely be operated by means of a graphical user interface, it must also contain well-defined/documented lower-level routines/APIs to access the study definitions, to be used by, e.g., the telemetry processing pipeline.

#### **4.2.3 [Product] Instrument simulator**

The SPICE Operations Team shall provide an instrument simulator. The Instrument simulator is an environment – implemented in either hardware or software – to test the studies and the timeline. The purpose of testing is to verify the correct study definitions and plan durations, telemetry rates, and that all parameters are within the safety margins.

#### **4.2.4 [Service] Operate and maintain instrument simulator**

The SPICE Operations Team shall operate and maintain the instrument simulator.

### **4.3 Planning of SPICE instrument operations**

#### **4.3.1 [Service] Planning of instrument operations**

The SPICE Operations Team shall plan instrument operations in line with Sect. 4.1.1; define observing plan timelines, provide planning support before and during the three baselined remote-sensing windows per orbit; generate and deliver IORs to the SOC, starting at CP. This task also includes potential re-planning based on low-latency (LL) data and selection of packets to be downlinked.

#### **4.3.2 [Product] Timeline Planning Tool**

The SPICE Operations Team shall provide a timeline planning tool. This tool is required to assemble a daily observing plan based on studies previously defined by the study generator. Integration with a field-of-view visualizer tool will be of added value. This tool shall be able to include data from other instruments and other missions to help select fine-pointing within the SPICE full field-of-view (which is fixed by S/C pointing). This tool shall also allow the definition of raster mosaics. It shall monitor and output the resource usage (power, TM) of the observing plan and help the designer to define a plan within the available resource envelope. As with the Study Generator, this tool must contain well-defined/documented lower-level routines/APIs for access to the timeline details from within the telemetry pipeline.

#### **4.3.3 [Service] Operate the Timeline Planning Tool**

The SPICE Operations Team shall maintain and operate the timeline planning tool.



## 4.4 Commanding the SPICE Instrument

The actual commanding of the SPICE instrument is carried out by the Solar Orbiter MOC, based on consolidated Payload Operations Requests (PORs) submitted by the SOC [4]. The PORs are the consolidated set of Instrument Operations Requests (IORs) provided by all the Instrument Teams, clear of conflicts and mission constraints. For this, the following tools are required:

### 4.4.1 [Product] Instrument Operations Request (IOR) generator

The SPICE Operations Team shall provide an Instrument Operations Request (IOR) generator. This is a software tool to convert the planning timeline into IORs, which form the routine planning input to the SOC. As input, the IOR generator requires a planning skeleton file, an instrument database and an XML schema.

For reference, Table 1 relates mission-planning cycles of different levels with planning products and required software (sections 4.1 to 4.4). The planning products are, from long-term to short-term planning:

- The mission-level Science Activity Plan (SAP), authored by the Project Scientist with support from the SWT and SOC,
- Solar Orbiter Operations Plans (SOOPs), consolidated by the SOWG to carry out observations in line with the mission's science goals (as agreed at SWT level). The SOOPs provide detailed information on observations, typically coordinated between several instruments and following a well-defined template issued by the SOC (similar to SOHO “campaigns”),
- Instrument Operations Requests (IORs), which form the routine planning input to the SOC,
- Pointing Requests (PTRs), which are submitted by the SOC to the MOC.

Planning level	Planning body	SPICE entity	Planning product	SPICE required software
Mission level	SWT	SSC	SAP	None
Long Term Plan	SOWG	SPICE Ops Team	SOOPs	Study generator Timeline planner with internal pointing
Medium Term Plan	Instrument Teams	SPICE Ops Team	IORs	IOR generator Timeline planner with internal pointing
Short Term Plan	Instrument Teams	SPICE Ops Team	IORs	IOR generator Timeline planner with internal pointing LL data pipeline
Very Short Term	SOC with input from SOWG representative	SPICE Ops Team representative	PTRs Delta-IORs <sup>1</sup>	LL data pipeline Internal pointing tool

<sup>1</sup> At VSTP, instrument teams can send so-called delta-IORs that allow last-minute parameter updates that do not alter resource usage. This service is optional, the rules and implementation details are described in [RD6].



Table 1: Relations between mission planning levels with planning products and required software (cf. sections 4.1 to 4.4).

## 4.5 Selection of Downlink Packets

In certain situations, it may be desirable to select certain time periods/studies for prioritised downlinking. These decisions will be based on quick-look data visualisation.

### 4.5.1 [Service] Selection of downlink packets

The SPICE Operations Team shall provide the SOC with selective downlink requests via the IOR interface based on their analysis of low latency data (SPICE and other instrument data).

## 4.6 Processing of telemetry for operational purposes

In particular during VSTP periods, reliable near-real-time handling of telemetry for production of lower-level data products (Level LLo1, see definition in [RD5]) must be available, to allow adjustments of the observation plans/study details based on recent data after assessing the appropriateness of the previously used studies.

The following data processing pipelines are foreseen:

1. Operational low-latency data pipeline run at SOC with software provided by the SPICE operations team.
2. Science Data processing pipeline run by the SPICE operations team at their premises to produce all levels of science data.

### 4.6.1 [Product] Operational telemetry pipeline up to Level LLo1

The SPICE Operations Team shall provide an operational telemetry pipeline up to Level LLo1. The operational low-latency data pipeline is to be operated within the SOC for planning purposes. It must consist of software modules to retrieve telemetry and produce files from science data.

The operational pipeline does not have to calibrate the data or to create higher-level products (e.g. robust velocity/line width maps). The operational pipeline must make it possible to assess e.g. signal to noise ratios and to detect “interesting” features in the observations (or lack thereof), to facilitate re-planning and/or redefinition of observing programs. Thus some preliminary/approximate processing *might* be required (e.g. flat-fielding and fixed-pattern removal). The output data from the low-latency pipeline shall be delivered in FITS files and shall follow the data format described in [RD5]. The pipeline software shall be provided in line with [RD7].

All output data products (science data files, HK and AUX files) will be catalogued to enable simple searches and browsing.

The default data levels, as defined in [RD3], are listed in [RD8].



#### **4.6.2 [Product] Science data decompression software**

The SPICE Operations Team shall provide science data decompression software. In order to produce science data files, most of the science telemetry will need to be decompressed. This process will be an integrated part of the pipelines, but should be considered a separate module with a well-defined/documented API to the decompression software provided under the SPICE development phase contract.

#### **4.6.3 [Product] Science-oriented quick-look/visualising software**

The SPICE Operations Team shall provide quick-look/visualising software, complementary to the operational low-latency data-display tool that will be implemented by the SOC for the whole payload. This software will be required to visualize the outputs of the low-latency telemetry pipeline, and to communicate with the pointing tool, to show the origin of specific observations. This software should allow inspection of both science data and HK/AUX data, although not necessarily integrated into a single package.

#### **4.6.4 [Product] Catalogue tools**

The SPICE Operations Team shall provide tools to browse through the data files produced by the operational pipeline, interfacing with (or integrated with) the operational quick-look software.

### **4.7 Monitoring instrument health and safety**

#### **4.7.1 [Service] Monitoring instrument health**

The SPICE Operations Team shall provide monitoring of instrument health based on housekeeping/engineering data. This includes all instrument subsystems. Will use previously mentioned products, e.g. catalogue tools & quick-look/visualizing software. A Health and safety monitoring software tool will be procured as part of the SPICE hardware development contract.

#### **4.7.2 [Service] Troubleshooting of instrument anomalies**

The SPICE Operations Team shall perform troubleshooting of instrument anomalies and data anomalies, including related communication with SOC, MOC and the user community. Engineering experts shall provide on-call support to SOC and MOC for all major subsystems: optical, thermal, mechanical, detector assembly, electronics box, and flight software.

### **4.8 Instrument Performance**

#### **4.8.1 [Service] Monitor and optimise instrument performance**

The SPICE Operations Team shall monitor and optimise instrument performance, through checks on HK, AUX science and engineering data. Provide input for maintaining instrument on-board software (Sect. 4.9) and for updating the calibration and analysis software (Sect. 5.1) as needed.

This includes design and scheduling of instrument operations/engineering studies required to optimise performance, in particular with respect to adjustments affecting e.g. pointing



accuracy/drifts, focus, sensitivity/degradation, dark rate, fixed patterning and flat field based on changes in instrument performance.

#### **4.8.2 [Product] Tools for analysis of instrument performance**

The SPICE Operations Team shall provide tools for analysis of instrument performance.

### **4.9 Instrument on-board software maintenance**

#### **4.9.1 [Service] Maintain instrument on-board software**

The SPICE Operations Team shall develop software patches and carry out on-board software updates as required.

## **5 TASKS REQUIRED TO ALLOW SCIENCE EXPLOITATION OF SPICE DATA: SCIENCE DATA PROCESSING AND CALIBRATION**

### **5.1 Data calibration for science use**

#### **5.1.1 [Service] Establish and maintain calibration data**

Based on the output from the operational pipeline, and other external (cross-calibration) sources, the SPICE Operations Team shall establish and maintain the necessary routines and data for flat-fielding, background/dark subtraction, radiometric calibration, geometric corrections, wavelength calibration, etc.

#### **5.1.2 [Product] Software module to apply data calibration**

The SPICE Operations Team shall provide a Software module to apply data calibration. This software module is to be used by the telemetry pipeline to produce Level-2 data products from Level-1 data.

### **5.2 Level-0/1/2/3 Science FITS Files**

#### **5.2.1 [Service] Produce Level-0/1/2/3 Science FITS files**

The SPICE Operations Team shall produce Level-0/1/2/3 Science FITS files. This service requires the following software products, effectively an extension of the operational telemetry pipeline. All data products will be catalogued.

#### **5.2.2 [Product] FITS file formatter**

The SPICE Operations Team shall provide a FITS file formatter. In order to produce FITS files conforming to community standards (e.g. VO-compatible, with proper WCS metadata) as well as conforming to [RD8] and SPICE-specific standards, a general tool to write higher-level data to FITS files should be considered a separate software product.



### **5.2.3 [Product] Level-0 FITS file generator**

The SPICE Operations Team shall provide a Level-0 FITS file generator. This software will take the decommutated, decompressed raw data from the science pipeline and produce FITS files containing those data. Metadata will only be the information that was in the telemetry packets themselves, (*i.e.*, not from external sources).

### **5.2.4 [Product] Level-1 FITS file generator**

The SPICE Operations Team shall provide a Level-1 FITS file generator. This software will take the outputs from the operational pipeline (both science and HK/AUX data) and collect the necessary metadata from the timeline and study definition databases in order to produce official Solar Orbiter SPICE Level-1 FITS files.

### **5.2.5 [Product] Level-2 FITS file generator**

The SPICE Operations Team shall provide a Level-2 FITS file generator. This software will use the Level-1 files (whether in FITS format or IDL save files) and apply the calibration software (5.1.2) in order to produce calibrated Level 2 files using the general file formatter.

### **5.2.6 [Product] Level-3 FITS file generator**

The SPICE Operations Team shall provide a Level-3 FITS file generator. SPICE Level-3 FITS files will contain velocity/intensity/line width maps. These products have to be derived from Level-2 data by fitting line profiles to the data. The software to derive these products will have to be as automated as possible. However, all automatically produced line fits/analyses of such data sets will have to be subject to verification before being used for publication.

### **5.2.7 [Service] Deliver all data products to the Solar Orbiter archive**

The SPICE Operations Team shall deliver Level-0, -1, -2, and -3 FITS files and corresponding HK and AUX files to the Solar Orbiter archive.

## **5.3 Software required for using SPICE data**

The following software is required for using SPICE data:

### **5.3.1 [Product] Preparation/calibration software**

The SPICE Operations Team shall provide software to prepare Level-1 data for science analysis, *i.e.* to convert data read in from Level-1 files into Level-2 data by applying standard calibrations. This is to be used when starting off with Level-1 FITS files, allowing the user to *e.g.* modify calibration parameters or skip certain steps in the calibration process. This software is identical to that used by the pipeline for the same functionality and shall be made available to end users through the publicly available SolarSoft library.



### **5.3.2 [Product] Browse image converter**

The SPICE Operations Team shall provide a browse image converter, a tool to take the full-complexity science data and convert it into browse images and movies representing what SPICE saw.

### **5.3.3 [Product] Spectroscopy quick look and data analysis tools**

The SPICE Operations Team shall provide spectroscopy quick look and data analysis tools. These are tools to inspect SPICE data (viewing both spectral images and line profiles), and to assist in the analysis of SPICE data, e.g. by extracting line intensity, width and plasma velocity from line profiles.

### **5.3.4 [Product] Archived housekeeping tools**

The SPICE Operations Team shall provide archived housekeeping tools, i.e. software to inspect instrument housekeeping data over the course of the mission, for example to look at long-term trends.

### **5.3.5 [Service] Pointing visualization**

The SPICE Operations Team shall support a generic Solar Orbiter tool to visualise where SPICE was pointing at any given time, incorporating images from other instruments or other missions. This is related to the pointing visualization in the timeline planner. Such a tool could be coordinated and shared between instruments.

## **6 REQUIRED SOFTWARE DOCUMENTATION AND MAINTENANCE, USER TRAINING AND SUPPORT**

All software products mentioned in this document – including those that will be used internally for operations and production of higher-level data – must be accompanied by proper documentation for the intended users. All software products – including those delivered before the end of commissioning – must be maintained to ensure proper operation when actual data starts flowing and as the software environment develops (new OS versions etc.). Furthermore, an adequate level of user support must be provided. All operational software must be accompanied by the required training for those that will be using it. Training is not required for software to be used by the community, but this means that the software and corresponding documentation (user guides) for this software must be written with this in mind.

### **6.1 Support to the science community**

#### **6.1.1 [Service] Update SPICE Instrument User Guide, write software notes**

The SPICE Operations Team shall update the SPICE Instrument User Guide and write software release notes.

#### **6.1.2 [Service] Develop and maintain SPICE operations website**

The SPICE Operations Team shall develop and maintain a SPICE operations website.



### **6.1.3 [Service] Communicate with users, answer questions on data and software**

The SPICE Operations Team shall communicate with users, answer questions on data and software.

## **7 TASKS REQUIRED FOR THE SPICE POST-OPERATIONS PHASE**

### **7.1 Final calibration**

#### **7.1.1 [Service] Maintain services defined in Sect. 5.**

The SPICE Operations Team shall maintain the services defined in Sect. 5.

### **7.2 Archiving**

#### **7.2.1 [Service] Archiving**

The SPICE Operations Team shall:

- Establish final calibration of SPICE science data.
- Calibrate and produce final data sets for each of the science-processed levels (L2, L3, ...)
- Deliver final calibration (software, calibration data, documentation...) to the Solar Orbiter archive (SOAR) at SOC.
- Deliver final science data products to the SOAR.

## **8 REFERENCE DOCUMENTS**

- [RD1] Solar Orbiter Science Management Plan (SMP), SOL-EST-PL-00880
- [RD2] Solar Orbiter Science Requirements Document (SciRD), SOL-EST-RS-1858
- [RD3] Solar Orbiter Science Implementation Requirements Document (SIRD), SOL-EST-RS-4514
- [RD4] Solar Orbiter Science Implementation Plan (SIP), SO-SGS-PL-0002
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