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DOCUMENT

# Solar Orbiter SPICE Instrument Description

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# 1 INTRODUCTION

This document provides the top level description of the design of the SPICE instrument for the Solar Orbiter spacecraft.

SPICE (SPectral Imaging of the Coronal Environment) is a high resolution imaging spectrometer operating at ultraviolet wavelengths. It will address the key science goals of the Solar Orbiter mission, by providing the quantitative knowledge of the physical state and composition of the plasmas at the solar source region and investigating the links between the solar surface, corona and inner heliosphere.

The EUV wavelength region 70.2 – 105 nm observed by SPICE is dominated by emission lines from a wide range of ionized atoms formed in the Sun's atmosphere at temperatures from 10,000 to 10 million K. SPICE will remotely determine plasma density and temperature, flow velocities, the presence of plasma turbulence and composition of the source region plasma. It will be observing, at all latitudes, the energetics, dynamics and fine-scale structure of the Sun's magnetized atmosphere.

SPICE will provide understanding of the linkage between in-situ measurements of solar wind streams using the suite of plasma instruments on Solar Orbiter and remote imaging of their source regions on and near the Sun.

# 2 REFERENCE DOCUMENTS

RD 1. SPICE Optical Unit Optical Design Description, SPICE-RAL-DD-0001, issue 4.0
RD 2. SPICE Scientific Performance Report, SPICE-RAL-RP-0002, issue 3.0
RD 3. Solar Orbiter Mission: In-Flight Contamination Monitoring System (CMS): Implementation, Responsibilities and Concept of Operation, SOL-EST-TN-13990, to be issued
RD 4. SPICE Budgets Report, SPICE-RAL-RP-0001, issue 5.0
RD 5. SPICE Instrument User Manual, SPICE-RAL-MAN-0001, issue 8.0
RD 6. Solar Orbiter Science Requirements Document, SOL-EST-RS-1858, issue 2.0, 29/10/2010

# 3 ACRONYMS LIST

| | |
|---|---|
| APS | Active Pixels Sensor |
| CFRP | Carbon Fibre Reinforced Plastic |
| DA | Detector Assembly |
| FEE | Front End Electronics |
| FSW | Flight Software |
| HAS2 | High Accuracy Startracker 2 |
| MCP | Micro-Channel Plate |
| SCM | Slit Change Mechanism |
| SDM | SPICE Door Mechanism |
| SEB | SPICE Electronics Box |
| SFM | Scan Focus Mechanism |
| SOU | SPICE Optics Unit |

# 4 INSTRUMENT SCIENCE DESCRIPTION

## 4.1 Scientific objectives

SPICE was included in the model payload with the objective of providing quantitative knowledge of the physical state and composition of the plasmas at the solar source region and investigating the links between the solar surface, corona and inner heliosphere. As such, the measurements provided by the instrument answer many of the key scientific questions to be addressed by Solar Orbiter. Full details can be found in RD 6, and are summarised below.

| No. | Science Question | Required SPICE Observations | SPICE Measurement Objective |
|---|---|---|---|
| 1 | 2.1.1 What are source regions of the solar wind & heliospheric magnetic field? | Composition of solar wind source regions | Determine FIP and Q/M effect in solar wind source regions |
| 2 | | spectral images of chromosphere & corona | Identify feature types that give rise to the solar wind by correlating Doppler shift to structure and composition |
| 3 | 2.1.2 What mechanisms heat and accelerate the solar wind? | High-res spectral images of loops & evolving structures | Evolution of source regions on time scale of network evolution. Measure outflow (from Doppler shift) and correlate with structure type. |
| 4 | | Wave propagation and heating | Line width, Doppler shift, & Intensity time series observations |
| 5 | | Off-limb observations of non-thermal velocities | Off-limb line profile measurements in H Ly-β & O VI up to 1.15Rs @0.3 AU |
| 6 | 2.1.3 What are the sources of solar wind turbulence and how does it evolve? | images of source regions in Doppler-broadened lines | Identify jets, heating, and turbulence; correlate to network evolution |
| 7 | 2.2.1 How do CMEs evolve through the corona and inner heliosphere? | Map CME source location, expansion, rotation and composition | Identify areas of coronal dimming; Measure velocities in the erupting CME; Establish identity of plasma in visible parts of a proto-CME on-disk and connect (via compositional correlation) to higher altitudes and in situ measurements |
| 8 | 2.2.2 How do CMEs contribute to solar magnetic flux and helicity balance? | Map source regions to in-situ properties magnetic connectivity, polarity, & helicity | Establish identity of plasma in visible parts of a proto-CME on-disk and connect (via compositional correlation) to higher altitudes and in situ measurements |
| 9 | | High-resolution coronal and chromospheric images | Establish identity of plasma in different parts of a proto-CME and connect (via compositional correlation) to higher altitudes and in situ measurements |

| | | | |
|---|---|---|---|
| 10 | 2.3.1 How and where are energetic particles accelerated at the Sun? | UV & X-ray imaging of loops, jets, flares, and CMEs | Identify jets and reconnection sites that give rise to SEPs |
| 11 | 2.3.2 How are energetic particles released from their sources and distributed in space and time? | Timing, location and intensity profiles of VUV emissions in relation to energetic particle intensities at a wide range of energies | Provide thermodynamic characteristics of plasmas in the SEP sources. Establish identity of plasma supplying SEPs and connect (via compositional correlation) to higher altitudes and in situ measurements |
| 12 | 2.4.1 How is magnetic flux transported to and re-processed at high solar latitudes? | High-resolution images of small-scale magnetic features at the poles | Determine evolution of magnetized regions on the time scale of network evolution, by observing evolution of the structure seen in the EUV emission and associated flows. Provide constraints on meridional circulation at high latitudes. Reveal the pattern of differential rotation in the chromospheric and transition region emission. |
| 13 | 2.4.2 What are the properties of the magnetic field at high solar latitudes? | Line-of-sight plasma flows, spatial distributions of intensities of chromospheric and transition region lines, and temperatures of polar regions | Identify feature types that give rise to the solar wind by correlating Doppler shift to structure and composition. Contribute to the investigation of the 3D structure of the inner heliosphere – study the links between the polar regions and the in-situ properties of the solar wind and the IMF. Study the response in the EUV emission to the magnetic field cancellation process during the polarity reversal. |

Table 2-1: SPICE Science goals and measurements

## 4.2 Scientific requirements and performance summary

Translating the above into specific measurement performance requirements leads to the following.

| Characteristic | Performance requirement |
|---|---|
| Spatial Resolution | ≤ 4 arcsec |
| FOV (scan range) | Minimum 4 x 10 arcmin |
| Temporal Resolution (raster cadence) | 2 min / arcmin |
| Signal-to-Noise (active regions) | ≥ 10 |
| Velocity Resolution | ≤ 5 km/s |
| Ion Species | H, C, O, Ne, Mg, Si, and Fe |
| Spectral Coverage (wavelength range) | 70.6 – 78.0 nm and 97.3 - 104.9 nm |
| Spectral Coverage (temperature range) | $10^4$ to $10^7$ K |
| Spectral Coverage (profiles / intensities) | 2 profiles, 4 intensities |

Table 2-2: Performance Requirements Summary

# 5 INSTRUMENT SYSTEM DESIGN DESCRIPTION

## 5.1 Overview

The instrument has two primary components that mount to the spacecraft, the SPICE Optics Unit (SOU) and the SPICE Electronics Box (SEB); these are linked by the SPICE Harness. The SOU contains the spectrograph optical elements (a telescope, an entrance slit, a diffraction grating, and two detectors). The SEB contains the power conditioning and command and control interface necessary to run the instrument and communicate with the spacecraft. The flight software responsible for controlling the instrument and for compression and packetisation of science data is resident in the SEB. For in-flight monitoring of outgassing and contamination SPICE will also implement two Quartz Crystal Microbalances (QCMs) with their read-out box.

## 5.2 SPICE Optics Unit (SOU)

### *5.2.1 Structure*

The SOU structure consists of a Carbon Fibre Reinforced Plastic (CFRP) and aluminium honeycomb baseplate with side walls and lids also made from CFRP panels. This is iso-statically mounted to the spacecraft panel. The structure is designed to have approximately zero CTE, therefore maintaining instrument alignment throughout the wide operating temperature range.

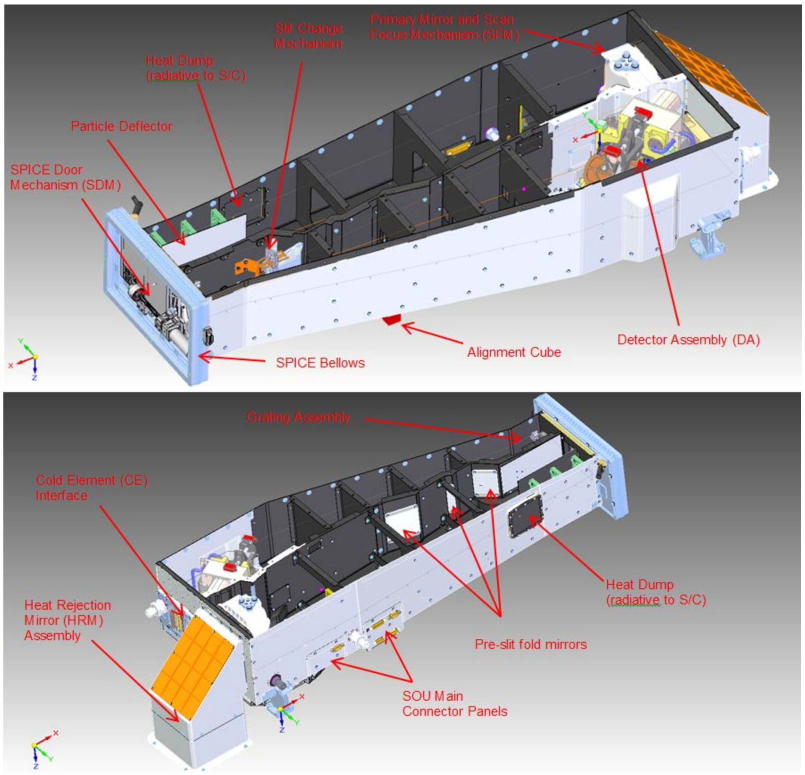


**Figure 4-1: SPICE SOU**

### *5.2.2 Optical design*

The SPICE instrument optical design is documented in full in RD 1.

The light enters the instrument through the entrance aperture, then an image is formed at the slit by the off-axis parabola mirror. The mirror off-axis distance has been increased from 45 mm to 55 mm during the phase B study in order to allow sufficient clearance between the thermal radiation beam envelopes from the full solar disc and the centre baffle wall that divides the instrument into two main compartments, the telescope side and the spectrometer side. The mirror is coated with a B4C layer that reflects a good proportion of the EUV light from the sun while allowing the majority of the visible and thermal IR energy to pass through the primary mirror and on to the heat rejection mirror behind. The primary mirror is mounted on a Scan Focus Mechanism which allows the rastering of the slit image on the sky. This scanning is done by rotation of the mirror about the centre of the front face of the mirror.

The slit defines the portion of the solar image that is allowed to pass onto a concave Toroidal Variable Line Space (TVLS) grating, which disperses, magnifies, and re-images incident radiation onto two detector arrays. The two wavebands cover the same one-dimensional spatial field, and are recorded simultaneously. The Shortwave band covers approximately 70 – 78 nm in first order diffraction; the Longwave band covers approximately 97 – 105 nm in first order diffraction.

Table 3-1 shows the instrument spatial resolution in field of view per pixel for the shortwave and longwave band, along both the length and width of the slit. The spectral resolution is also displayed in wavelength per pixel. A full derivation and explanation of these values is documented in RD 2.

| | | | |
|---|---|---|---|
| Spatial plate scale along slit | SW | 1.1 | arcsec/pixel |
| | LW | 1.06 | arcsec/pixel |
| Spatial plate scale across slit | SW | 0.979 | arcsec/pixel |
| | LW | 0.865 | arcsec/pixel |
| Spectral plate scale | SW | 0.0095 | nm/pixel |
| | LW | 0.0083 | nm/pixel |

**Table 3-1: Instrument Spatial and Spectral Resolution**

### *5.2.3 Particle Deflector*

The SPICE instrument includes a particle deflector to prevent 1 keV protons in the solar wind from reaching the telescope mirror and degrading the optical coating. The particle deflector consists of two plates with a moderate voltage applied across the plates to set up a static electric field across the optical path. This electric field effectively sweeps the 1 keV protons out of the optical path, thus protecting the mirror.

The electrostatic field will be nominally on whenever SPICE is powered. Either the SPICE Door or the Solar Orbiter heatshield feedthrough door must be closed whenever the particle deflector is powered off for extended periods of time.

### 5.2.4 *Internal Mechanisms*

The instrument contains four mechanisms:

- The SPICE Door Mechanism (SDM) which can be actuated to provide contamination protection for the entrance aperture during non-operational periods (both during ground handling and non-operational periods in flight) and as protection for the primary mirror coating from the solar wind during periods when the instrument is turned off.

- The telescope mirror is mounted to a two-axis mechanism (tilt and focus), the Scan Focus Mechanism (SFM), that is used to direct different portions of the solar image onto the selected entrance slit and to focus the telescope relative to the entrance slit.
  - The image of the Sun is repeatedly scanned across the entrance slit. During each scan the image of the Sun is stepped across the entrance slit in increments (normally equal to the selected slit width but could be sparsely sampled if science case desired), such that the region of interest is completely sampled.
  - It is also possible to operate in “sit and stare” mode where the scan mechanism is not moved and a specific slit of the sun is studied for extended periods.

- A Slit Change Mechanism (SCM) provides four interchangeable slits of different widths, any one of which can be selected depending upon the science activities to be conducted. These slits have a 2”, 4”, 6” and 30” width on the external field of view.

- A vacuum door mechanism on the Detector Assembly (DA Door). The micro-channel plate and image intensifier used to translate the incident EUV photons into visible light photons which can be detected by the detectors must be maintained either at vacuum or in <30% relative humidity during ground handling. Therefore the detector assembly contains a door mechanism which is only opened during vacuum testing on ground, and opened finally once on-orbit.

### 5.2.5 *Detector Assembly (DA)*

The SPICE Detectors consist of two independent, identical, intensified APS camera systems mounted in a common vacuum housing. Each camera consists of a HAS2 (High Accuracy Startracker 2) 1024 x 1024 x 18 micron pixel format CMOS APS with digital readout electronics fed by a KBr coated MCP intensifier.

The SPICE intensifier tubes consist of a microchannel plate (MCP) and a phosphor screen packaged in a lightweight housing. Each will provide a 30 mm diameter active area that circumscribes the sensor active area. A KBr photocathode is deposited on the front surface of the MCP to enhance response in the SPICE passbands, while remaining visible light blind. Photons absorbed by the KBr layer are converted to photoelectrons and amplified through the MCP based on the applied voltage across the MCP. The nominal MCP voltage from the high-voltage power supply is 1500 V and is programmable in flight dependent on the gain required for a particular observation.

Electrons exit the 6 μm MCP pores and are accelerated by a ~3000 V potential across a sealed proximity gap (0.5 mm) onto an aluminized phosphor screen deposited onto a fibre optic output window. Electrons are converted into a visible light image at the phosphor screen. The resulting image is transferred through a fibre optic coupler to the APS sensor. A direct bond between the fibre optic and the APS seals the APS active area and eliminates environmental contamination on the APS. The MCPs are scrubbed to stabilize the MCP gain against localized charge depletion. After scrubbing, the MCP housing is maintained as a dry atmosphere or at vacuum throughout all handling until launch.

The HAS2 sensors will be cooled within the focal plane assemblies to -20 °C when in operation to reduce dark charge and the effects of radiation damage. The APS sensors are inherently well shielded by the surrounding structures. The predicted increase in dark rate due to total ionizing dose and proton damage will not impact the science investigations. Cooling is accomplished by connecting the sensors to the cold element radiator.

## 5.3 SPICE Electronics Box (SEB)

The instrument control function will be provided by a dedicated electronics box, the SPICE Electronics Box (SEB). This provides the drive and monitoring for all mechanisms, the acquisition and processing of all housekeeping telemetry and the processing and packetisation of the science data. It controls and communicates with the detector Front End Electronics (FEE) via a SpaceWire link. The SEB also contains the SPICE Flight Software (FSW) which is responsible for all control and monitoring of the instrument, plus the processing and compression of the science data to allow the data rate and volume requirements to be achieved. A functional block diagram of the SEB is shown below.

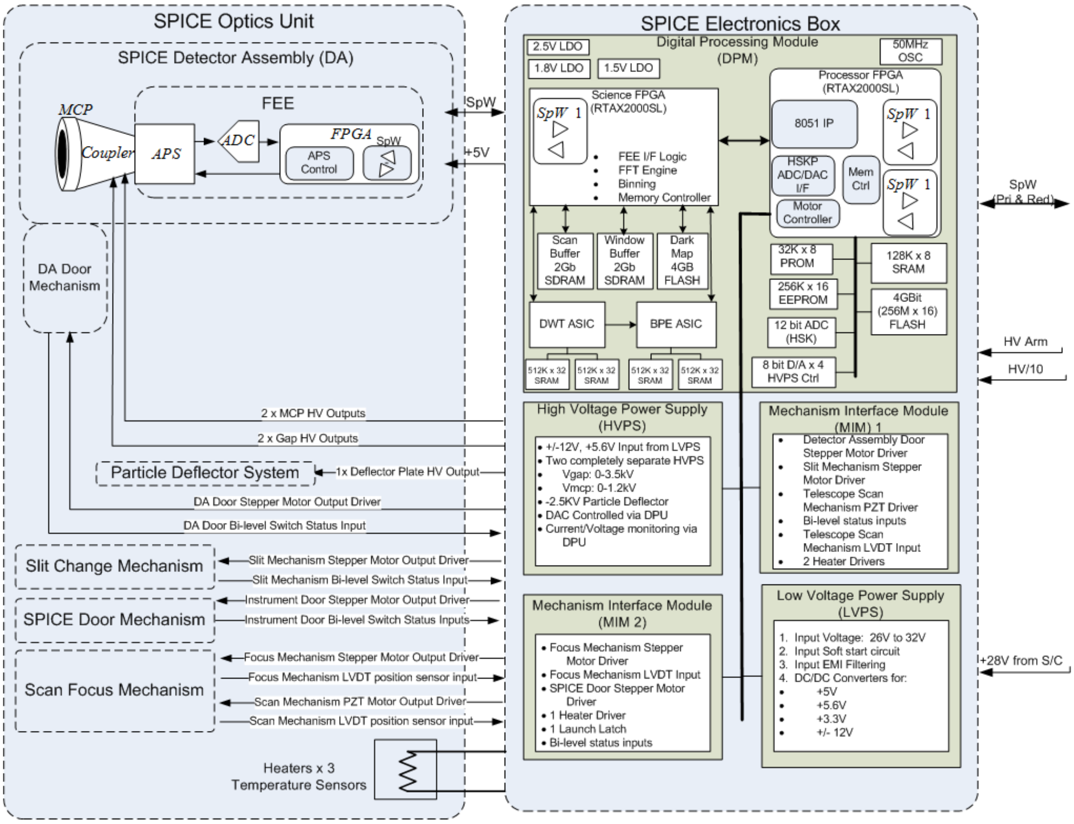


**Figure 4-2: SEB Block Diagram**

## 5.4 In-Flight Contamination Monitoring System (CMS)

See RD 3.

## 5.5 Instrument resources

SPICE is compliant with all resource allocations as defined in the Solar Orbiter Experiment Interface Requirements Document – part A (EID-A), SOL.EST.RCD.0050, issue 5.0:

- Allocated Mass: 23.60 kg (including the contamination monitoring system);
- Allocated Average Power: 30.00 W;
- Allocated Data Rate: 17.5 kbps;
- Allocated Data Storage Volume: 45.4 Gbits per orbit.

A summary of the mass, power, heat load, data rate resources required by SPICE is given in detail in RD 4.

## 5.6 Operations

For details on the SPICE in-flight operations, see RD 5.