Appendix G

Solar Orbiter SPICE
Thermal Design, Analysis and Testing

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Abstract

[1] The Spectral Imaging of the Coronal Environment (SPICE) is one of ten instruments comprising the ESA Solar Orbiter payload. The instrument, currently being built at the STFC Rutherford Appleton Laboratory, is a high resolution imaging spectrometer operating at extreme ultraviolet wavelengths. We are currently in the build phase, with thermal testing of the flight model instrument due to commence shortly.

At an orbital perihelion of just 0.28 AU, there are numerous key design challenges that must be overcome for the instrument to survive the harsh thermal environment that it will be subjected to. In the last 18 months, the instrument has already undergone considerable thermal testing to qualify the design. The results of the tests completed thus far have provided essential inputs into the existing detailed thermal model, which is constructed using ESATAN-TMS. This presentation will discuss how the thermal analysis and testing have complemented each other for this project, while also providing impressions of ESATAN-TMS from the perspective of a relatively early user.

[1] Due to severe weather conditions the author was unable to attend the workshop and present this material.

Solar Orbiter SPICE

Thermal Design, Analysis and Testing

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Science & Technology Facilities Council

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Solar Orbiter - Overview

- Scheduled to launch in 2018
- Science goals are to address how the Sun creates and controls the heliosphere
  - Achieved by observing polar regions of the Sun from as close as 0.28 AU
- Payload comprised of ten instruments:
  - Six remote sensing, including the Spectral Imaging of the Coronal Environment (SPICE) instrument
  - Four in-situ instruments
- Heatshield provides main defence against solar load
  - Contains feedthroughs for remote-sensing payload

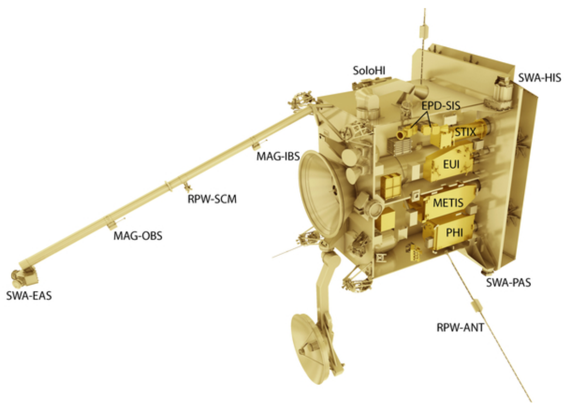

Image credit: ESA

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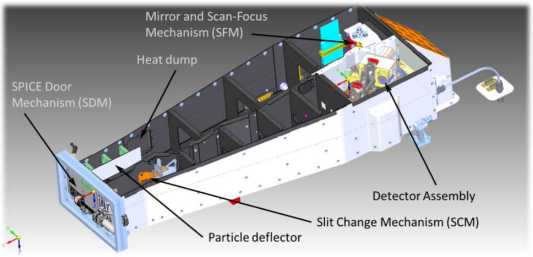
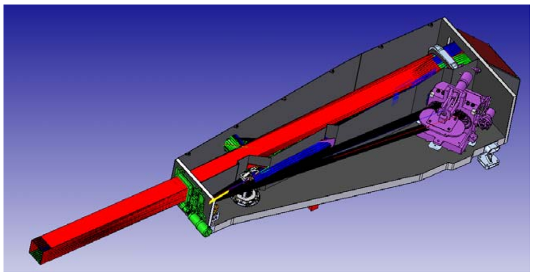
SPICE – Overview

- High resolution imaging spectrometer operating at EUV wavelengths (70.2-105 nm)
- Objective is to provide data on the plasma composition of the Sun
  - Investigate links between the solar surface, corona and inner heliosphere
- Precise optics reflect light beam to detector assembly
- Currently in build phase of project
- Instrument mechanisms being provided by collaborating organisations





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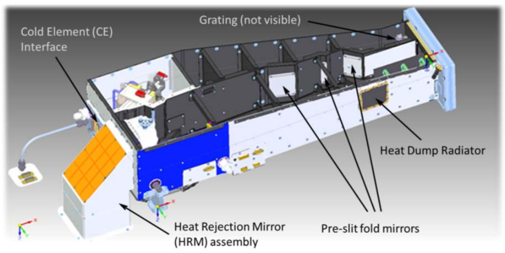
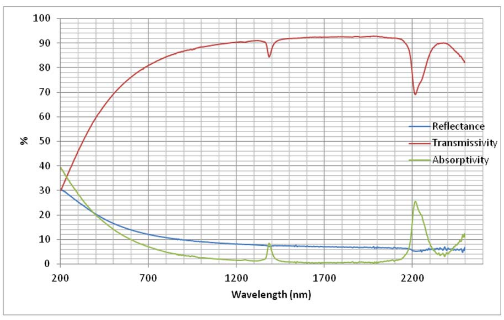
SPICE – Thermal Design

- Solar load is roughly 13 times greater than on Earth orbit
- Spacecraft heatshield blocks most incoming radiation
- Primary mirror has a 10 nm boron carbide (B_4C) coating
  - Reflective to UV radiation, but mostly transparent to visible and IR
- Secondary mirror (HRM) rejects this unnecessary load to deep space
- Only a small fraction of reflected UV load required, so pre-slit mirrors and heat dump radiator used to further reject heat
- Cold element interface maintains detectors at -20 ºC





Boron carbide wavelength dependent thermo-optical properties, data obtained by MPS

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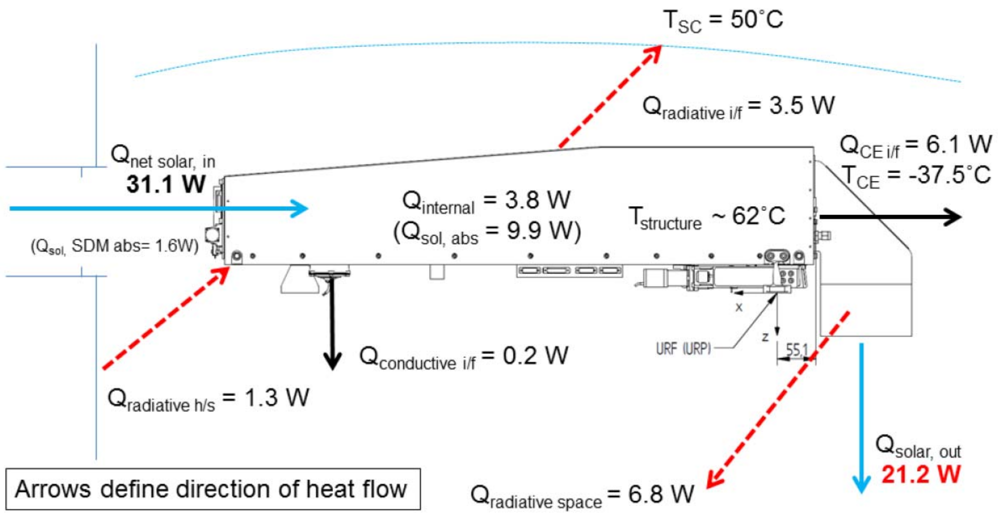
SPICE – Thermal Design



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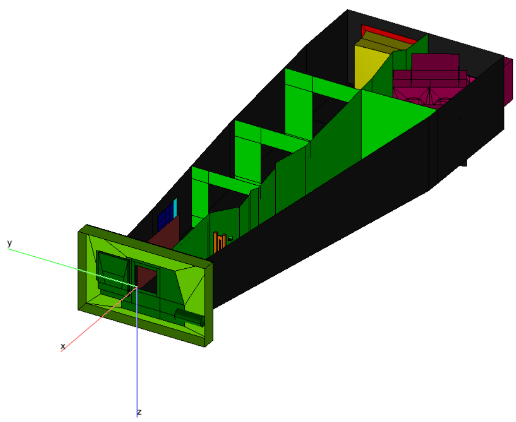
Detailed Thermal Model

- Constructed using ESATAN-TMS r7sp2
- Sub-models used for each subsystem
- Numerous configurations:
  - BOL/EOL
  - Door open/closed
  - Operational/Non-operational
- Three primary radiative cases:
  - Hot operational (0.28 AU)
  - Cold operational (0.91 AU)
  - Cold non-operational (1.5 AU)

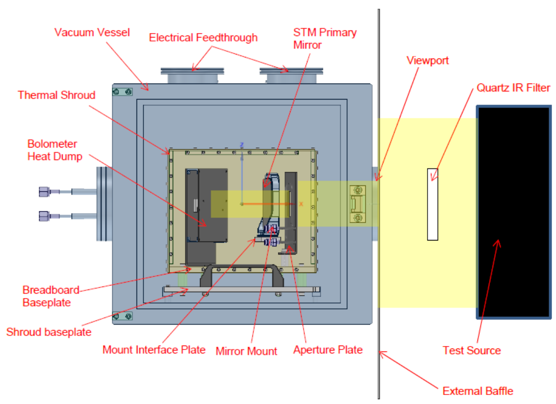


Test Objectives and Plan

- To verify the thermal design, specifically:
  - Management of solar load
  - Key internal thermal interfaces (e.g. across mirror mounts)
  - External thermal interfaces
  - Minimum and maximum temperatures
- Key tests to achieve this:
  - STM
    - High Flux Mirror Test
    - Thermal Balance Test
  - FM
    - Detector Assembly Thermal Balance Test (in progress)
    - Thermal Balance Test (to be completed)
- Thermal Vacuum Test on STM and FM to qualify the thermal design over predicted temperature range

High Flux Mirror Test

- Designed to simulate the primary mirror in the worst case hot environment
- Objectives:
  - To experimentally determine thermo-optical properties of mirror
  - Observe impact on mirror temperatures
- High intensity lamp used as the test source to provide solar-like flux
  - Intensity roughly 20% of flight load
- Heat dump positioned behind mirror
  - Heat load absorbed from the lamp is deduced by replicating temperatures using heaters
- Test completed both with and without mirror
  - Difference in values indicates transmitted heat load



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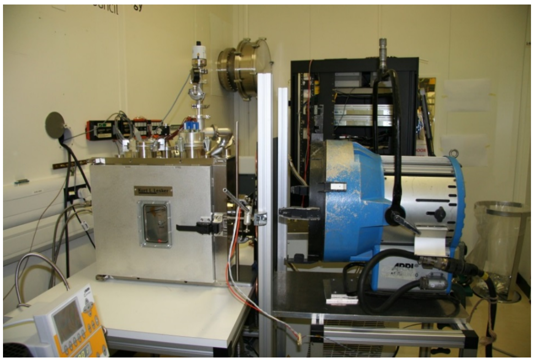
High Flux Mirror Test

- Results showed that ~80% of the incoming beam was transmitted
- Analysis of the incident spectrum show that this closely matched the expected transmission from the MPS data



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SPICE – Test Rig

- Specialised test rig built for thermal testing of SPICE, to simulate spacecraft cavity
- Fluid pipes around shroud allow interface temperatures to be simulated
- Heaters simulate heat flows from instrument to spacecraft
- Shroud is wrapped in multi-layer insulation (MLI) to minimise heat flow from vacuum chamber
- Test rig successfully completed commissioning tests prior to instrument testing

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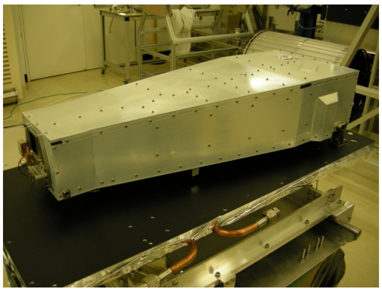
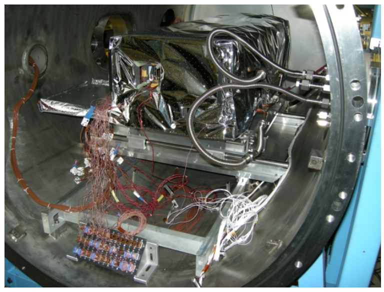
STM Thermal Balance Test

- Eight test cases in total
  - Two involving mercury lamp (less intensity than previous lamp, but more flight-representative UV spectrum)
  - Six use test heaters to simulate absorbed loads
- ‘Beam dump’ maintained at 100 K by cryocooler to simulate deep space view from heat rejection mirror
- STM thermal model built to provide test predictions and inform test inputs





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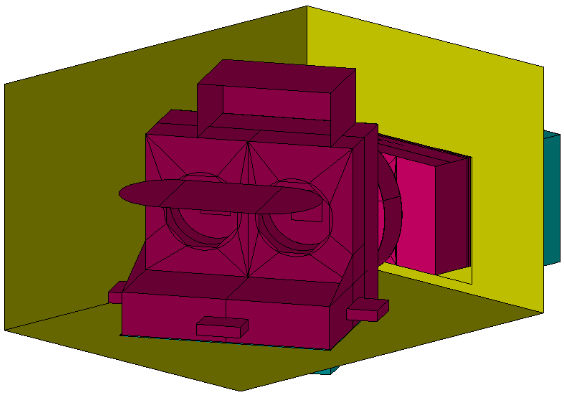
Detector Assembly Thermal Test

- Thermal vacuum and thermal balance testing on GSFC produced Detector Assembly (DA)
  - Verify thermal design (particularly cold element interface) and functional performance
  - Correlate DA submodel (not included in STM)
- DA has its own separate test rig
- Submodel extracted from flight model to generate test predictions
- Test is ongoing



Correlation

- ECSS standard used:
  - Temperature deviation < 5 ºC
  - Mean deviation of temperature difference within ±2 ºC
  - Standard deviation of temperature difference < 3 ºC
- Particularly essential for this instrument because a realistic solar load cannot be easily replicated during testing
- Submodel structure has proven useful

Future Tests

- Upcoming tests on flight instrument
  - Thermal balance and thermal vacuum
  - First test with instrument and DA together
- No test heaters available for instrument structure
- Mercury lamp to be used once more for hot operational test cases

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ESATAN-TMS Impressions

- Generally good!
- Workbench is relatively user friendly
- Library system should be reviewed
  - Store data in text format? Easier to modify
  - Update process between ESATAN-TMS versions is not well documented
- Performing cutting operations can sometimes be frustrating
- Undo button!

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Conclusion

- SPICE must withstand extreme thermal environment
- Tests carried out:
  - High Flux Mirror Test
  - Thermal Rig Commissioning Test
  - STM Thermal Balance Test
- Future tests:
  - FM Detector Assembly Thermal Test
  - FM Thermal Balance Test

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