Solar Orbiter/SPICE

Contribution to SO science objectives, data, operations

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(with material from D. Hassler, A. Fludra, S. Parenti)

Quels outils pour l'analyse de Solar Orbiter?
Toulouse, 4 November 2014

2008

RAL Space · SwRI · NASA · ESTL · MPS · pmod wrc · RUAG

Solar Orbiter: SPICE Instrument

Unsolicited Proposal

Volume 1 – Technical Proposal

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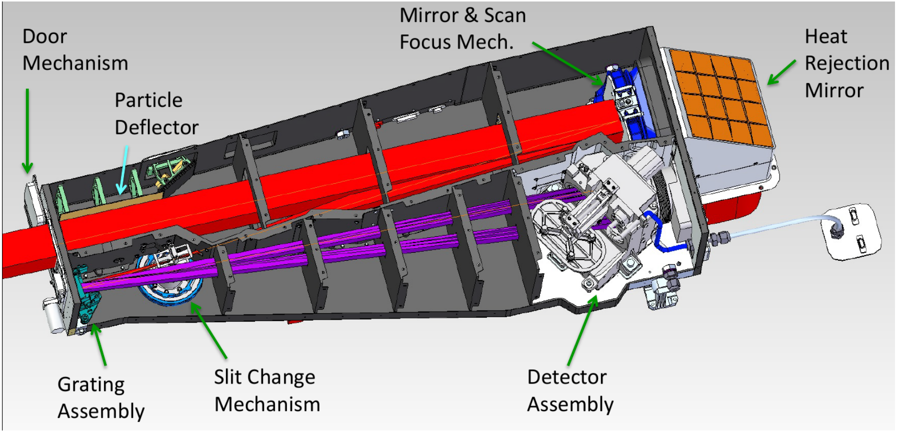
1. Instrument and data overview
2. SPICE contribution to SO science objectives
3. Operations

SPICE: Spectral Imaging of the Coronal Environment

High-resolution *imaging spectrometer* (spectra, and spectral images)
2 bands in EUV: 70.39–79.02nm and 97.25–104.92nm

- Excellent plasma diagnostics (50 lines, 20000K–10MK)
- Images: structure of corona at different temperatures



Spectroscopy: plasma diagnostics and flows

Line parameter	Physical parameter
Intensities and ratios	Temperature, density, emission measure, abundances
Width	Turbulent/unresolved velocity
Shape	Non-Maxwellian distributions
Position	Line-of-sight velocity
Intensity (out-of-limb)	Radial velocity (Doppler dimming: resonant scattering)

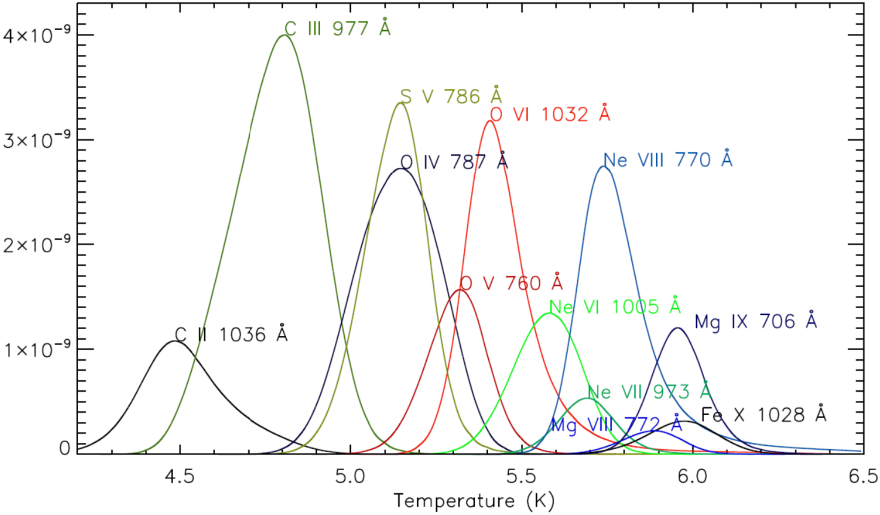
SPICE lines

- Wide range of T, FIP, M/q
- *Intensity* only for most lines, *full profiles* for some lines
- Series of ions, doublets

Ion	λ	log T	FIP	M/q
H I	102.5	4.0	13.6	
C II	103.6	4.5	11.3	12.0
C III	97.7	4.8	11.3	6.0
O IV	78.77	5.2	13.6	5.3
O V	76.0	5.3	13.6	4.0
O VI	103.2	5.4	13.6	3.2
O VI	103.7	5.4	13.6	3.2
S V	78.65	5.2	10.36	8.0
Ne VI	100.5	5.6	21.6	4.0
Ne VII	97.3	5.7	21.6	3.3
Ne VIII	77.0	5.8	21.6	2.8
Ne VIII	78.0	5.8	21.6	2.8
Mg VIII	77.2	5.9	7.7	3.0
Mg IX	70.6	6.0	7.7	2.4
Mg XI	99.7	6.2	7.7	3.4
Si VII	104.9	5.7	8.1	4.8
Si XII	52.1*	6.3	8.1	2.6
Si XII	49.9*	6.3	8.1	2.6
Fe X	102.8	6.0	7.9	6.2
Fe XVIII	97.5	6.9	7.9	3.3
Fe XX	72.1	7.0	7.9	2.9

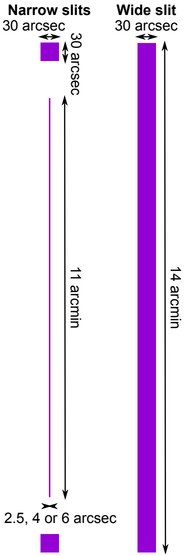
SPICE lines: temperature coverage

Contribution functions $G(T)$:



Power: $P(\lambda_{gj}) = 0.83\ \mathrm{Abund(X)}\ G_{\lambda_{gj}}(T_e)\ n_e^2\ \Delta E_{gj}$ (in coronal approx.)

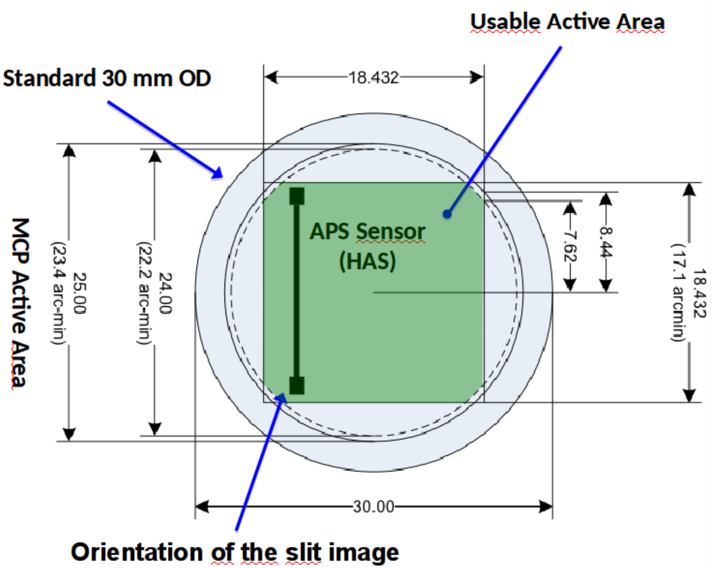
SPICE slits



- Telescope forms image of the Sun on the slit
  - 1 wide (30 arcsec) slit
  - or 1 of 3 narrow "dumbbell" slits:
    spectral resolution / throughput compromise,
    wide part for FOV alignment

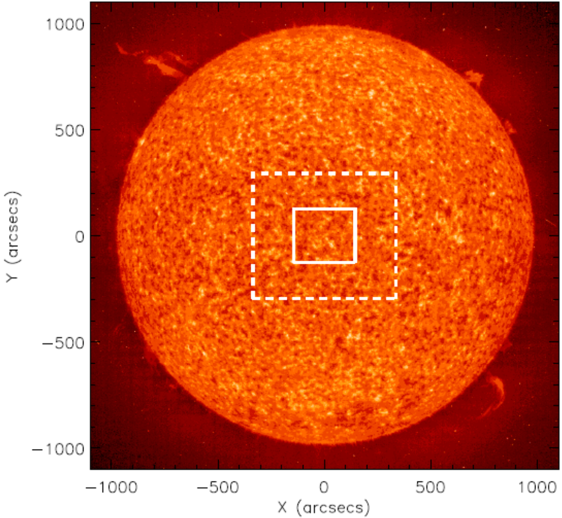
  Note: 1 arcsec $\equiv$ 3 μm on the slit
- Toroidal Varied Line Space grating:
  wavelength dispersion and re-imaging on detectors

One (of 2) detectors



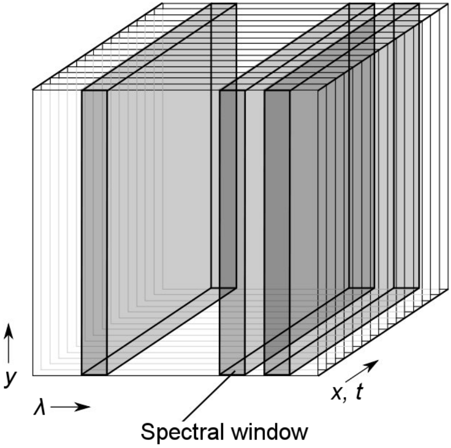
On detector: FWHM 4 pixels (4 arcsec)×4 pixels (40 pm) (2 arcsec slit)

SPICE field-of-view



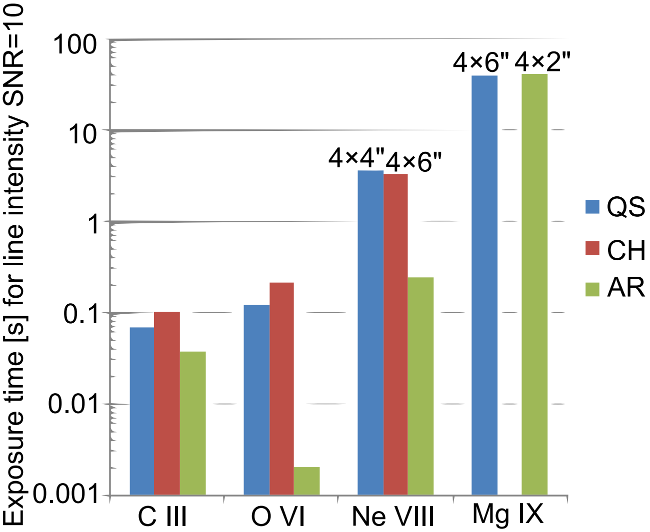
- N-S slit,
  E-W raster scan
  capability
  (16 arcmin)
- $16 \times 14(11)$ arcsec;
  —: at 0.3 AU
  - -: at 0.7 AU

SPICE data cube and spectroheliograms



- 2D detector $\times$ $x(t)$: data cube
- *Spectral windows*: n_λ pixels, Fourier-based compression of *full profiles*, or *total intensity*
- JPEG2000 compression in image directions

Sensitivity: line intensity SNR, accuracy



SNR=10 for 150 photons in line;

Allows accuracy of 10% for intensity and 6km/s for velocity.

Binnning required for ≤30s exposure time in some lines.

1. *Instrument and data overview*

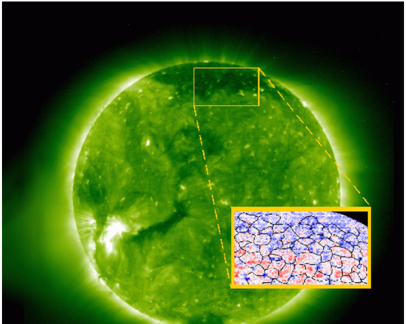
2. *SPICE contribution to SO science objectives*

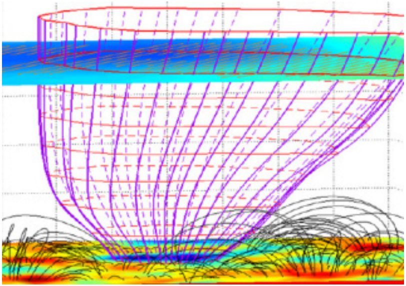
3. *Operations*

1. How and where do the solar wind plasma and magnetic field originate in the corona?

1.1 What are the source regions of the solar wind and the heliospheric magnetic field?
1.2 What mechanisms heat and accelerate the solar wind?

- Composition of solar wind source regions:
  Determine FIP and Q/M effect in solar wind source regions
- Spectral images of chromosphere and corona (Doppler shifts, composition): *Identify source structures of solar wind*
- Line width, Doppler shift, and intensity time series:
  Wave propagation and heating processes





1. How and where do the solar wind plasma and magnetic field originate in the corona?

1.3 What are the sources of turbulence in the solar wind and how does it evolve?

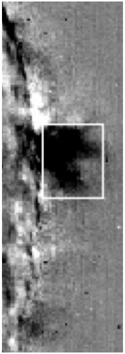
- Images of source regions in Doppler-broadened lines:
  Identify jets, heating, and turbulence on time scale of the chromospheric oscillations, correlate to network evolution

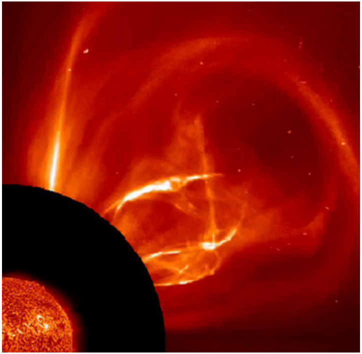
2. *How do solar transients drive heliospheric variability?*

2.1 How do CMEs evolve through the corona and inner heliosphere?

2.2 How do CMEs contribute to the solar magnetic flux and helicity balance?

- Coronal dimming, shock fronts, turbulent broadening:
  CME onset and early propagation processes
- Map source regions composition:
  Link to in-situ measurements

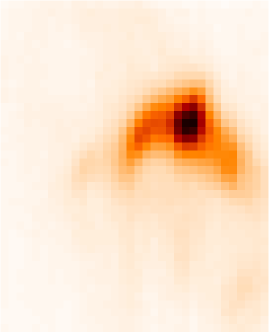




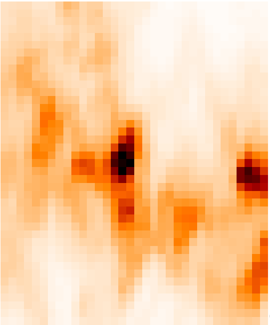
3. How do solar eruptions produce energetic particle radiation that fills the heliosphere?

3.1 How and where are energetic particles accelerated at the Sun?

- UV and X-ray imaging of loops, hot flare plasma, and CMEs: *Identify jets and reconnection sites that give rise to Solar Energetic Particles*



Fe XVIII



O V

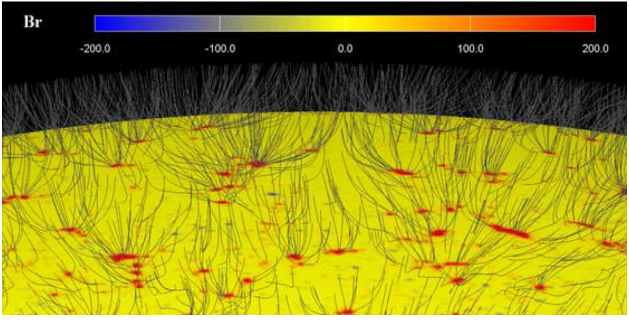
4. How does the solar dynamo work and drive the connections between the Sun and heliosphere?

4.1 How is magnetic flux transported to and reprocessed at high solar latitudes?

4.2 What are the properties of the magnetic field at high solar latitudes?

- Spectral images of small-scale magnetic features at the poles:
  Determine evolution of magnetized structures and associated flows

- [Magnetic fields], plasma flows, and temperatures of polar regions:
  Identify source structures of polar solar wind by correlating Doppler shift to structure and composition



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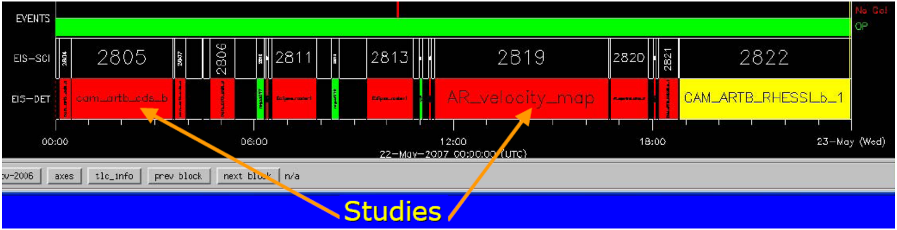
3. *Operations*

Operations concept

- A *raster*: scan $x(t)$, or sit-and-stare $x(t) = x_0$
- A *study*: one ore more rasters, with given:
  - exposure time: 0.2–180 s
  - spectral windows (wavelengths, widths)
  - slit, fraction of slit length
  - mirror step ($\delta x = 2, 4, 6 \ldots$ arcsec) and number of steps
  - compression scheme, binning along slit
- Operations timeline: *series of studies* (selected in list), with *pointing* information.



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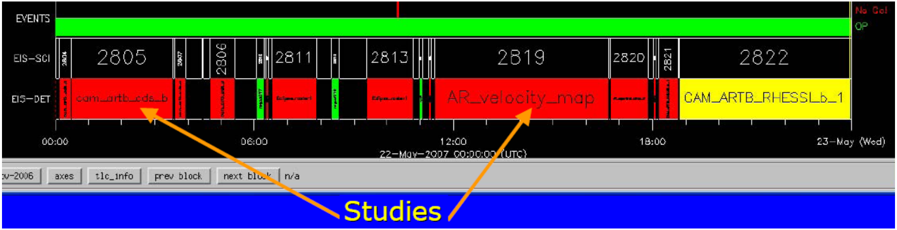

Responsibilities during operations: RAL (instrument control), IAS (planning), Oslo (post-downlink activities)

Data volume and observing modes

Telemetry: 17.5 kb/s during the remote-sensing science windows: 44 Gb/orbit (1500×raw data for one exposure of both detectors).

Compression: 10:1 with JPEG2000 (images, wide slit, dumbbells), 20–26:1 with spectral hybrid compression (for spectral profiles).

Selection of wavelength windows and line intensities allow to reach high duty cycle with 5–30 s exposure.

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Typical observing modes (will be interlaced):

- Dynamics (high data volume):
  4 spectra+6 intensities, 5 s exposure,
  20–60 arcsec FOV width, 1–3 min cadence
- Composition mapping and connectivity (lower data volume),
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Each study preceded by its low-latency counterpart (reduced window height, slit positions, scan repeats): 0.1MB each, 1MB/d total.

SPICE standard data products

- L0 (acquisition+1d): FITS files in instrument units
- L1 (acquisition+<60d): FITS files in scientific units
- L2 (acquisition+<60d): Calibrated spectral image products:
  - Dopplergrams (line shifts in each line)
  - Thermograms (line broadening)
  - Parameters of 2-component spectral fit
  - FIP fractionation map (generated from ratios of low-/high-FIP lines)
  - Q/M fractionation map (generated from ratios of low-/high- Q/M lines)
- L2ql (acquisition+1d): same as L2,
  but generated from L0 instead of L1.

Summary

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Choices to be made for *planning*: studies (linked to SO orbit planning), pointing (need visualization of low-latency data).

Complex data sets; need easy visualization and analysis tools.
L2 data maps can be used directly, otherwise interpretation relies on atomic physics data.