SPECTROMETER/TELESCOPE FOR IMAGING X-RAYS (STIX) ON-BOARD THE SOLAR ORBITER

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Solar Hard X-Ray emission

Typical (spatially unresolved) HXR spectrum is a mixture of several sources of various parameters.

Observations reveal at least five (or four) types of HXR sources:

- above-X-point
- above-the-loop-top
- thermal loop top
- foot point
- halo/albedo

Therefore, the important step in understanding HXRs may be taken with imaging spectroscopy – present instruments allow for this.
Solar Orbiter Instruments

- **EUI**: Extreme Ultraviolet Imager
- **METIS**: Multi Element Telescope for Imaging and Spectroscopy
- **PHI**: Polarimetric and Helioseismic Imager
- **SoloHI**: Heliospheric Imager
- **SPICE**: Spectral Imaging of the Coronal Environment
- **STIX**: Spectrometer/Telescope for Imaging X-rays
- **EPD**: Energetic Particle Detector
- **MAG**: Magnetometer
- **RPW**: Radio and Plasma Waves Experiment
- **SWA**: Solar Wind Analyser

Launch date: 2018
Duration: 3 years cruise + 4 years mission (+ 3 year extension)

Fahmy et al. (2013)
The orbit
Mission profile
STIX science goals and observations

STIX will determine the intensity, spectrum, timing, and location of solar hard X-ray sources.

detection X-rays from 4 to 150 keV

Hard X-ray Spectrum and Image from RHESSI

Figure 1. Typical hard X-ray observations of a solar flare (observations are taken by RHESSI). Left: Solar flare spectrum (black histogram) with a thermal (red) and non-thermal (blue) fit to the data. Right: Imaging observations of the same event. The non-thermal emission is seen from the chromospheric footpoints (blue) of the thermal flare loop (red).
The STIX instrument

The STIX instrument consists of three mechanically separate parts:

- **Imager**
- **Detector Electronics Module (DEM)**
- **X-ray windows**

**Technical Specifications**

- **Energy Range**: 4 – 150 keV
- **Energy Resolution (FWHM)**: 1-15 keV (energy dependent)
- **Effective area**: 6 cm²
- **Finest angular resolution**: 7 arcsec
- **Field of view**: 2°
- **Image placement accuracy**: ~4 arcsec
- **Time resolution (statistics limited)**: ≥ 0.1 s

*Source: Benz et al. (2012)*
**X-ray windows**

Placed in the heat shield of the spacecraft

A thermal baffle that rejects all radiation below 4 keV

Solar flux at 0.28 AU: **17 kW/m²**

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Benz et al. (2012)

Fahmy et al. (2013)
The imager

- 32 collimators made of pairs of grids
- Aspect system for absolute pointing with accuracy ±4 arcseconds

Structural and thermal model of the imager (2013)
Coded aperture, fourier imagers

Idea of Fourier imagers for astronomy was born in the late 60s of XXth century

- Oda et al. 1965, Nature 205, 554
- Schnopper et al. 1968, Space Sci. Rev. 8, 534
- Bradt et al. 1968, Space Sci. Rev. 8, 471
- Takakura et al. 1971, Sol. Phys. 16, 454
Example: RHESSI

IDEAL RMC PROFILES OF GAUSSIAN SOURCES

1. UNIT FLUX, FWHM=0, \((R, \phi) = (8+P, 0)\) \((P=\text{PITCH}=68^\circ)\)

2. HALF-UNIT FLUX, FWHM=0, \((R, \phi) = (8+P, 0)\)

3. UNIT FLUX, FWHM=0, \((R, \phi) = (8+P, \pi/4)\)

4. UNIT FLUX, FWHM=P, \((R, \phi) = (12+P, 0)\)

5. UNIT FLUX, FWHM=P/2, \((R, \phi) = (8+P, 0)\)

6. UNIT FLUX, FWHM=P, \((R, \phi) = (8+P, 0)\)

7. UNKNOWN SOURCE DISTRIBUTION

- point source, unit flux
- point source, half-unit flux
- point source, position change (angle)
- point source, position change (radial)
- size of the source = pitch/2
- size of the source = pitch

Reality…
Imaging: grids and Moire patterns

- Front grid and rear grid with slightly different relative orientation and/or pitch create so-called Moiré pattern (Mp)
- Phase of Mp is very sensitive to incident direction of X-ray in plane perpendicular to slits.
- Amplitude and phase of Mp measures amplitude and phase of an X-ray visibility
- Spatial frequency of grid pair determines measured spatial frequency of X-rays
- Pixelized detectors → determine phase and amplitude of Mp = encoded visibility information

Phase of Morie pattern is very sensitive to incident direction of X-ray in plane perpendicular to slits

Slight differences in pitch of grids

Slightly tilted pair of grids
Pixel pattern $\rightarrow$ visibilities

Simulated incident X-rays from an arbitrary direction

The amplitude and phase of a sinusoid fitted to the histogram directly measures the visibility

$\begin{align*}
\text{Real (V)} &= C - A \\
\text{Imag (V)} &= D - B \\
\text{Flux} &= A + B + C + D \\
\text{Check: } A + C &= B + D
\end{align*}$

* Independent of background
** Independent of source morphology

Benz et al. (2012)
Converting Visibilities to Images

- The process of converting a set of measured visibilities to an image is identical to that used for many years in radio interferometry.

- The simplest algorithm for doing this is "back projection" whereby a measured visibility is expressed as a probability map on the sky of possible origins of the source.

- For a single visibility, this takes of the form of parallel stripes with a sinusoidal profile, whose period and orientation corresponds to the period and orientation of the x-ray grids.

- By combining the visibilities with different angular resolution and orientation, the ambiguities associated with any single visibility are removed.

Hurford et al. (2012)
**STIX detectors (Caliste-SO)**

Single Caliste-SO unit
(1 cm$^2$ CdTe detector - left; ASIC inside the body - right);

“First light” of Caliste-SO spectrometers.
Source: Americium

Energy resolution at 60 keV

Pixel layout of an individual detector:
8 large (~10 mm$^2$) pixels
4 small (~1 mm$^2$) pixels

32 Caliste-SO in total
Handling high dynamic range

- The ratio between the smallest microflare that STIX can detect and the largest X-class flare is $10^5$.
- An additional factor of $\sim 10$ in overall intensity must be accommodated because of SO’s varying distance from the Sun.
- The ratio between the flux at 4 and at 150 keV for the typical steep flare spectrum can be as high as $10^7$ to $10^9$.

Several strategies are implemented like attenuator or disabling selected pixels (reducing the effective area).
Summary

STIX will measure:

▪ intensity
▪ spectrum
▪ timing
▪ location

of X-rays caused by Bremsstrahlung of thermal and non-thermal electrons in the corona.

Main parameters

▪ Energy range 4 - 150 keV
▪ Energy resolution 1 - 15 keV energy dependent
▪ Fourier components 30
▪ Effective area 6 cm²
▪ Angular resolution 7 arcsec
▪ Pointing accuracy 4 arcsec
▪ Field of view 2°
▪ Time resolution 0.1 s statistics limited