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

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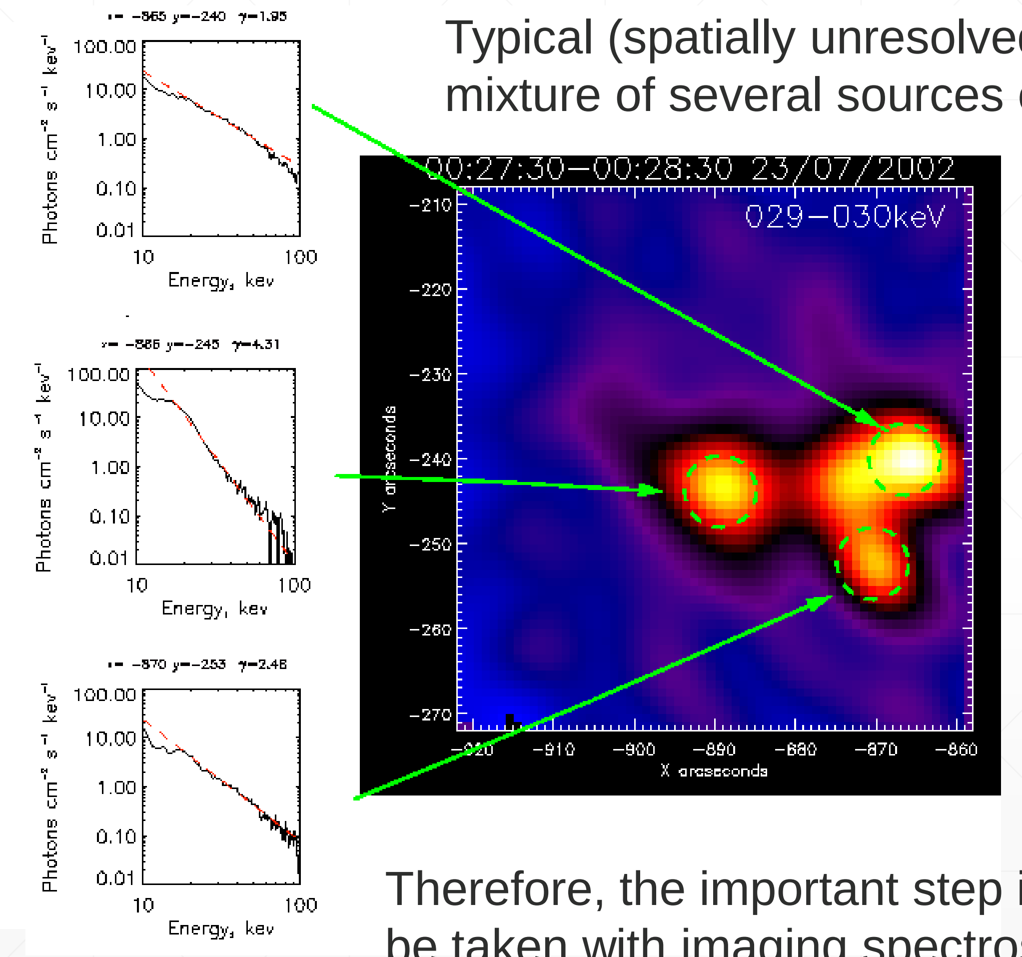
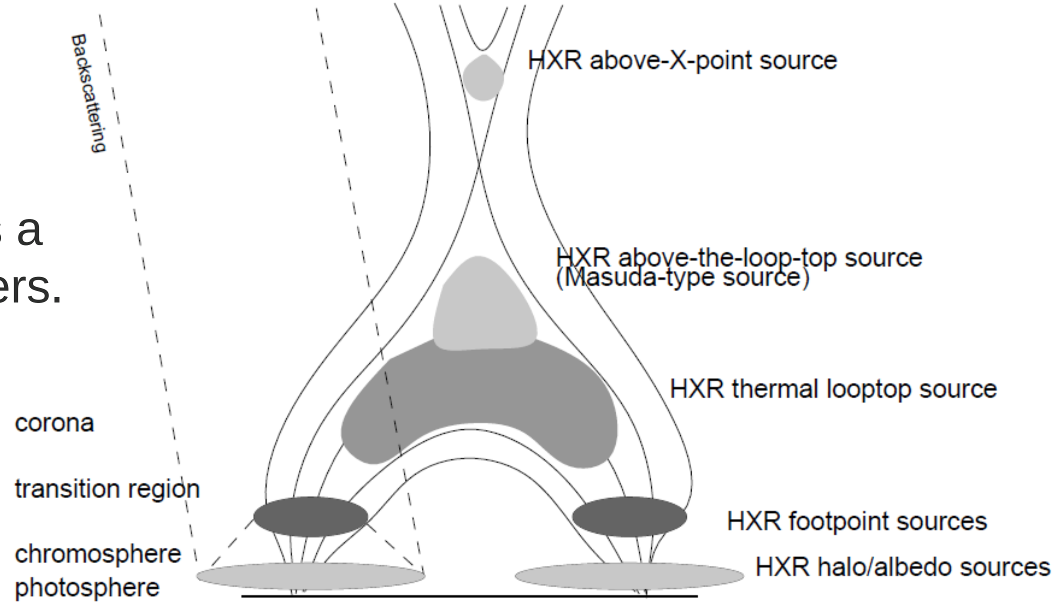
Solar Hard X-Ray emission

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





Aschwanden 2005, „Physics of the Solar Corona"

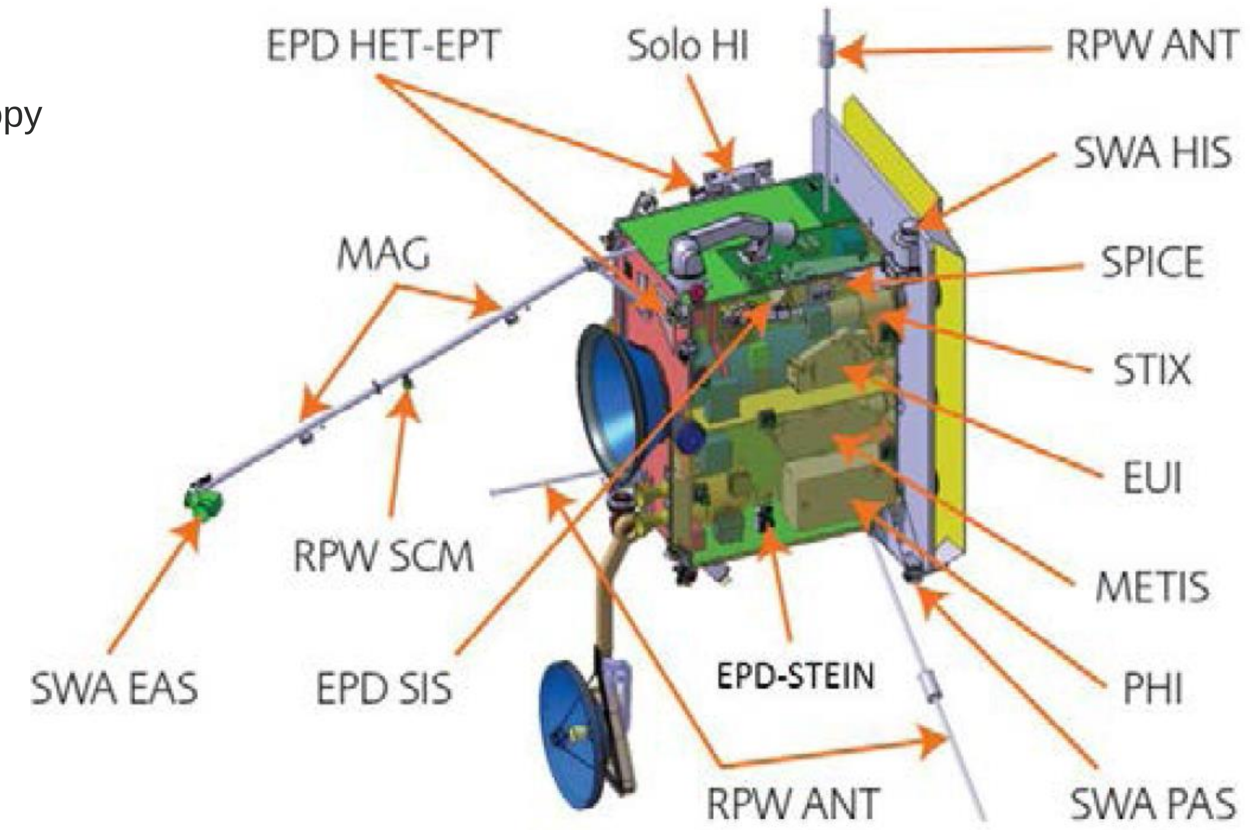
Observations reveal at least five (or four) types of HXR sources:

- 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

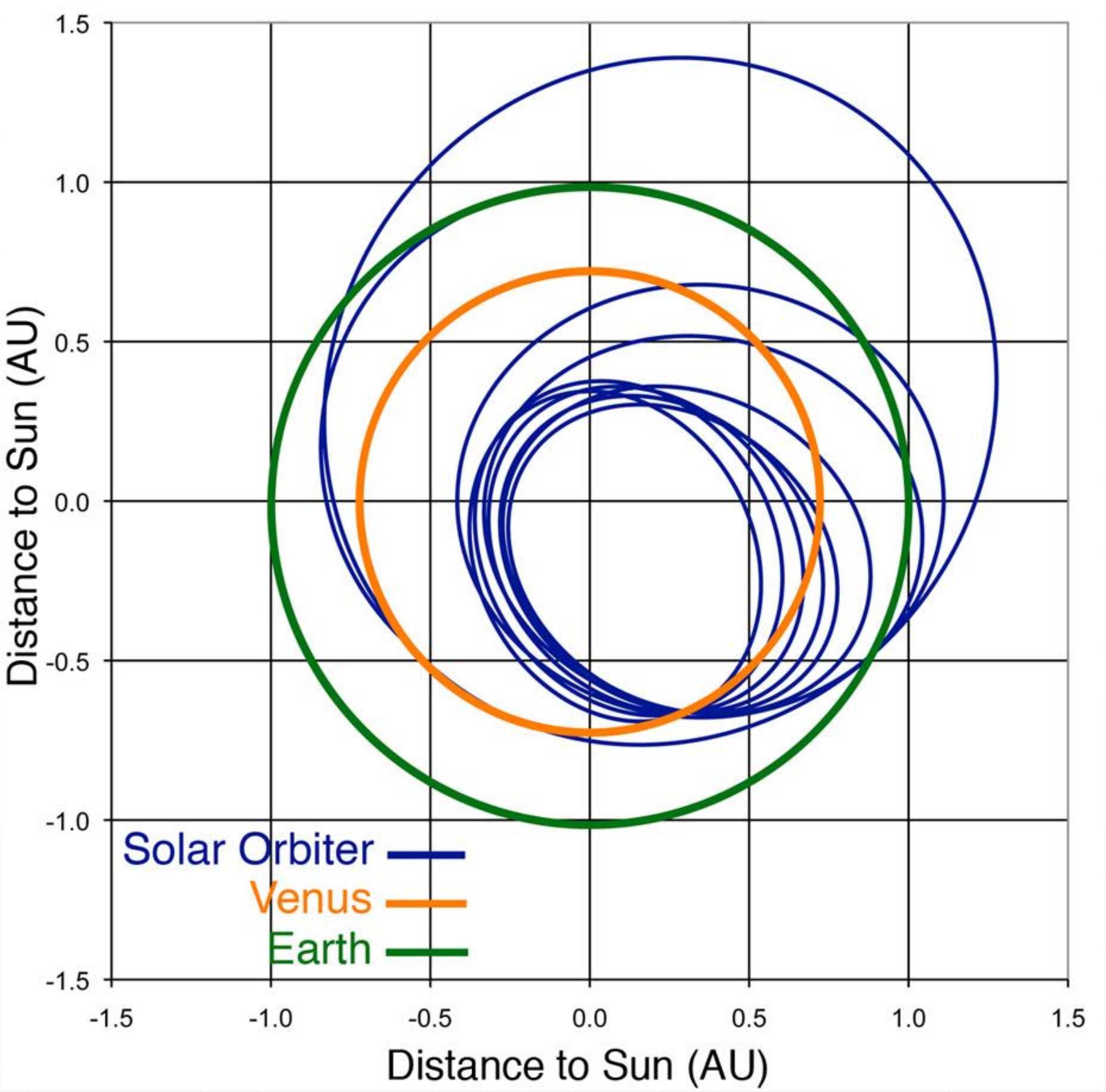
- **EUI**: Extreme Ultraviolet Imager
- **METIS**: Multi Element Telescope for Imaging and Spectroscopy
- **PHI**: Polarimetric and Helioseismic Imager
- **SoloHI**: Heliospheric Imager
- **SPICE**: Spectral Imaging of the Coronal Environment
- **STIX**: Spectrometer/Telescope for Imaging X-rays
- **EPD**: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



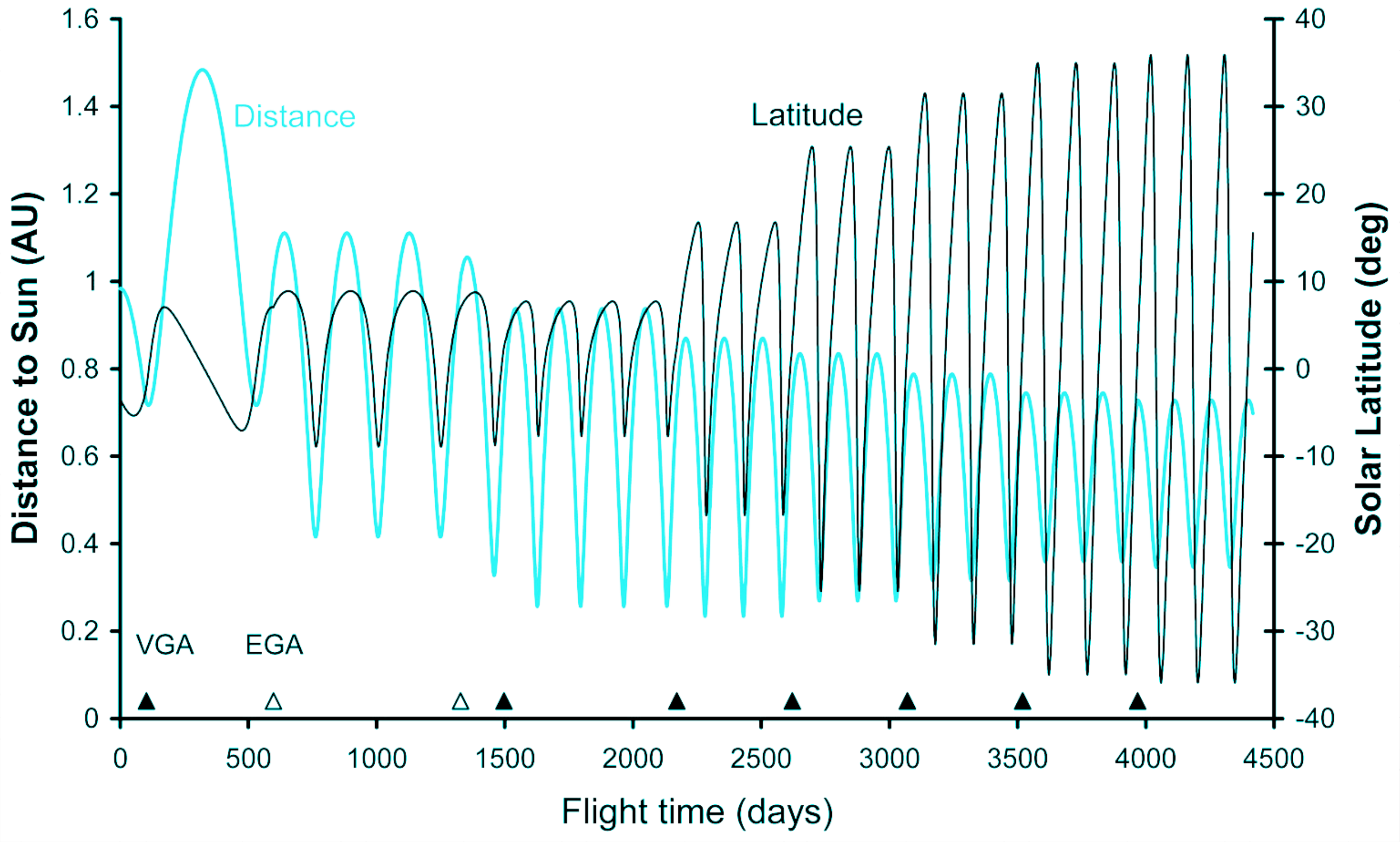
Fahmy et al. (2013)

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

The orbit


1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Distance to Sun (AU)
Solar Orbiter
Venus
Earth
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Distance to Sun (AU)

Mission profile



STIX science goals and observations

detection X-rays from 4 to 150 keV

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

Hard X-ray Spectrum and Image from RHESSI

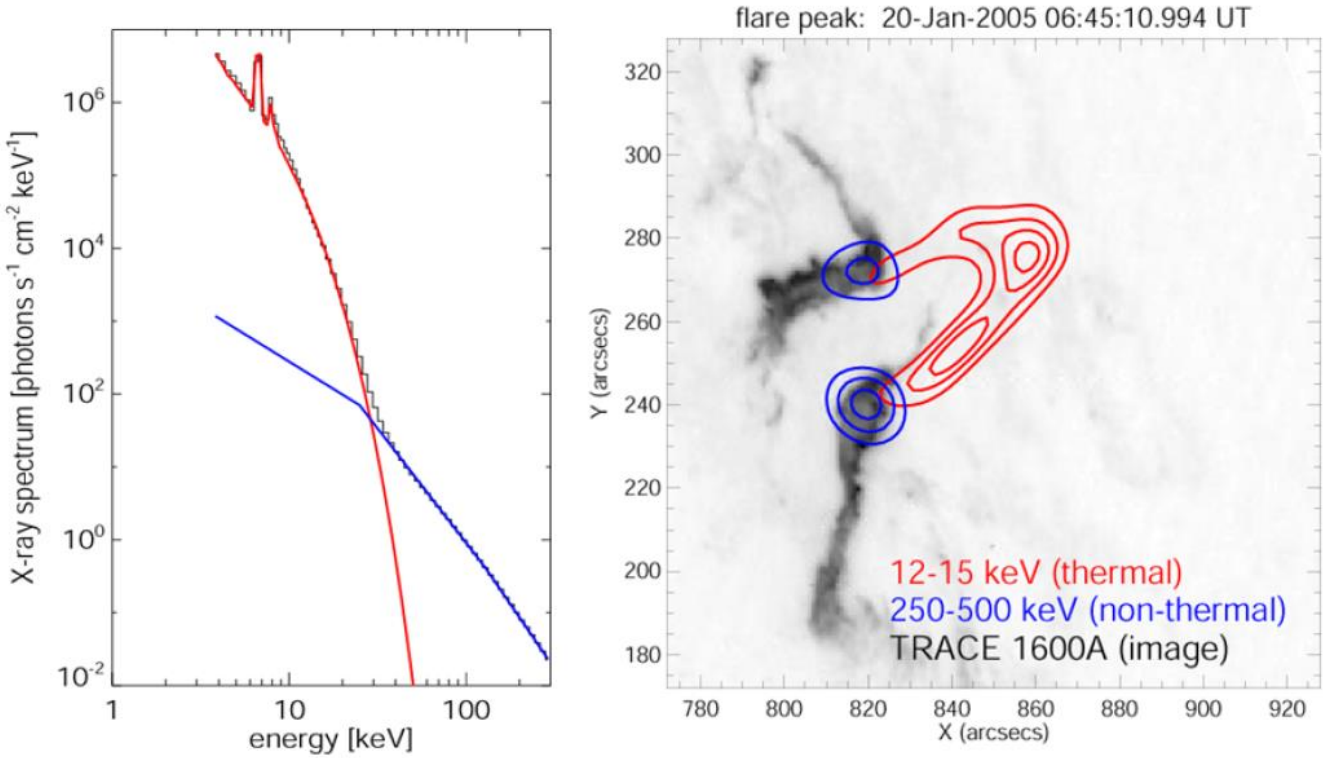
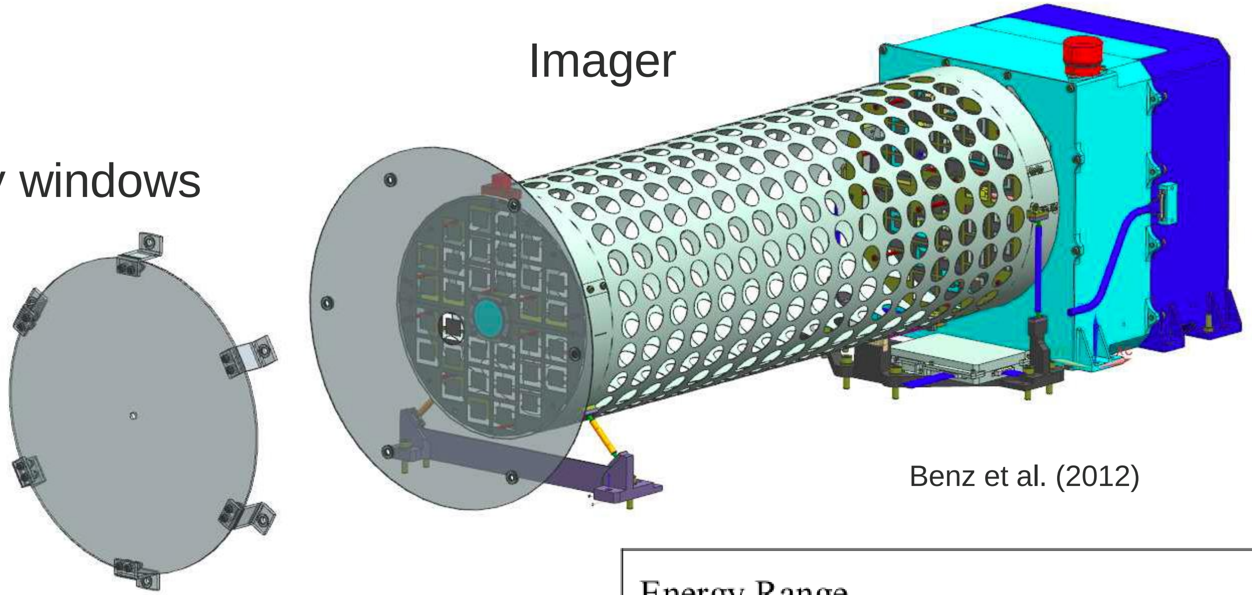


Figure 1.Typical hard X-ray observations of a solar flare (observations are taken by RHESSI). *Left:* Solar flare spectrum (black histogram) with a thermal (red) and non-thermal (blue) fit to the data. *Right:* Imaging observations of the same event. The non-thermal emission is seen from the chromospheric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

Benz et al. (2012)

The STIX instrument

The STIX instrument consists of three mechanically separate parts



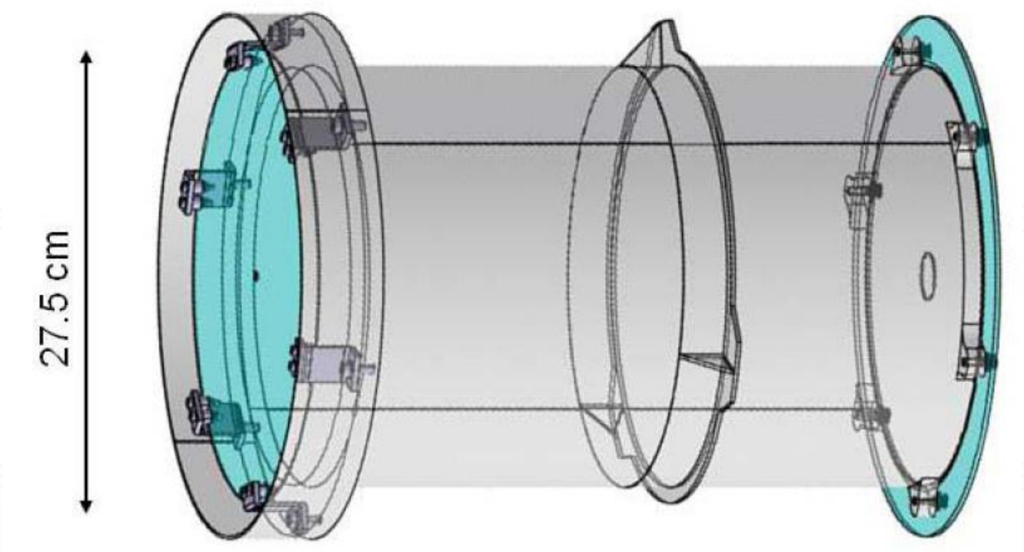
Benz et al. (2012)

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

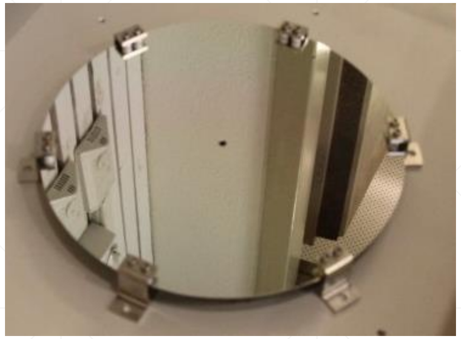
X-ray windows

Placed in the heat shield of the spacecraft

A thermal baffle that rejects all radiation below 4 keV



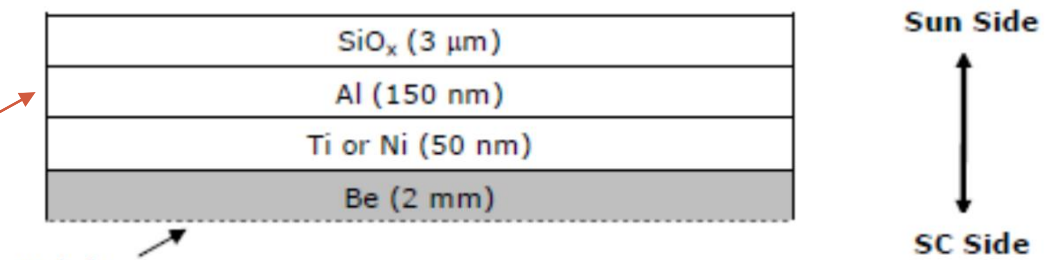
Benz et al. (2012)



Ø 275 mm

Solar flux at 0.28 AU: **17 kW/m²**

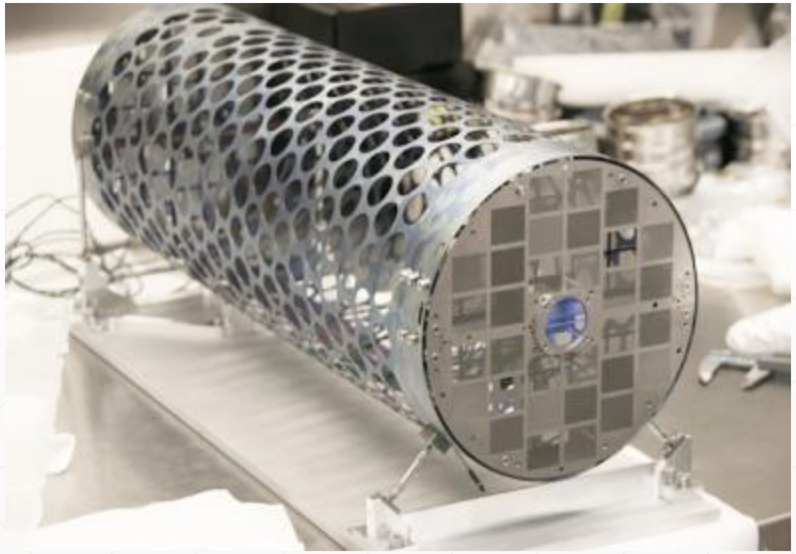
protective thermal coating



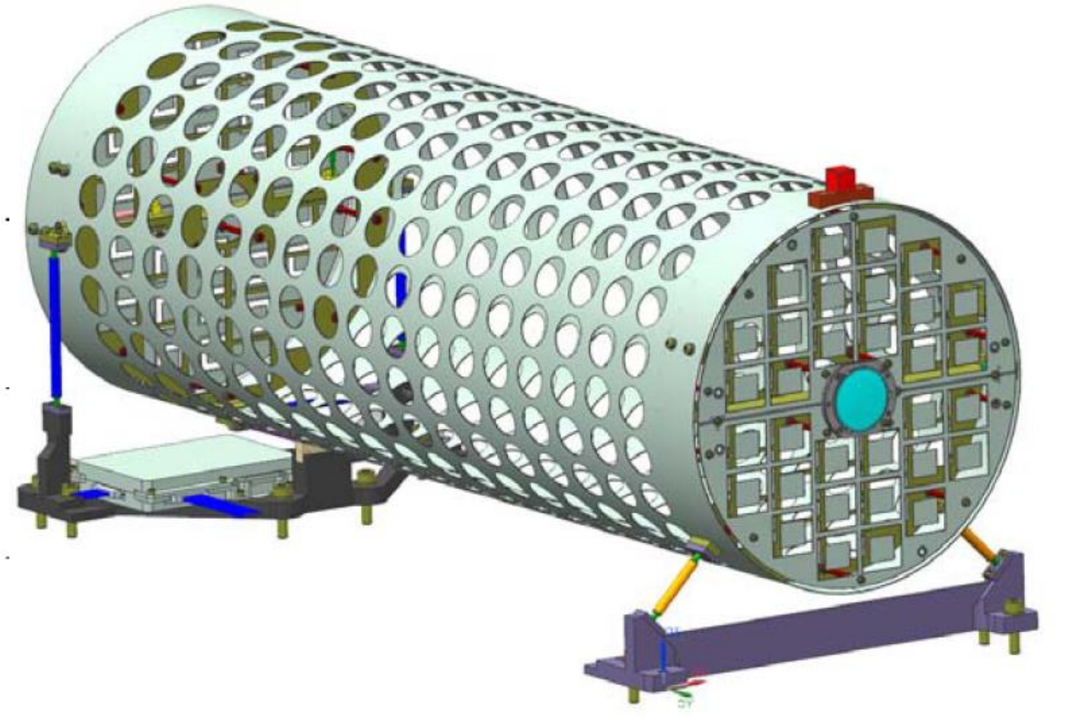
Fahmy et al. (2013)

The imager

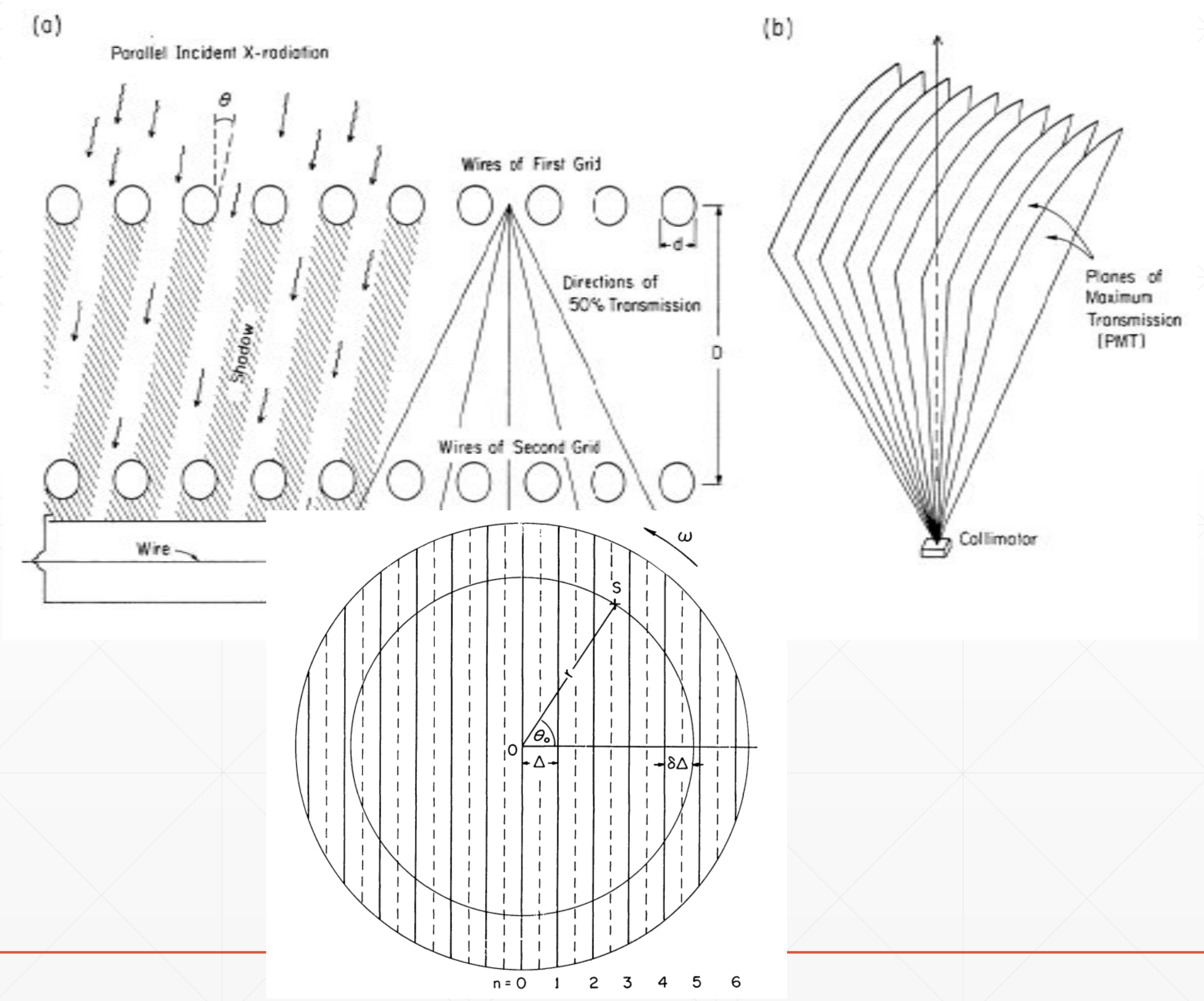
- 32 collimators made of pairs of grids
- Aspect system for absolute pointing with accuracy ±4 arcseconds



Structural and thermal model of the imager (2013)

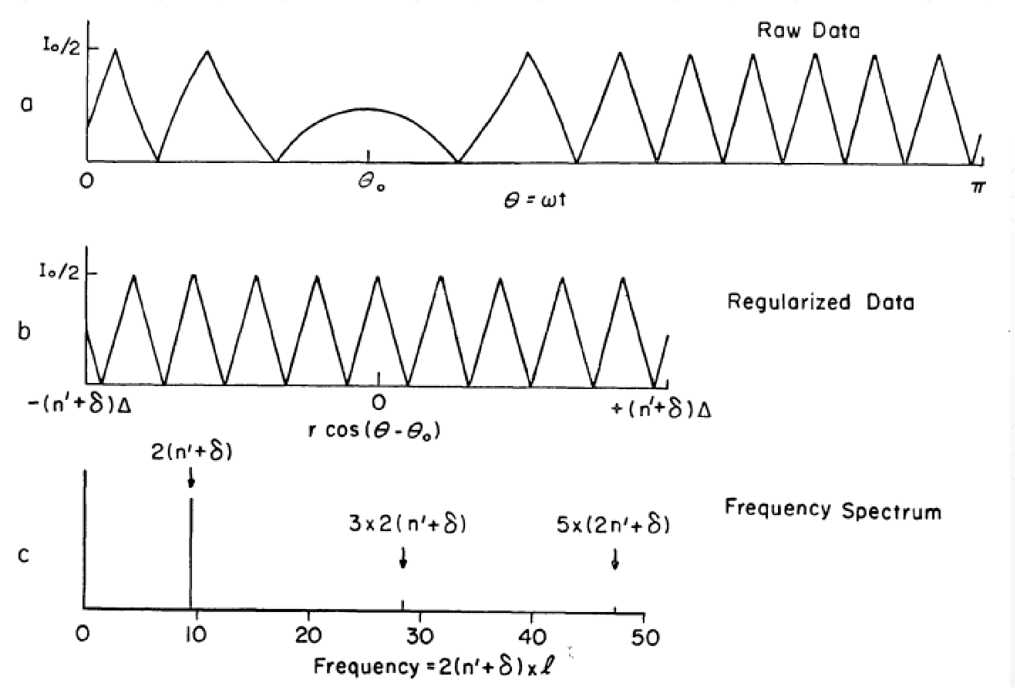


Coded aperture, fourier imagers

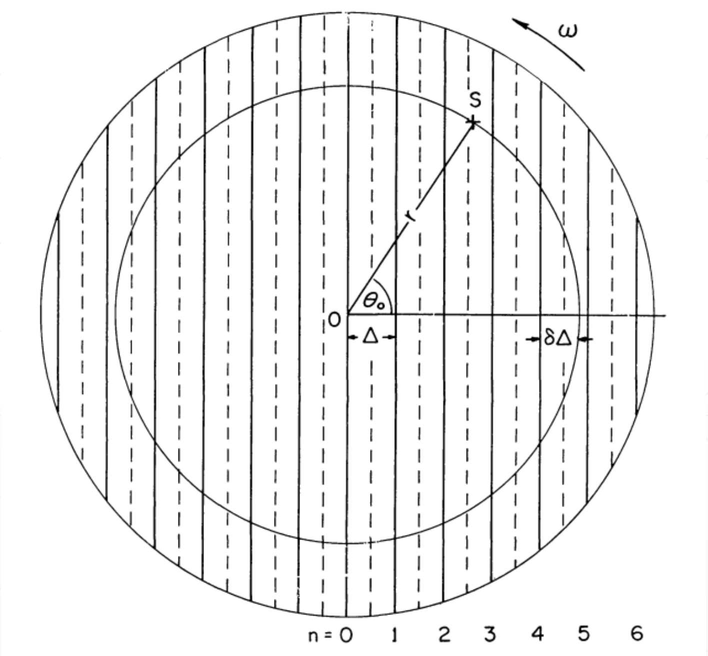


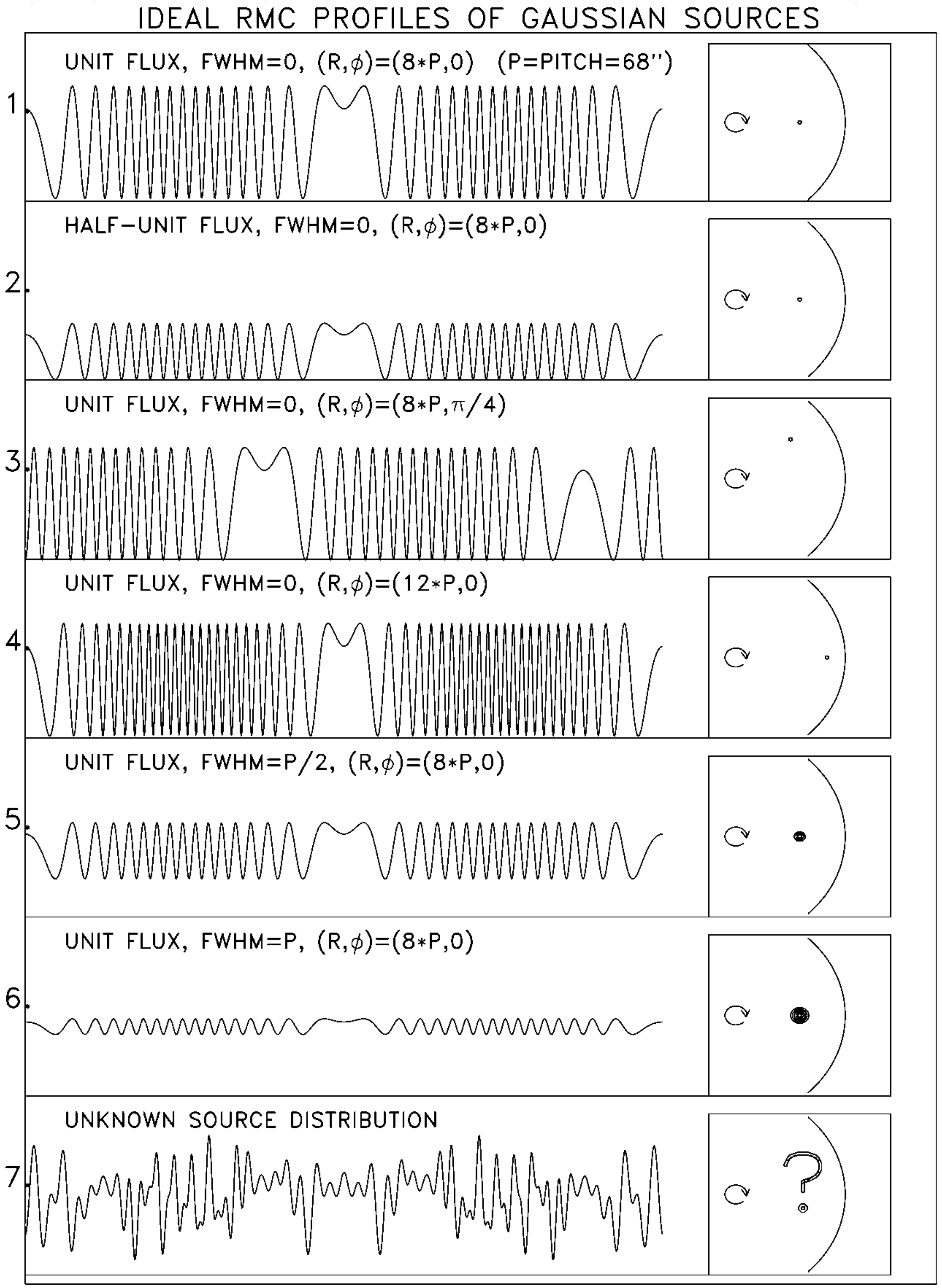
Idea of Fourier imagers for astronomy was born in the late 60s of XXth century

- Oda et al. 1965, Nature 205, 554
- Oda 1965, Proc. Int. Conf. Cosmic Rays
- Mertz 1968, Proc. Symp. Modern Opt.
- 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





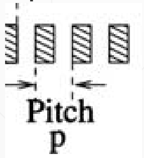
point source,
unit flux

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

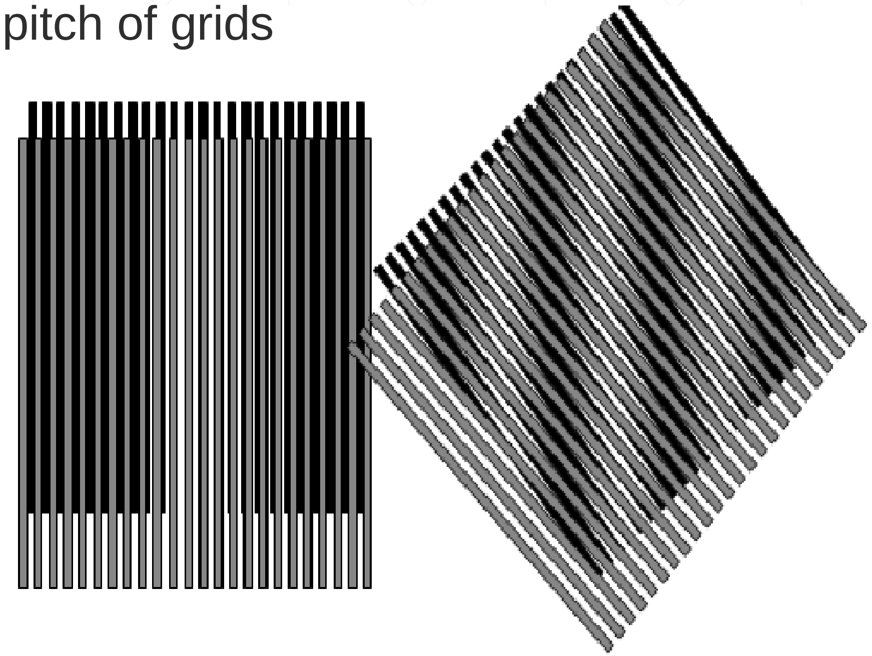
Reality…

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

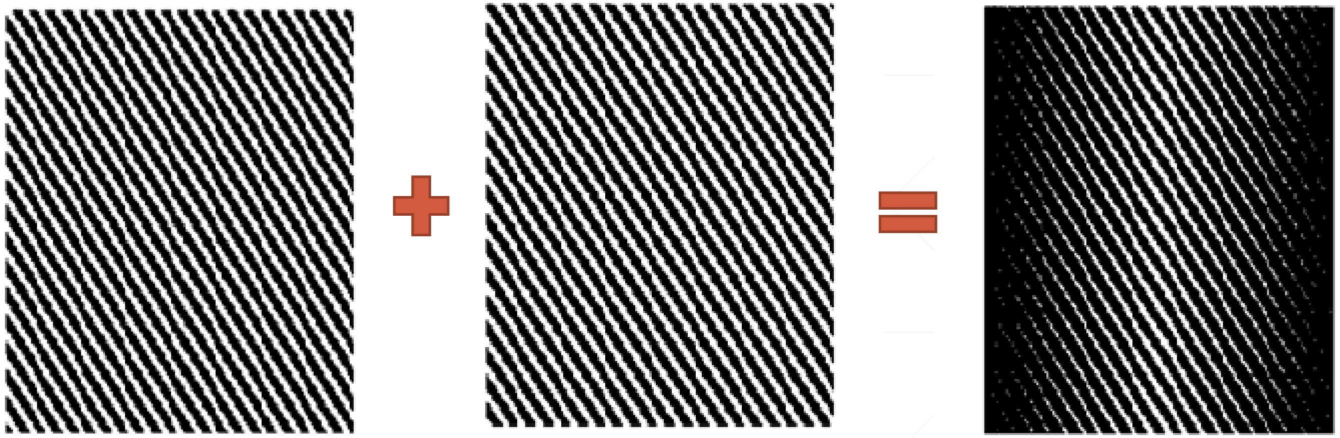
Slight differences in pitch of grids

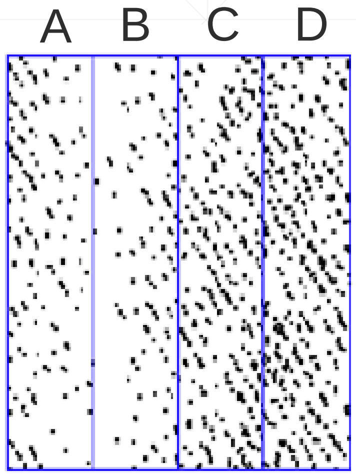
Slightly tilted pair of grids



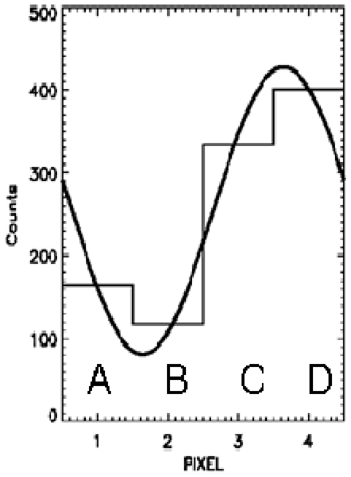
Phase of Morie pattern is very sensitive to incident direction of X-ray in plane perpendicular to slits

Pixel pattern → visibilities





Simulated incident X-rays from an arbitrary direction



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

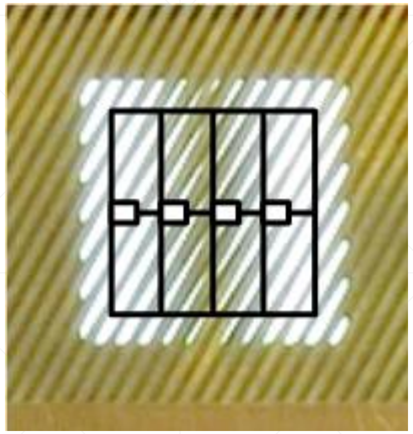
*Real (V) = C - A
*Imag (V) = D – B
**Flux = A+B+C+D
**Check: A + C = B + D

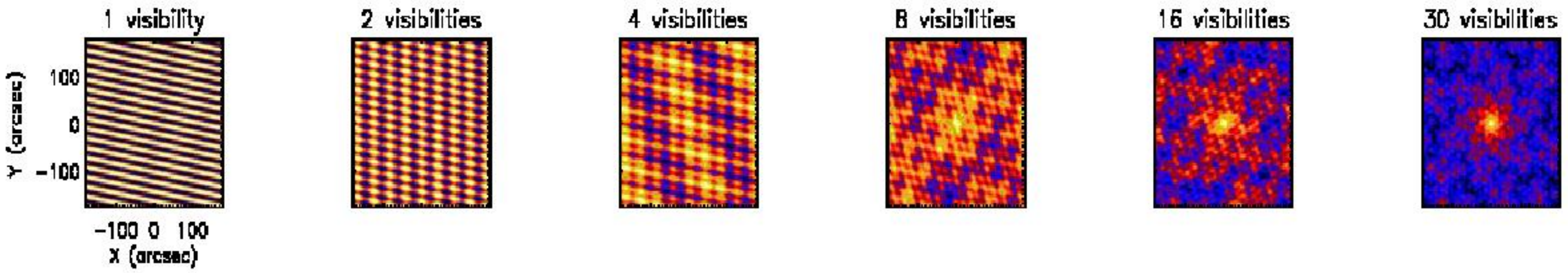
* Independent of background
**Independent of source morphology

Benz et al. (2012)

Converting Visibilities to Images

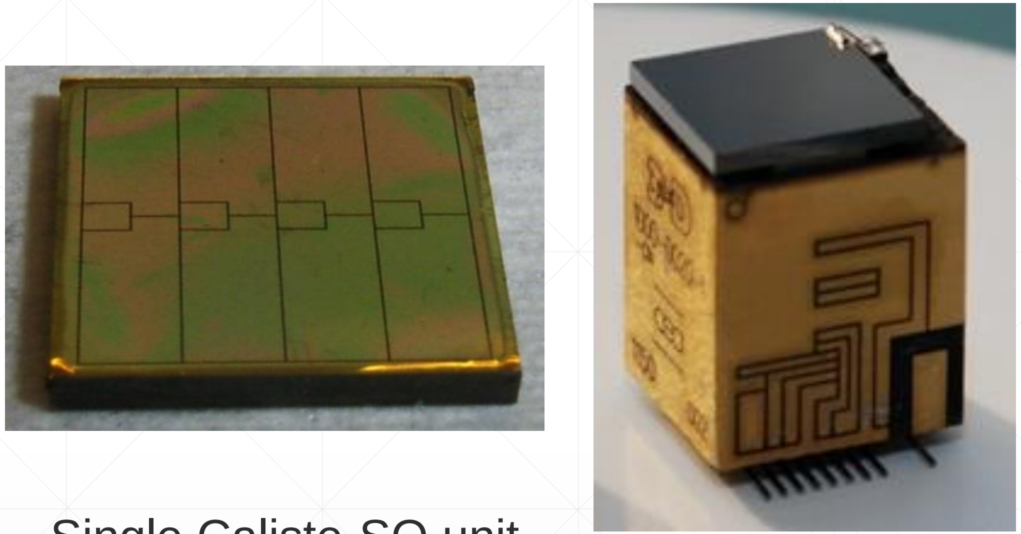
- The process of converting a set of measured visibilities to an image is identical to that used for many years in radio interferometry.
- The simplest algorithm for doing this is "back projection" whereby a measured visibility is expressed as a probability map on the sky of possible origins of the source.
- 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.



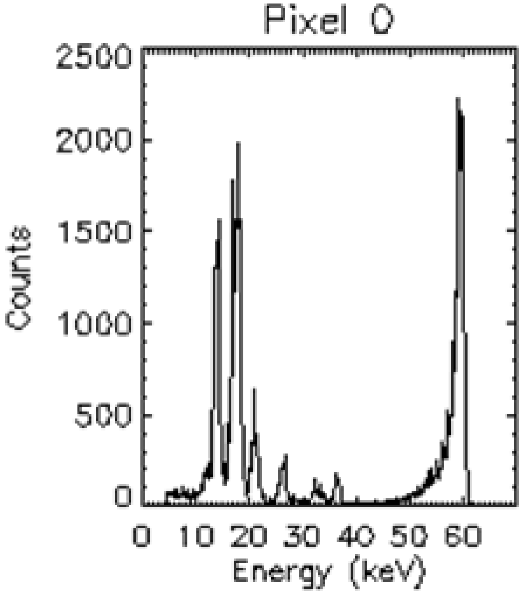


Hurford et al. (2012)

STIX detectors (Caliste-SO)

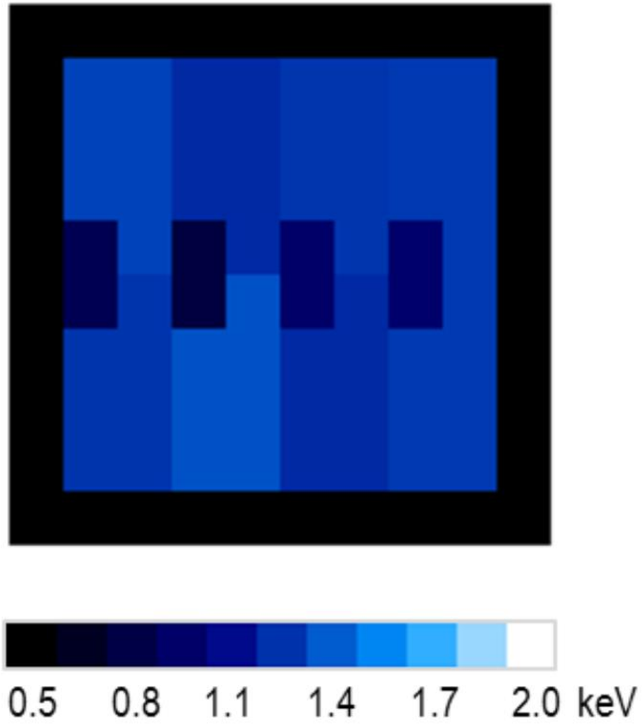


Single Caliste-SO unit
(1 cm^2 CdTe detector - left;
ASIC inside the body - right);



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

Energy resolution at 60 keV

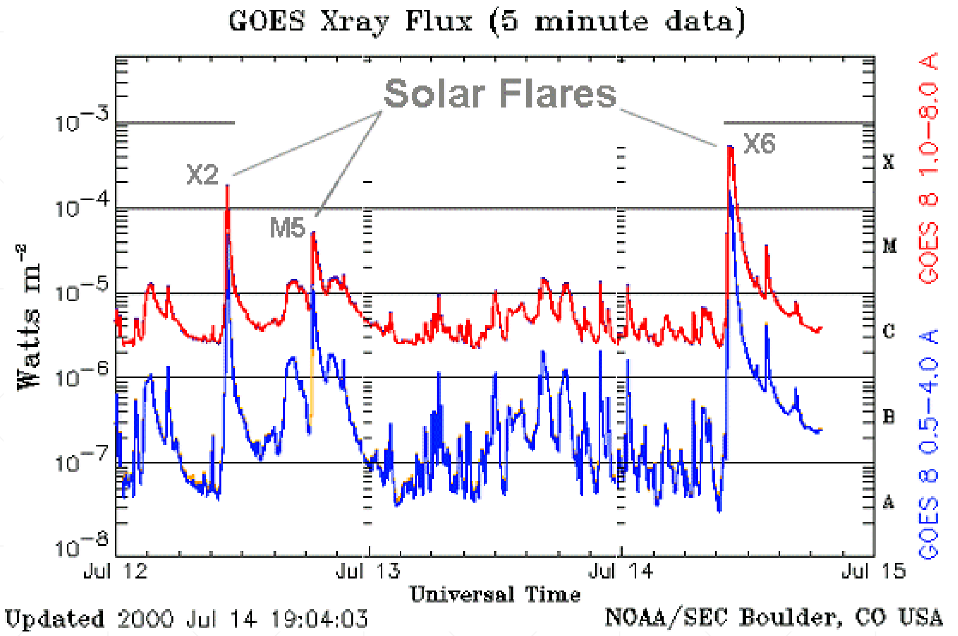


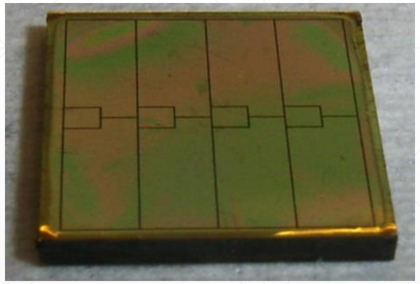
Pixel layout of an individual detector:
8 large (~10 mm^2) pixels
4 small (~1 mm^2) pixels

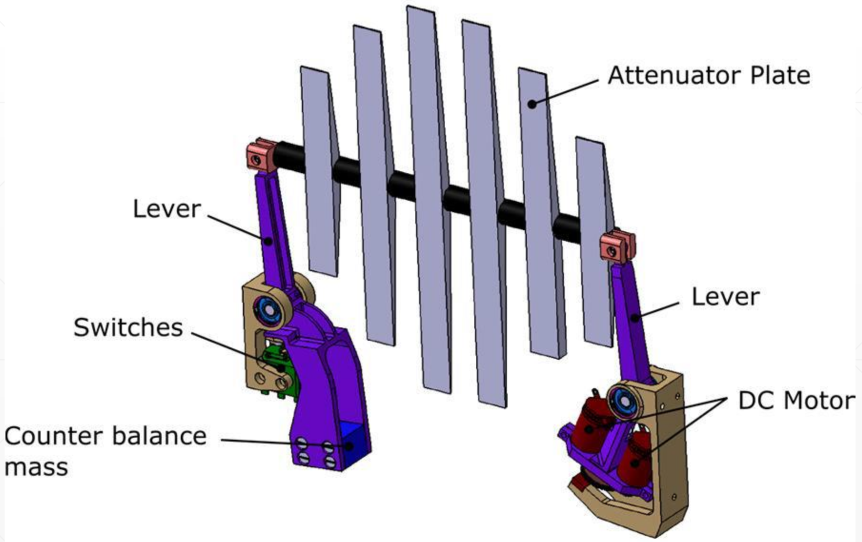
32 Caliste-SO in total

Handling high dynamic range

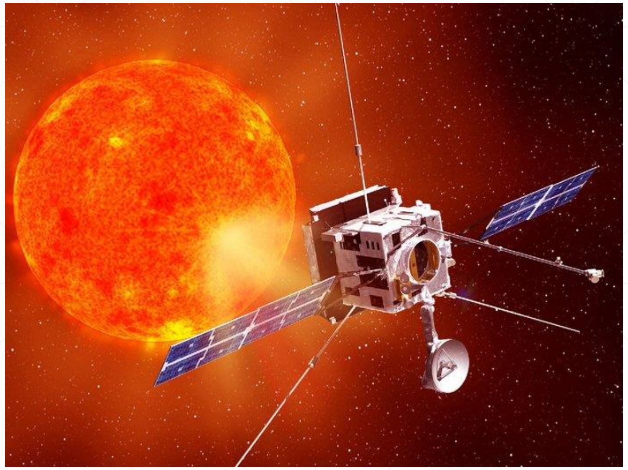
- The ratio between the smallest microflare that STIX can detect and the largest X-class flare is 10^5.
- An additional factor of ~10 in overall intensity must be accommodated because of SO's varying distance from the Sun
- The ratio between the flux at 4 and at 150 keV for the typical steep flare spectrum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







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

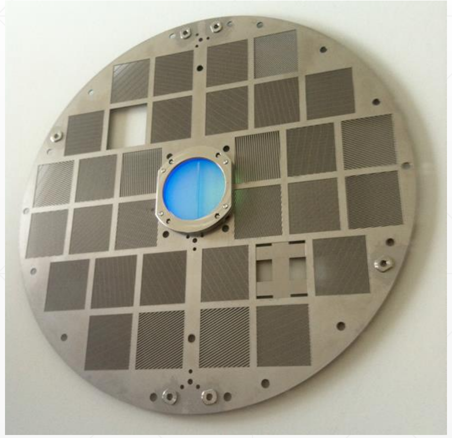


Summary

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 cm^2
- Angular resolution 7 arcsec
- Pointing accuracy 4 arcsec
- Field of view 2°
- Time resolution 0.1 s statistics limited