The Spectrometer Telescope for Imaging X-Rays on-board the ESA Solar Orbiter satellite

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—— for the STIX collaboration ——

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University of Applied Sciences Northwestern Switzerland

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

AIP Leibniz-Institut für Astrophysik Potsdam

PAUL SCHERRER INSTITUT PSI

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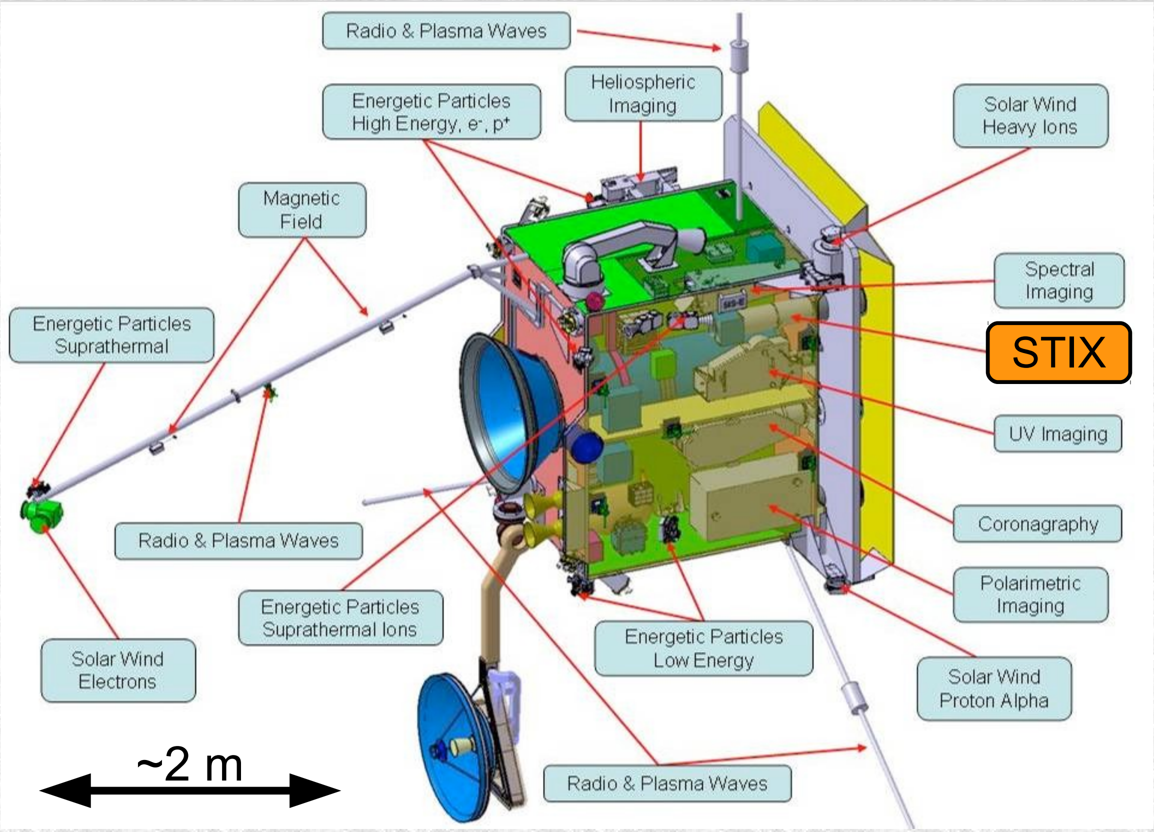
CBK PAN

ESA Solar Orbiter

“How does the Sun create and control the heliosphere?”

- Sun-heliosphere interaction
- Energetic solar phenomena
- Solar transients, heliospheric variability
- Solar wind accelerating mechanisms
- Solar wind plasma, coronal magnetic fields
- Solar dynamo working principle



10 instruments
(remote-sensing and in-situ)

Mass **1.8 t** (payload 180 kg)
Power **180 W**
Telemetry **150 kbps** (@ 1 AU)

Launch January **2017**
Mission duration **4+3 years**

Resonance orbit with Venus

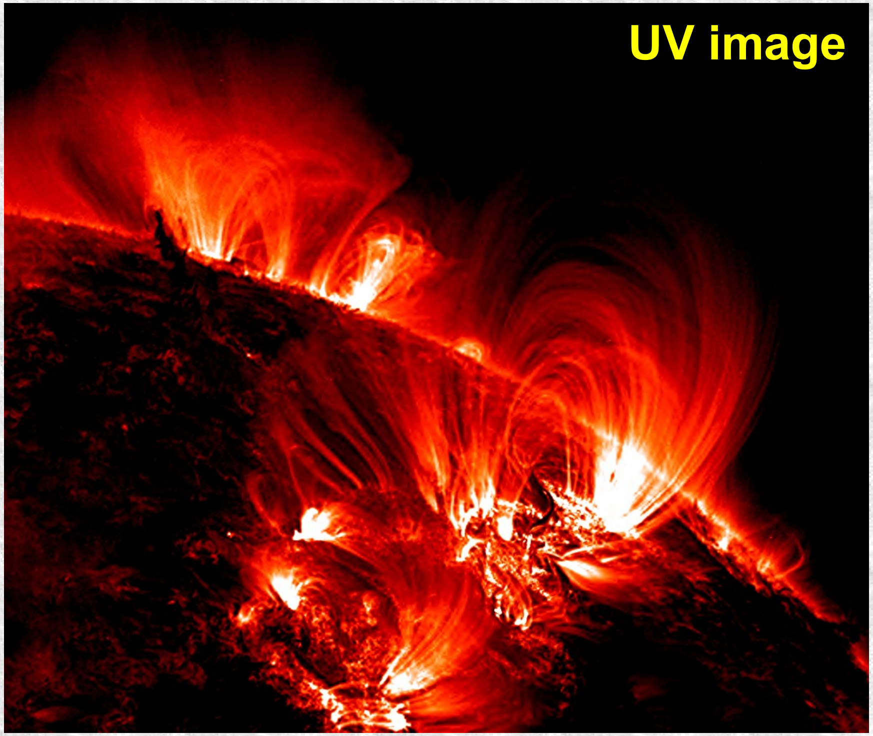
Currently in realization phase C

STIX Science Goal

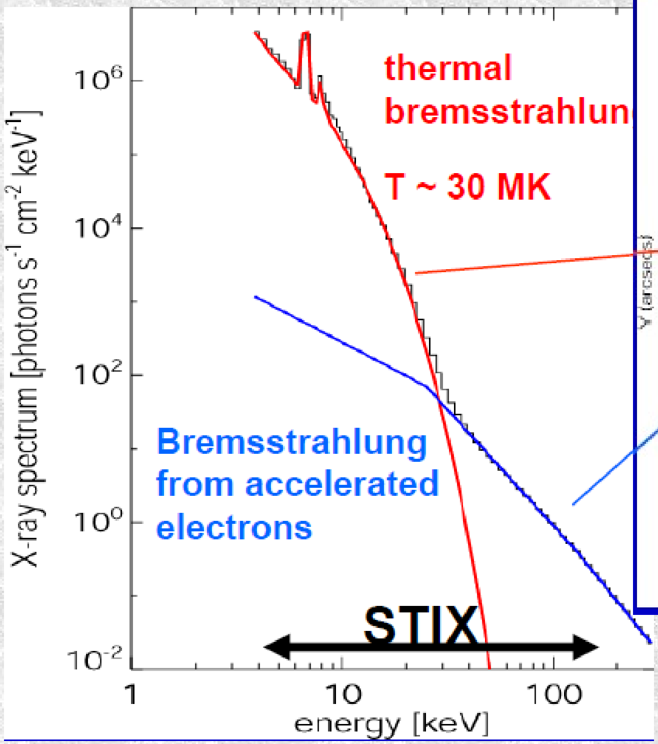
Imaging 4-150 keV x-rays

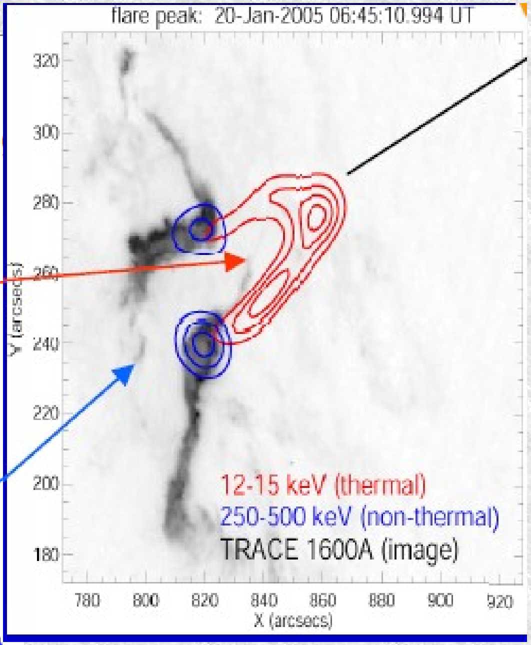
determines **intensity, spectrum, timing and location** of **accelerated electrons** near the Sun.

Study
- **acceleration mechanism of electrons** at the Sun
- electron transport into interplanetary space



SDO AIA image



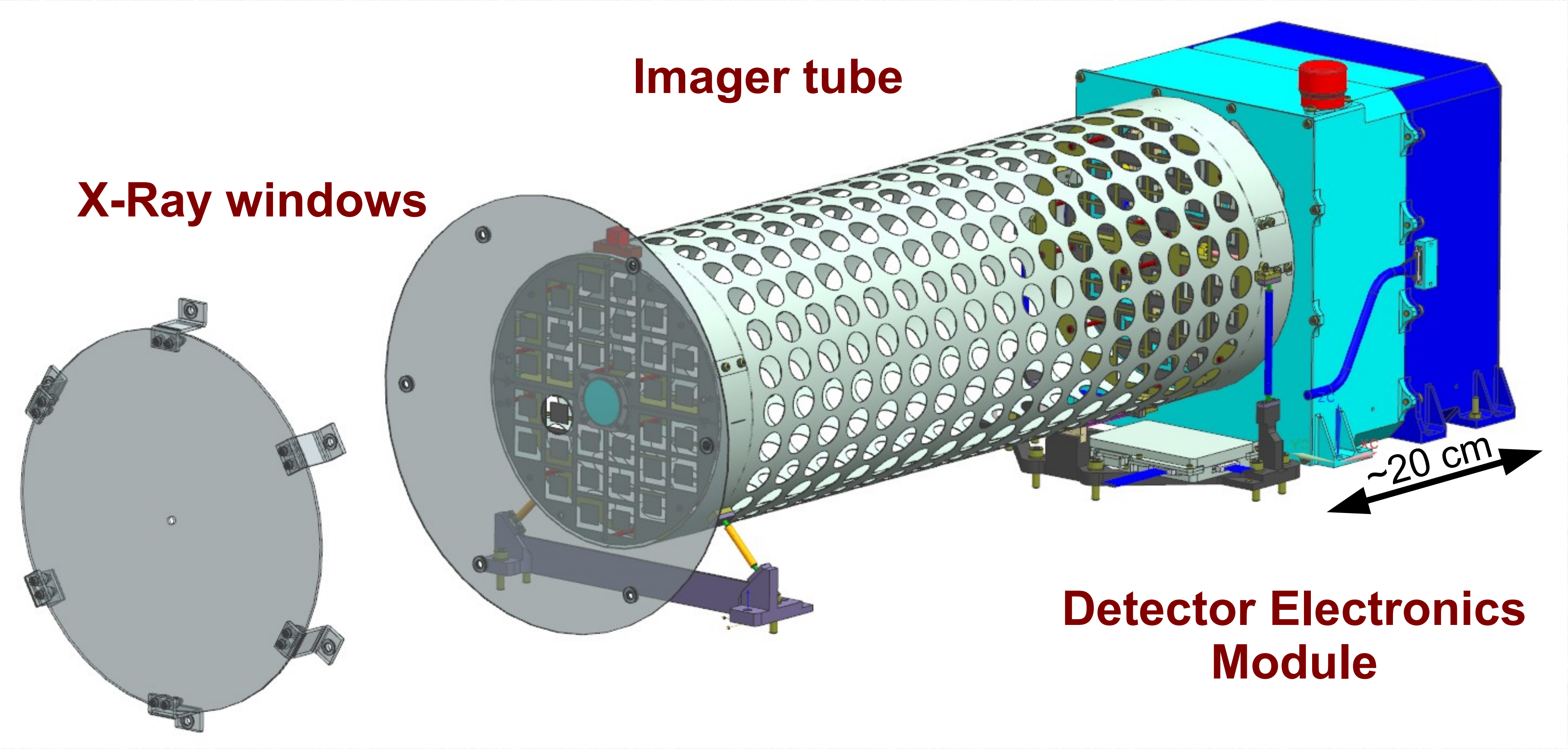


X-ray source structures are not very complex

STIX Design

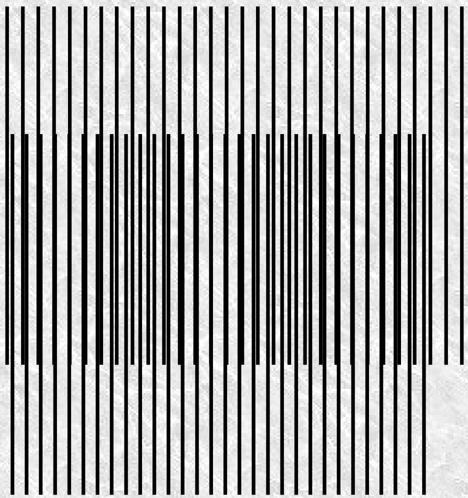
Instrument allocation is **4 W** power, **7 kg** mass and **700 bits/s** telemetry.

→ only indirect Fourier imaging feasable at X-ray energies for required parameters



Energy range	**4-150 keV**	Angular resolution	**7 arcsec**
Energy resolution	**1 keV (FWHM @5 keV)**	Pointing accuracy	4 arcsec
Effective area	6 cm^2	Field of view	**2°**
		Time resolution	0.1s (statistics limited)

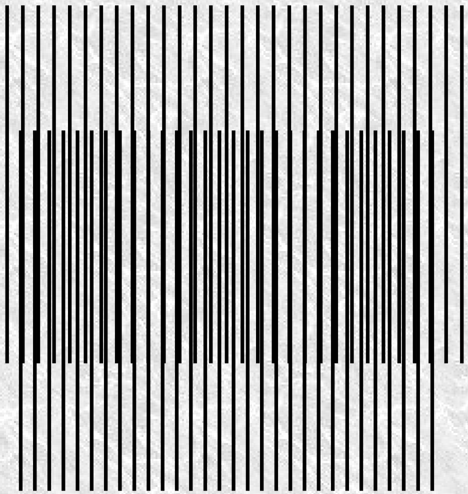
STIX imaging: Basic principle



2 grids with slightly different pitch

Illuminated by point source at large distrance
→ **Moire transmission pattern**

Large-scale Moire structure encodes direction to point source



One grid shifted by ½ period
→ **Large-scale pattern moved by ½ period**

Shift equivalent to source moved in angle by $\frac{\frac{1}{2}\text{ grid pitch}}{\text{grid separation}}$

→ **Coarsly pixelized detector sufficient for high angular resolution**
(if fine grids with large separation used)

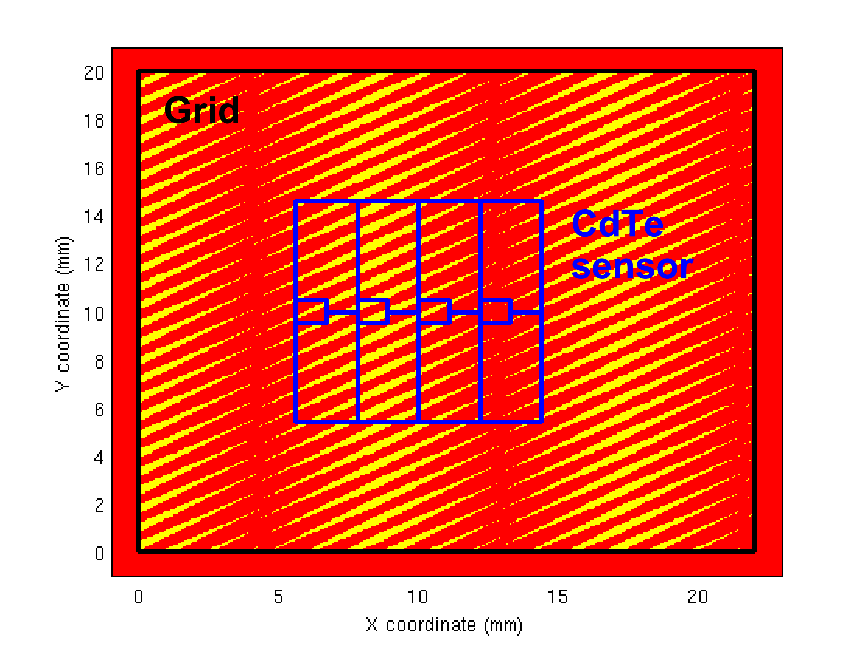
Number of grid pairs determines allowable **source complexity**

Slightly different angles on grids generates Moire pattern

→ orientation of Fourier component and Moire pattern decoupled

Pitch 666 / 690 µm
Angle 60° / 64°
Vertically impinging x-rays

→ Large scale Moire pattern period 10 mm

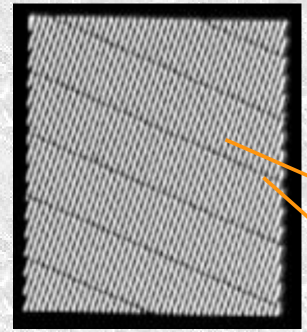


Pixel count rate differences encode source direction

Imaging in STIX

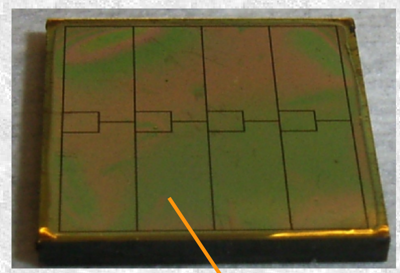
32 Tungsten grid-pairs

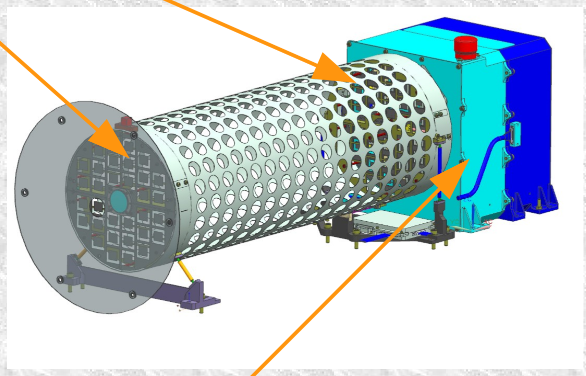
Pitch 38 µm – 1 mm
400 µm thick
30 Fourier components in three directions
2 special counters



32 CdTe semiconductor sensors

$10 \times 10 \times 1$ mm^3
Sensors from Acrorad (Japan)
Pattering and testing at PSI, Switzerland

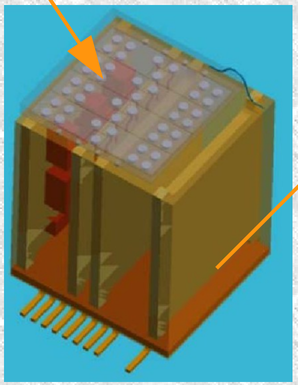




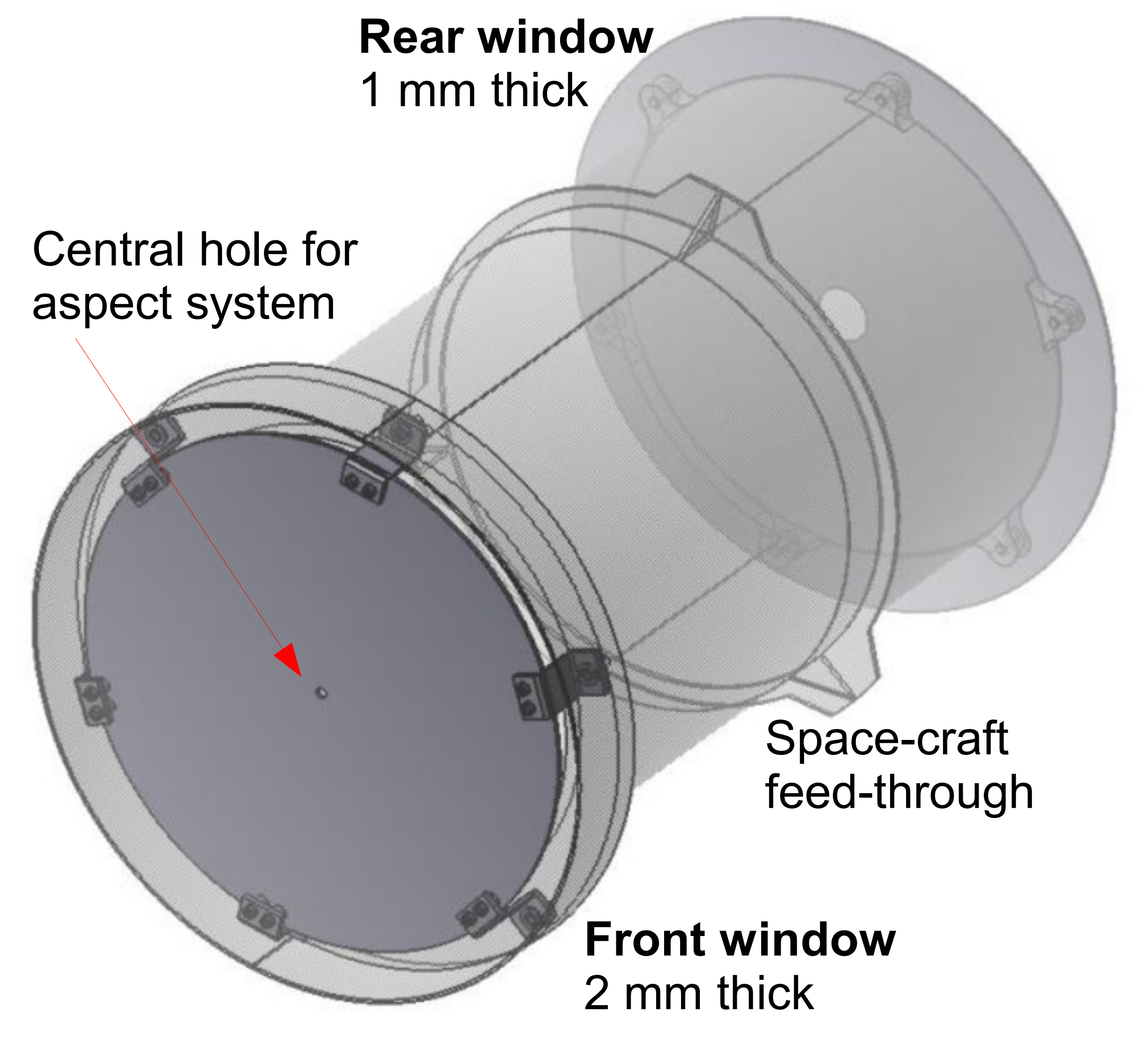
32 Caliste-SO hybrids

ASIC, voltage filtering and bias routing

ASIC and hybrid developed at CEA Saclay, France



Beryllium X-ray windows



Al-SiOx coating

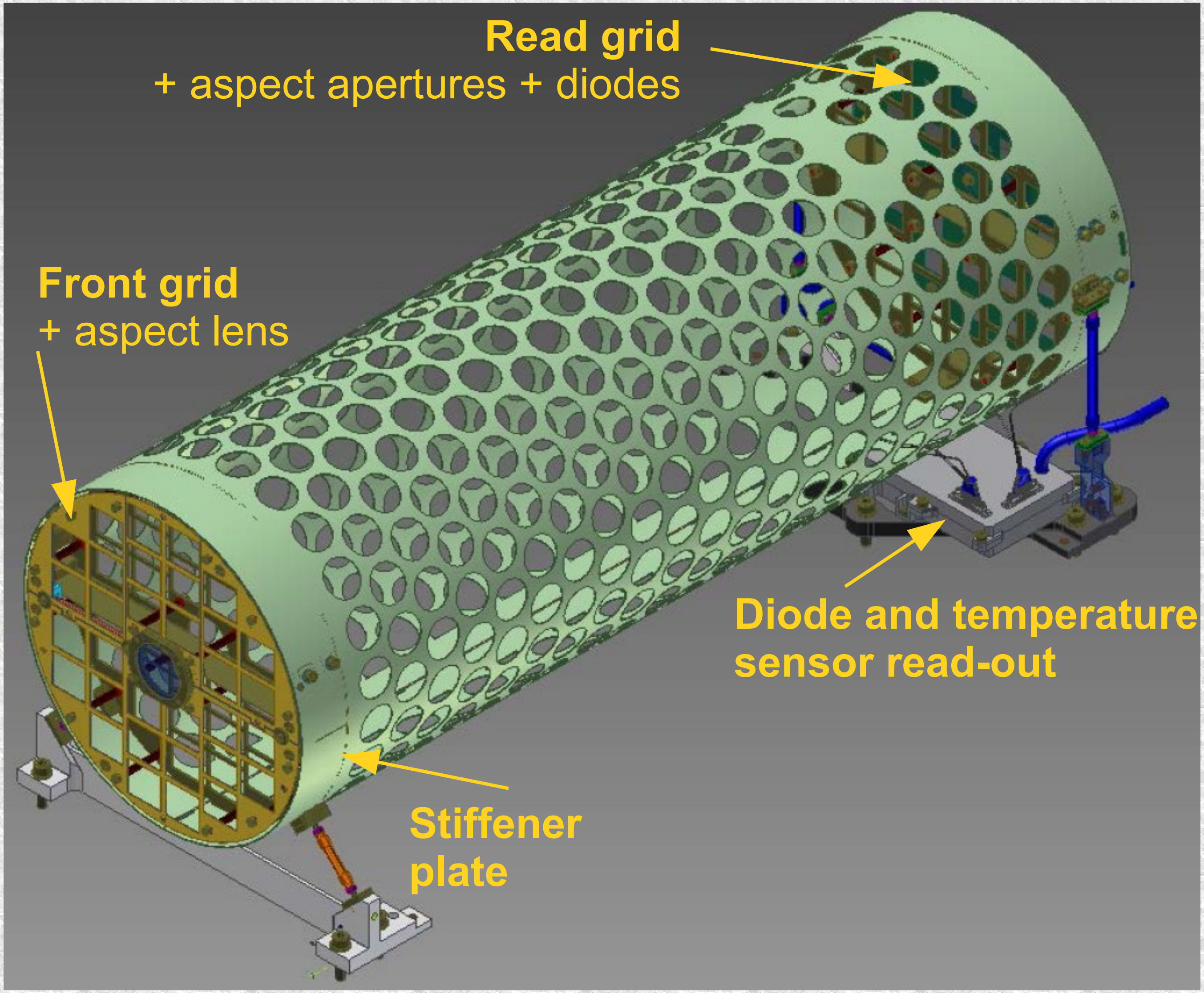
Redundant against failure of one window (e.g. micrometerorite)

Mass 360 g (without feedthrough)

Temperatures at perihelion
- 300°C front
- 180°C rear

Courtesy almatech

Imager



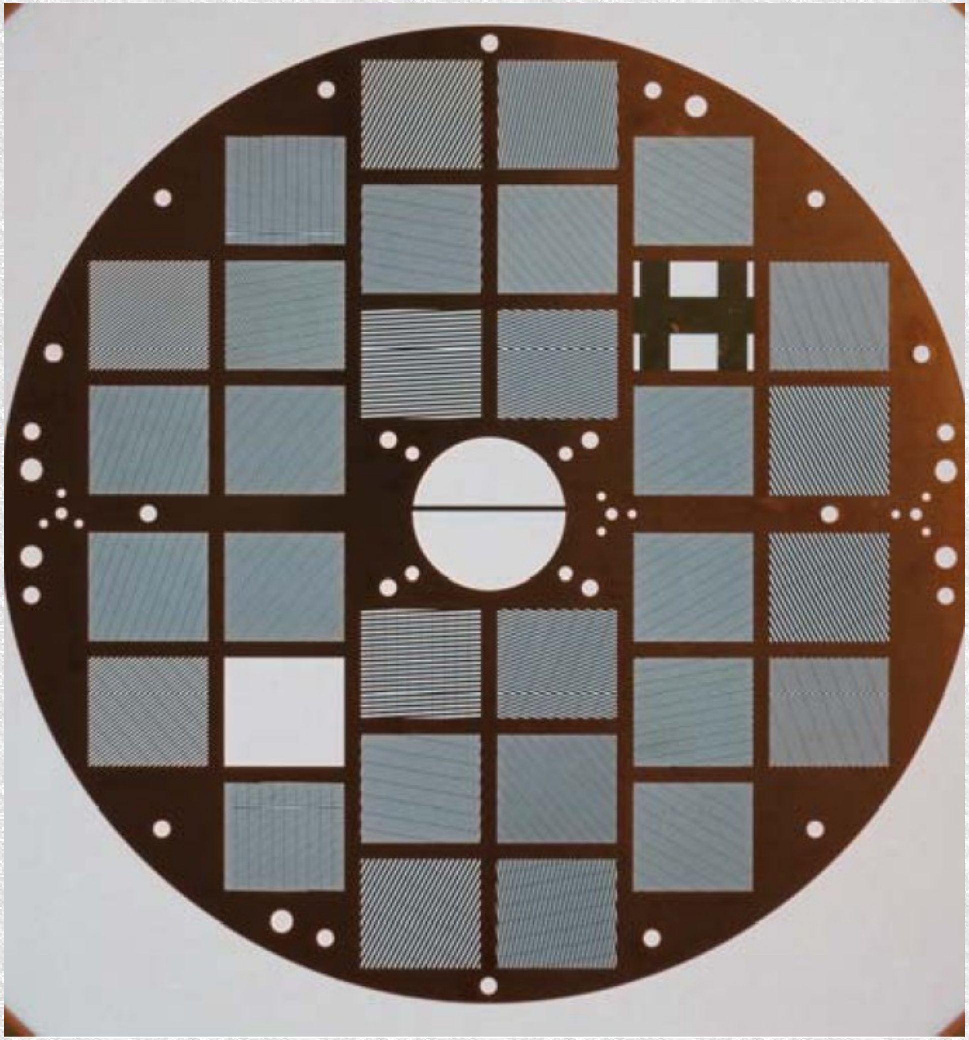
Tube supports front and rear grid assembly

Prevents twisting of grids

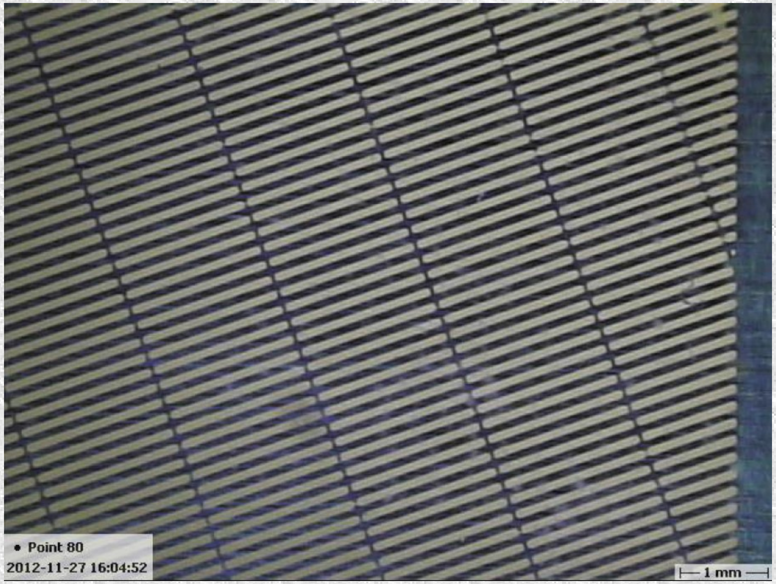
Mass ~1.6 kg

Aspect system to establish line of sight

400 µm thick Tungsten grids



Front grid copper dummy



32 subcollimators
Pitch 38 µm to 1 mm

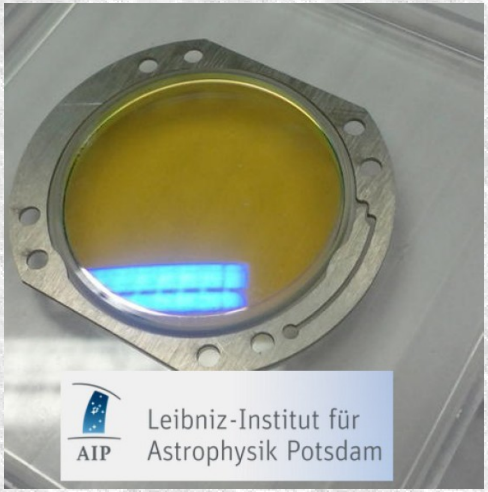
Mounting & alignment apertures

Produced from etched and stacked Tungsten foils

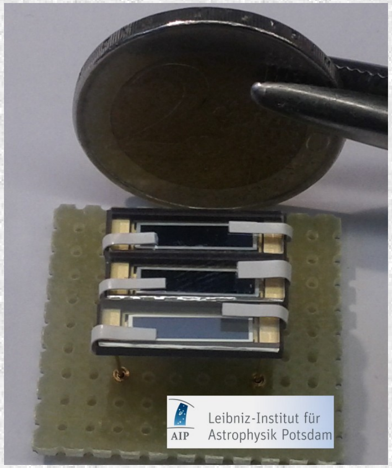
Aspect system

Lens in front grid casts solar image on rear grid

Linear photodiodes illuminated through holes in rear grid



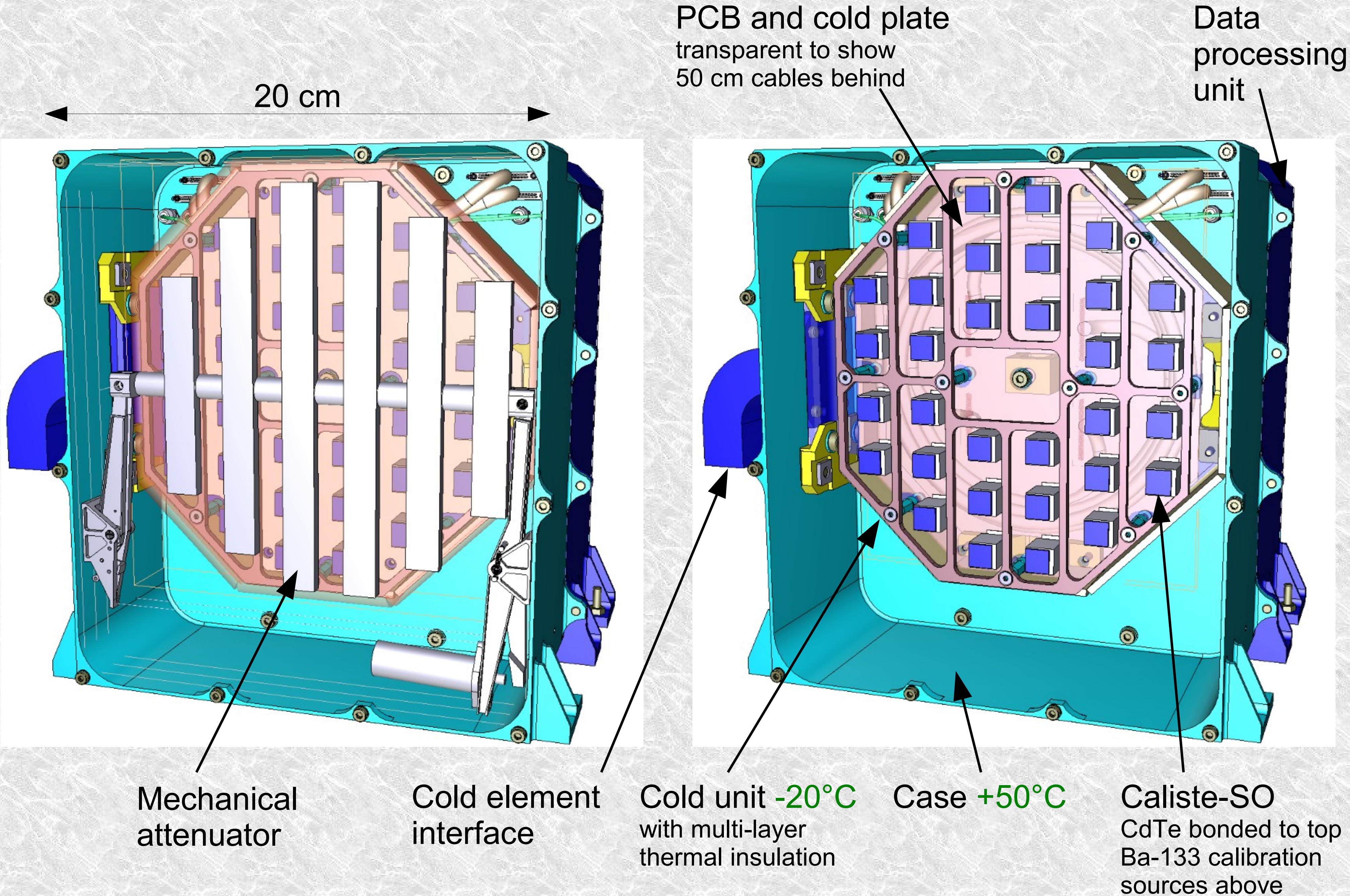
- Step-wise change in diode signal
  when solar limb crosses hole
- Signal decrease due to diode aging
  not signficant for limb detection
- 3 points define solar disk
  4^{th} point for redundancy/error determination



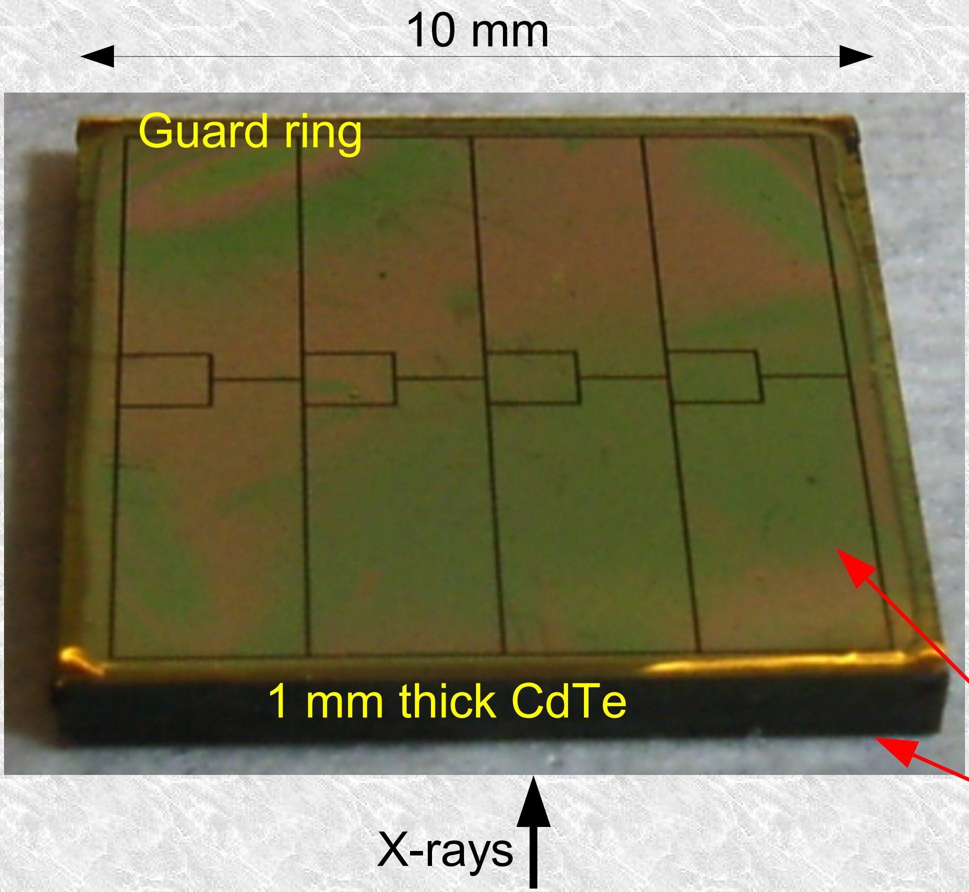
Imager line-of-sight determined to 4 arcsec

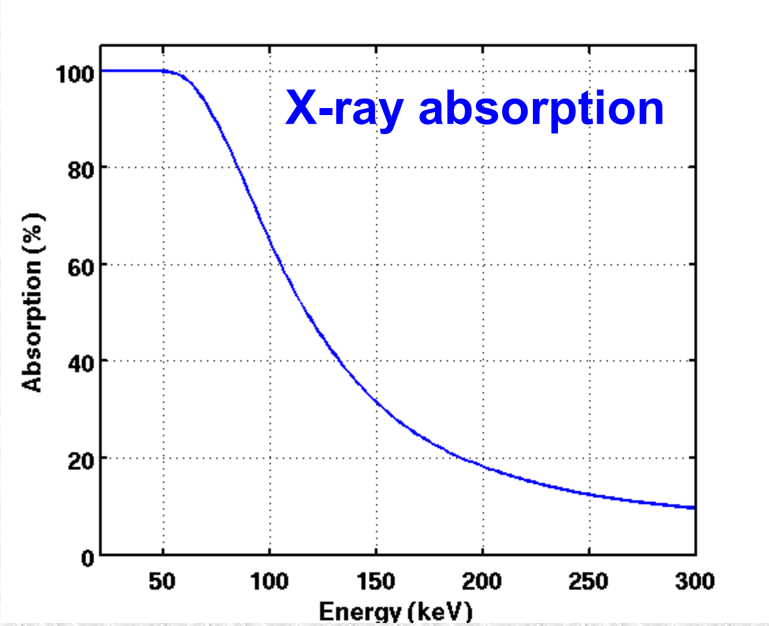
→ **X-ray images can be accurately placed on Sun**

Detector Electronics Module (DEM)



CdTe semiconductor sensors





Pixilized Au-Ti-Al Schottky electrode (connected to ASIC inputs)

Monolithic Platinum Electrode (-300 V)

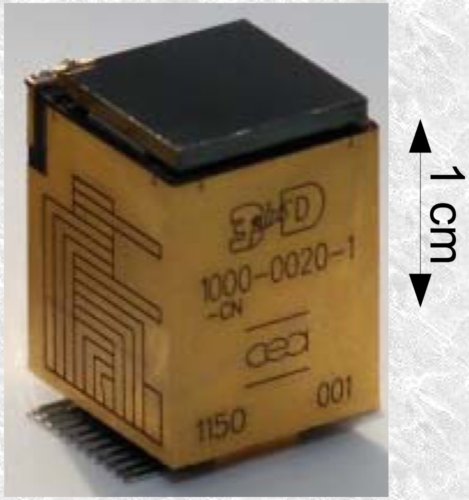
Pair creation energy	4.43 eV (870 pairs at 4 keV)
Leakage current (large pixel)	<60 pA (-20ºC, 300 V)
Charge absorption length	10 cm / 0.6 cm (electron/hole)

Non-ionizing dose (NIEL) will degrade charge collection over mission duration
Total ionizing dose of 30 krad otherwise not severe

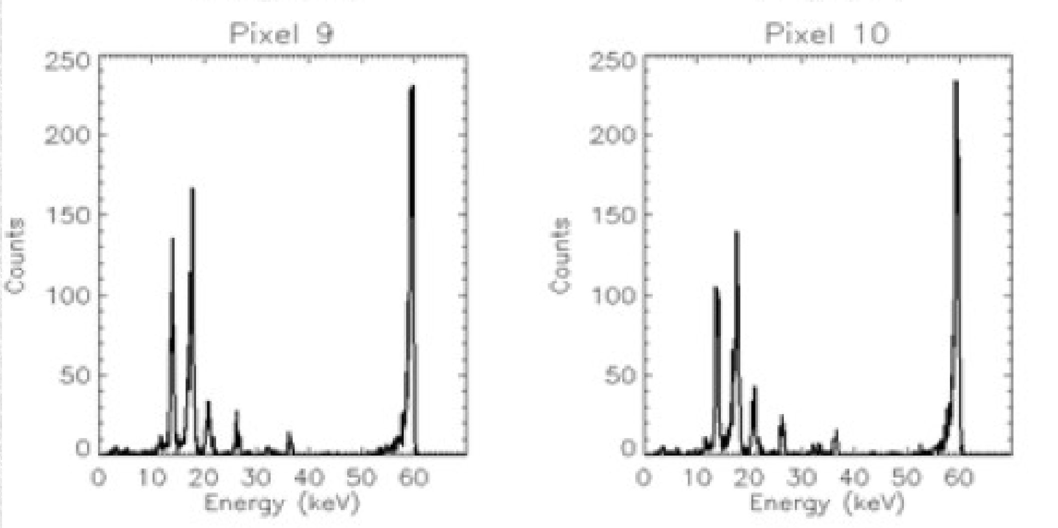
Caliste-SO read-out hybrid / ASIC

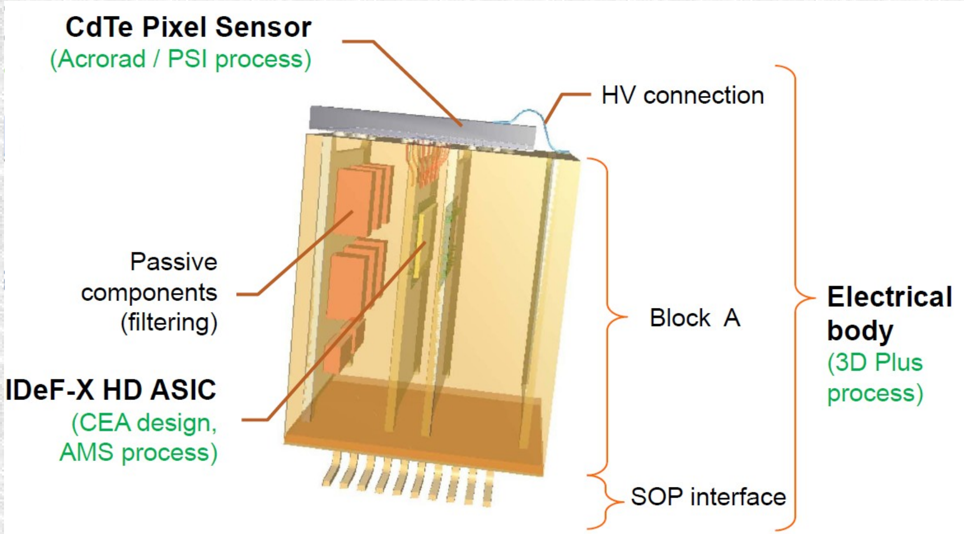
Caliste-SO hybrid contains CdTe bonded to top
IDeF-X HD ASIC
bias routing, filtering

ASIC 32 charge-sensitive amplifiers, ENC ~80 e^-
multiplexed readout (~6.6 μs per hit @ 20 MHz clock)
~1 mW/active channel



Americium-241 spectrum

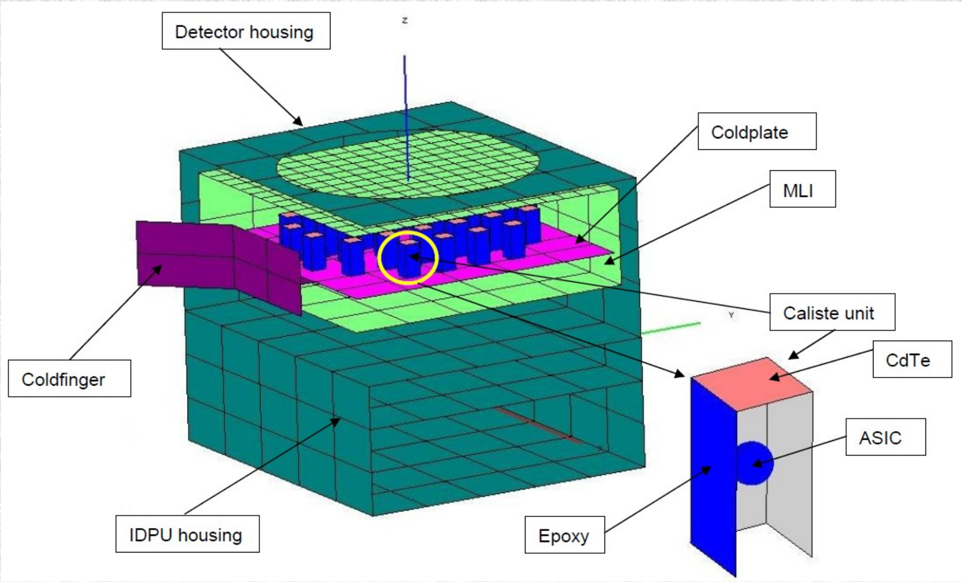




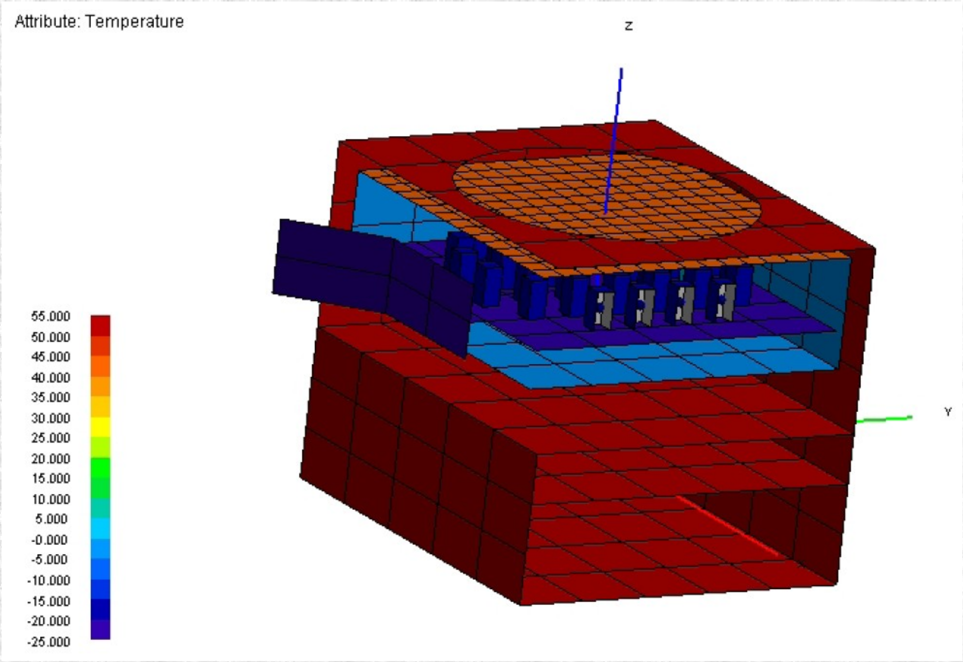
Resolution FWHM < **1.2 keV @ 14 keV**

Thermal simulation

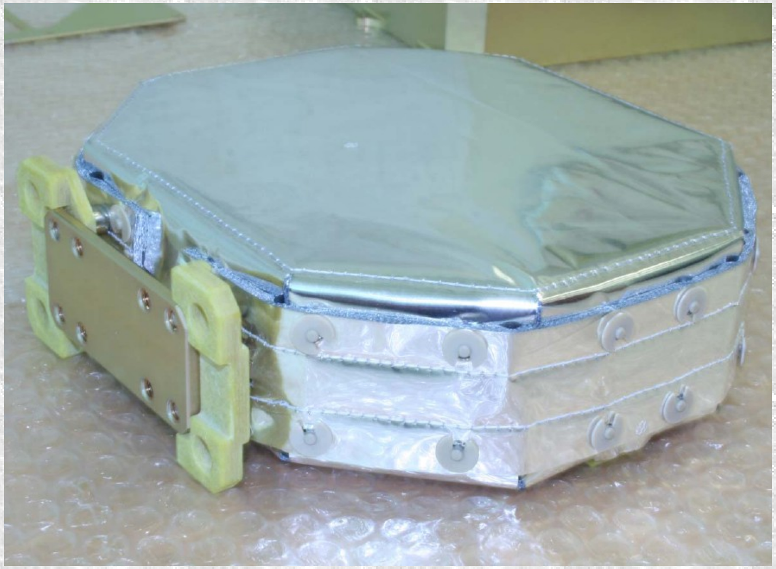
ESATAN model



Temperatures (hot operational case)



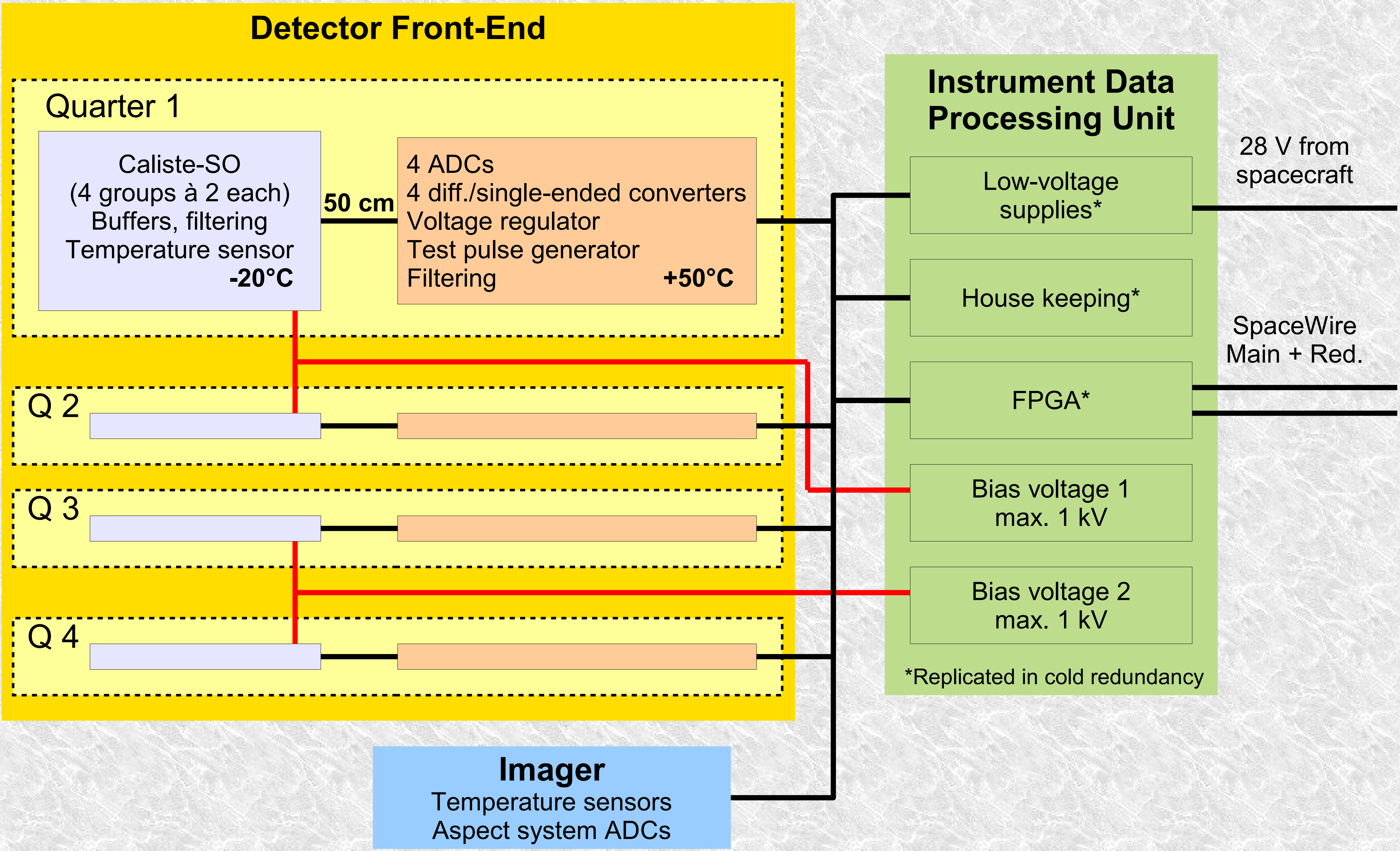
Test unit



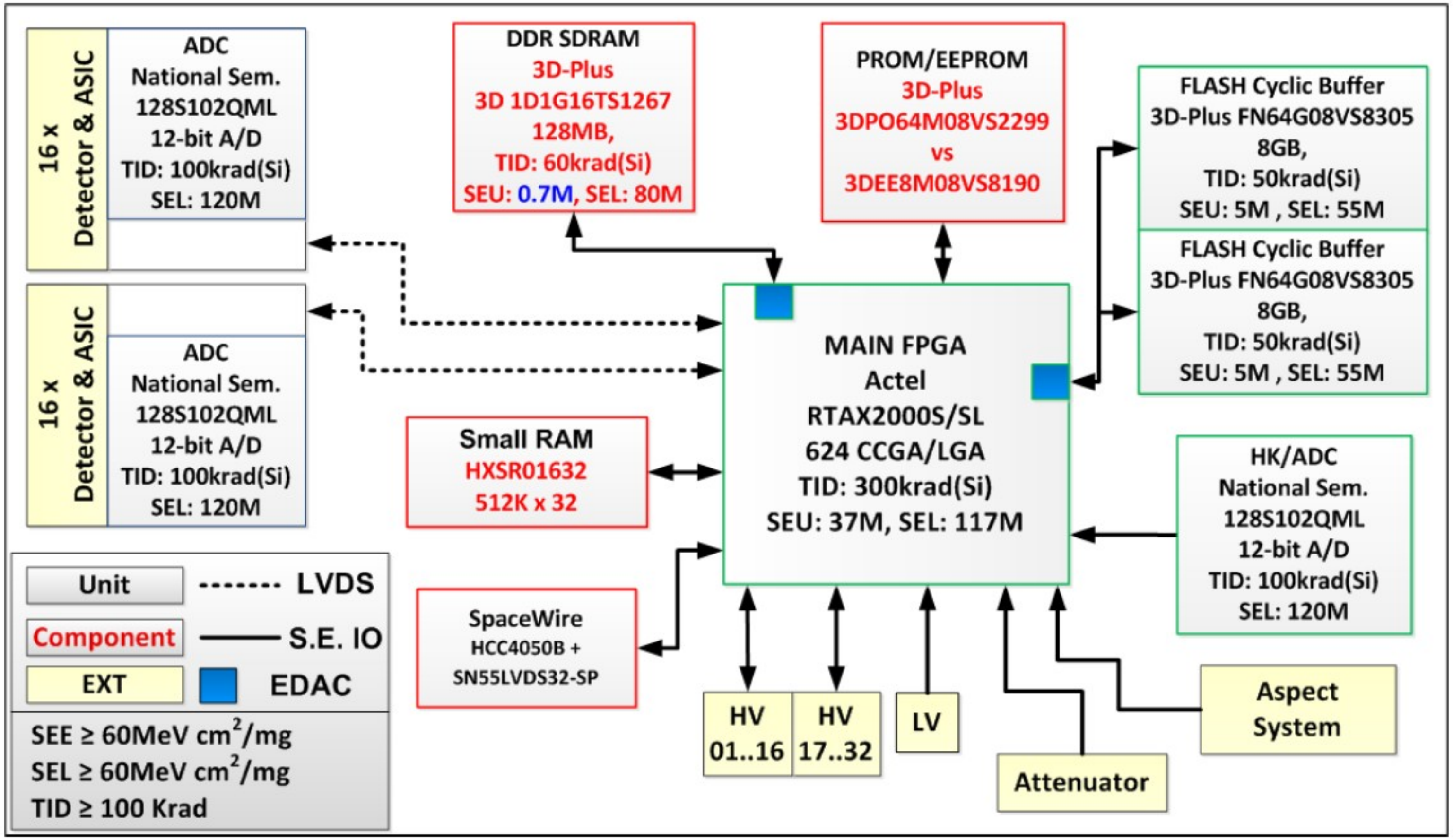
Model predicts heat flux to cold element of **2.5 W**

→ above current space-craft allocation
→ under study with a bread board

Simplified STIX block diagram



Instrument Data Processing Unit



Event rates up to 10^5 s^{-1} during strong Solar flares (all Caliste simultaneously)

Autonomous operation up to 80 days

Several month of science data can be stored on-board
→ provides telemetry flexibility by allowing off line data selection and downlinking

Outlook

STIX currently in realization phase C

ESA critical design review in 2013

Industrial prime contractor will oversee instrument construction in phase D

Flight instrument delivery to ESA January 2015

Launch January 2017

Extra slides

In-flight energy calibration

ADC count to x-ray energy has to be established over 10-year mission duration

CdTe charge collection degrades due to displacement damage from protons

Changing leakage current will alter response of ASIC

ASIC gain / offset have small dependence on temperature

Requirements on calibration

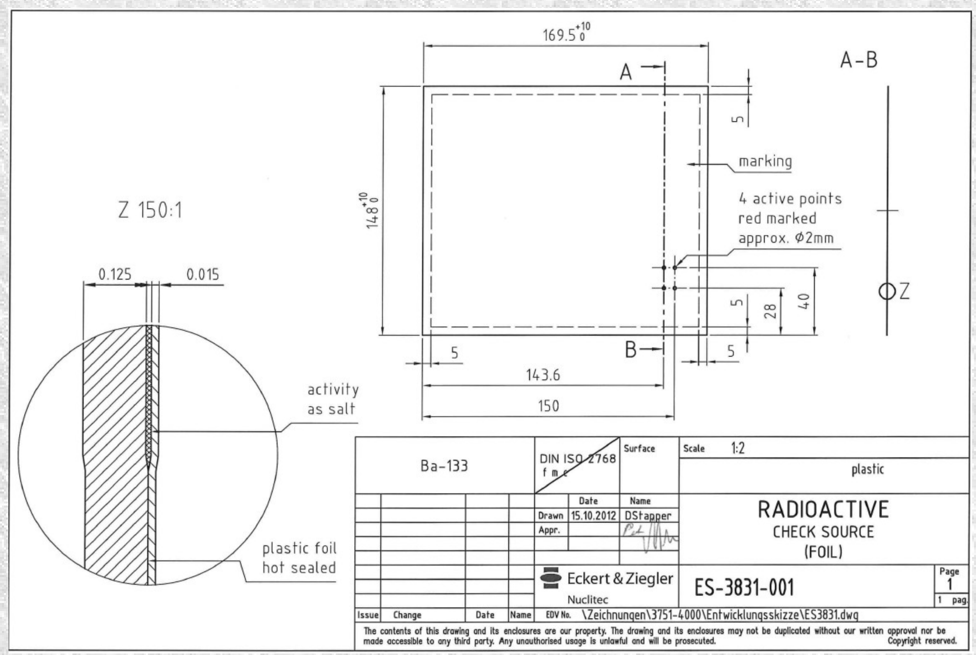
Steep spectra → $100\ eV_{rms}$ precision for each pixel
Low background → Source strength must be low

Technical realization

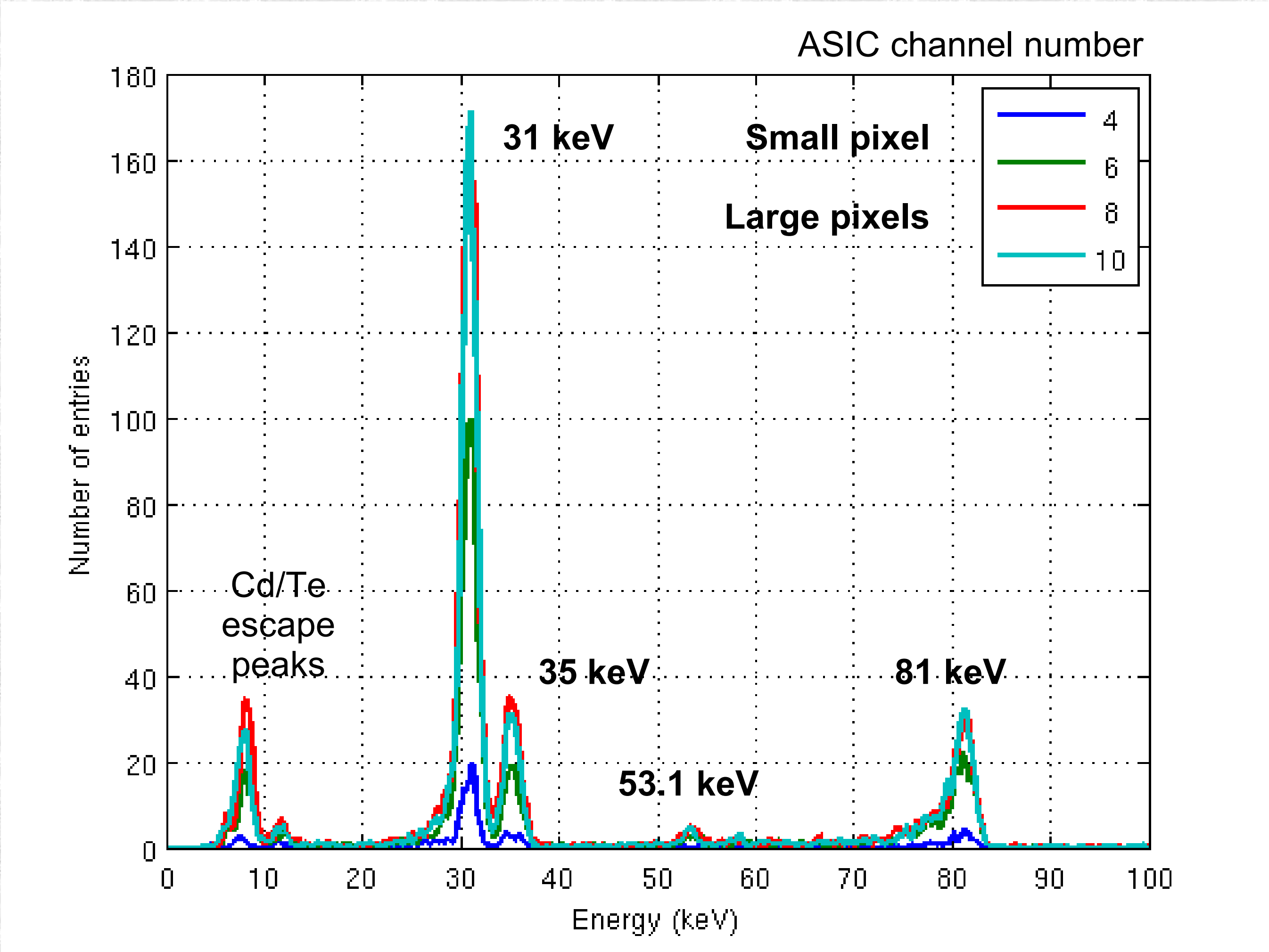
Barium-133 ($t_{1/2}$=10.5 years)

Ø1 mm dots (<1 Bq activity) wedged between plastic foils

Mounted on support of multilayer insulation

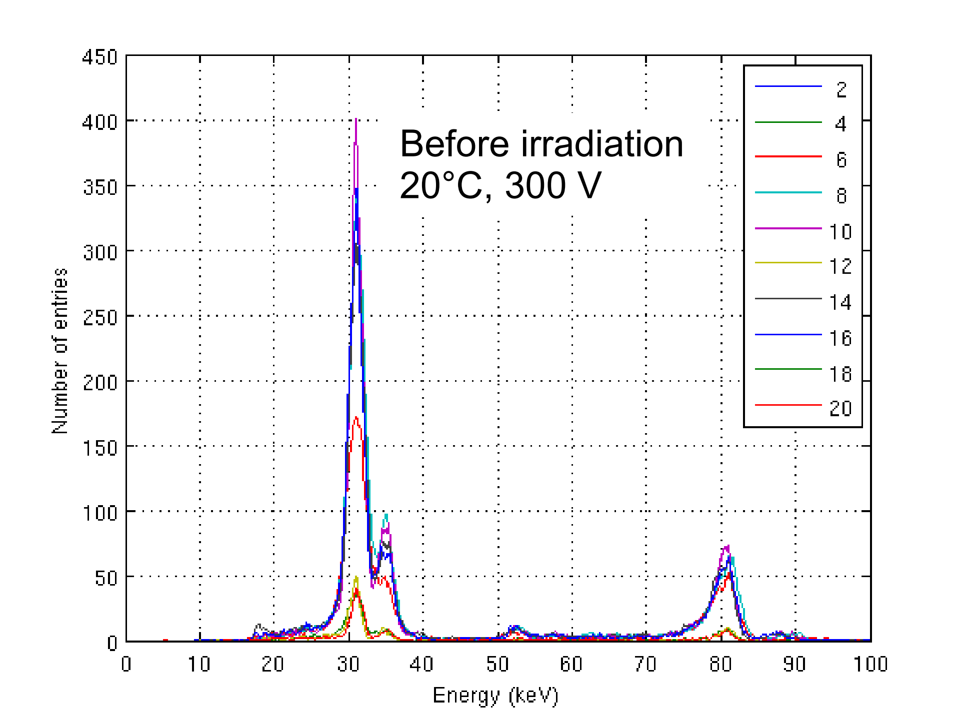


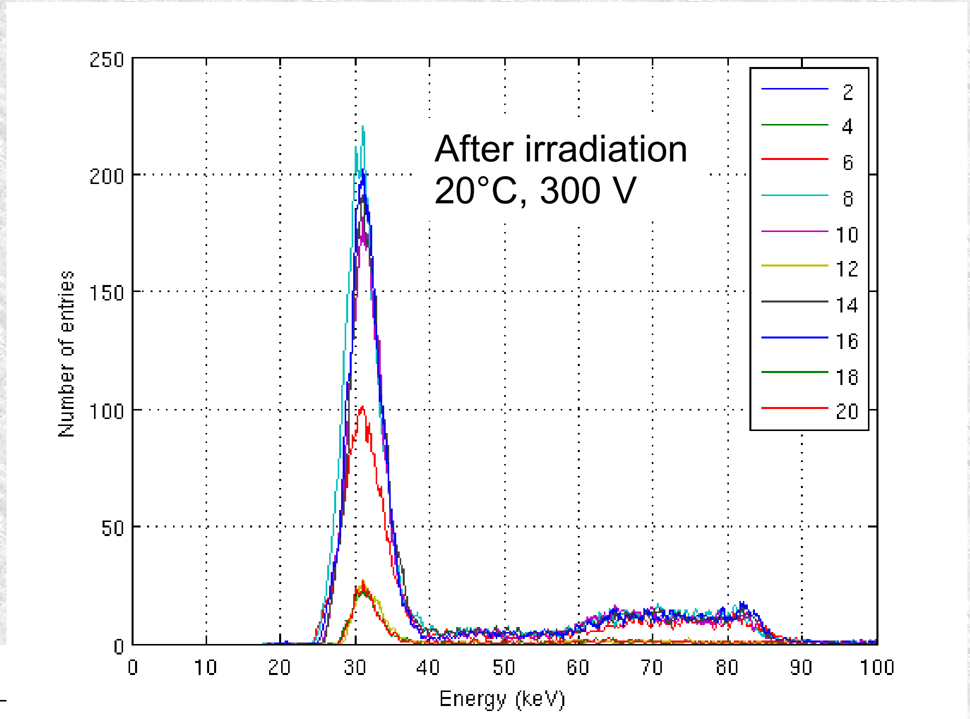
Barium-133 spectrum



Bias **300 V**, temperature **-20ºC**

Radiation damage of CdTe





200 MeV protons

Fluence $3.6 \cdot 10^{10}$ p/cm^2

approx. 1.4 krad

STIX worst-case ~20 krad

Duration 10 hours

^{133}Ba spectra