STIX
The Spectrometer/Telescope for Imaging X-ray on Solar Orbiter

Flight design, challenges and trade-offs

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—— for the STIX collaboration ——

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n|w University of Applied Sciences Northwestern Switzerland

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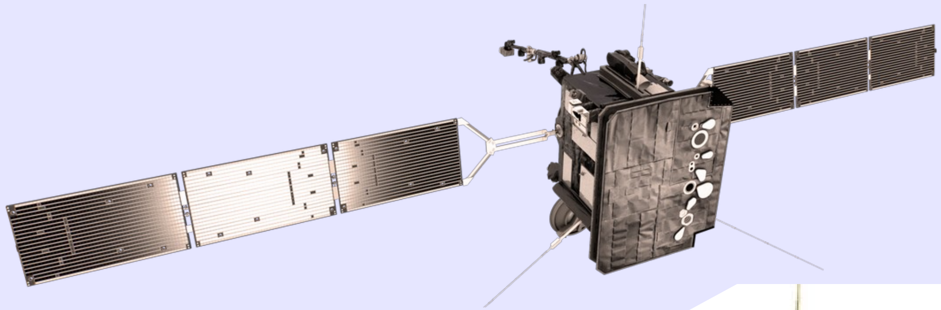
AIP

ESA Solar Orbiter

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

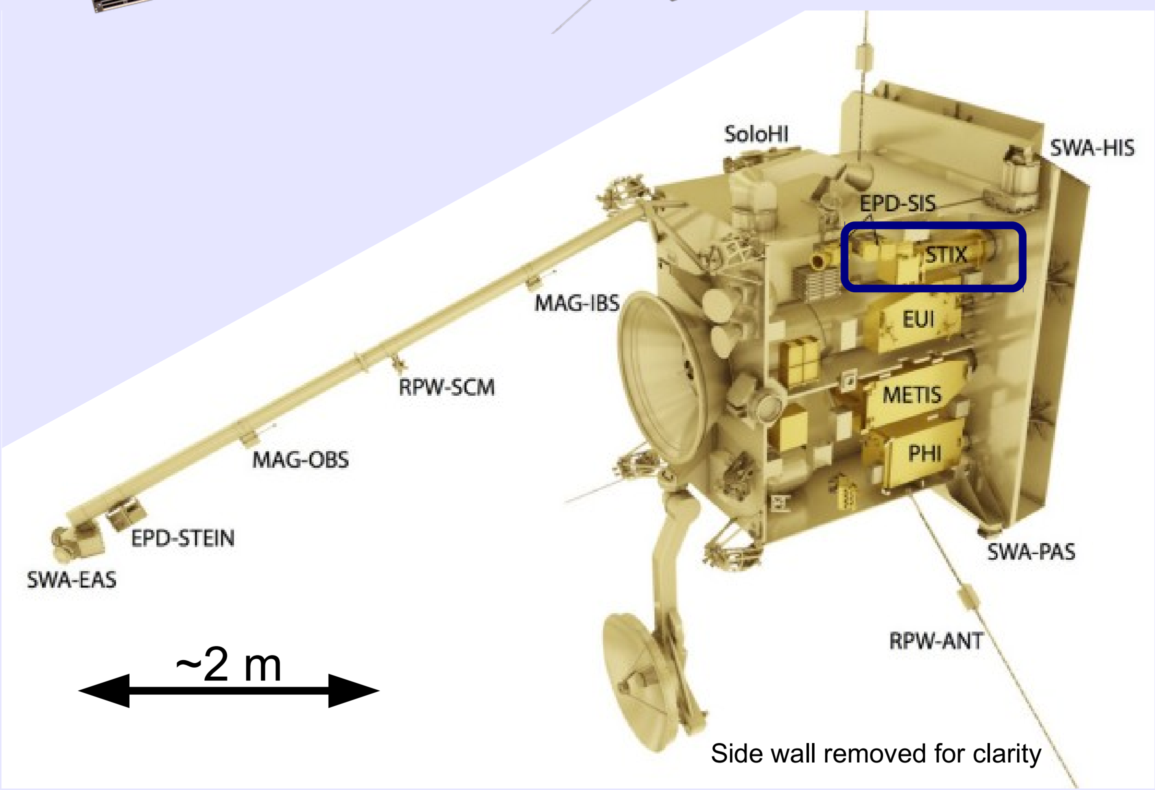
- Sun-heliosphere interaction
- Energetic solar phenomena
- Solar transients, heliospheric variability
- Solar wind accelerating mechanisms
- Solar wind plasma, coronal magnetic fields
- Solar dynamo working principle

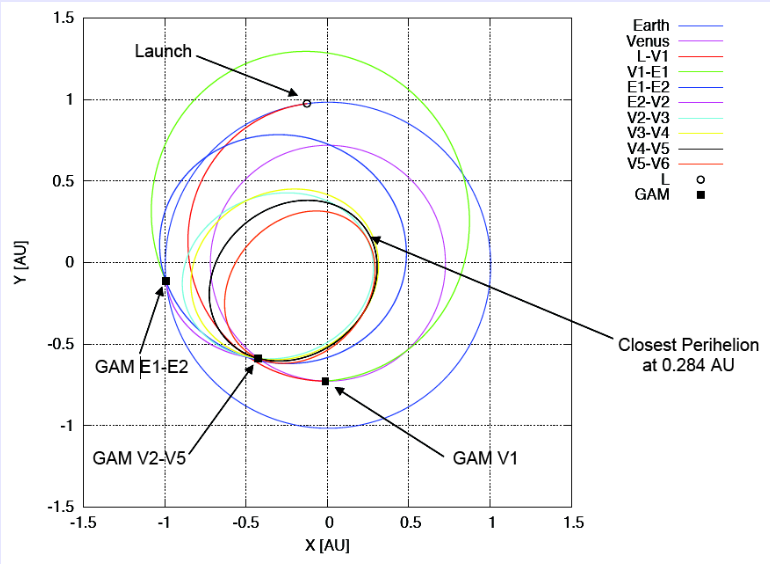


10 instruments
remote-sensing and in-situ

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

Launch October **2018**
Mission duration **4+3 years**



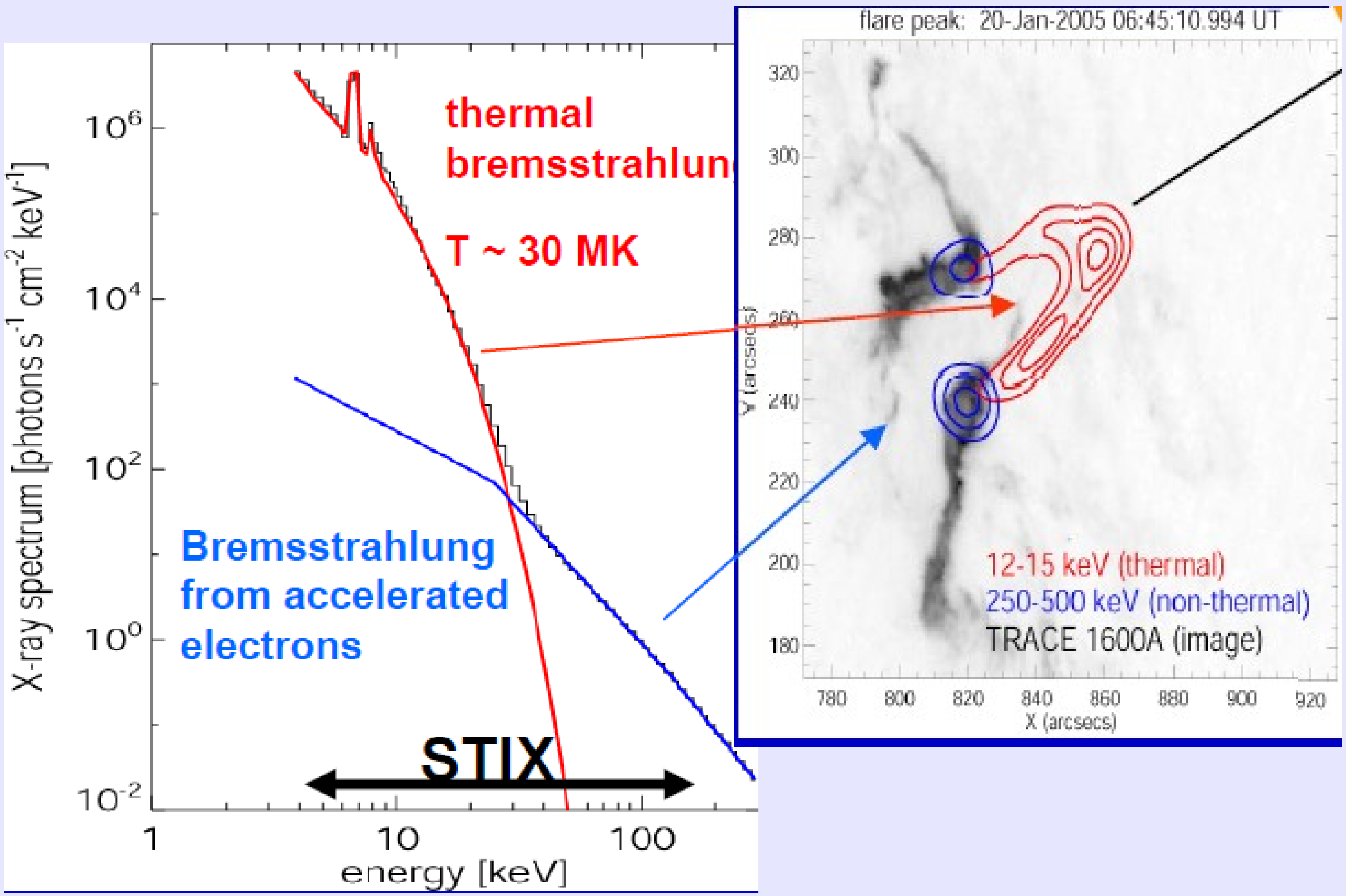


STIX Science Goal

Imaging of the Sun in **4-150 keV X-rays** determines

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

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



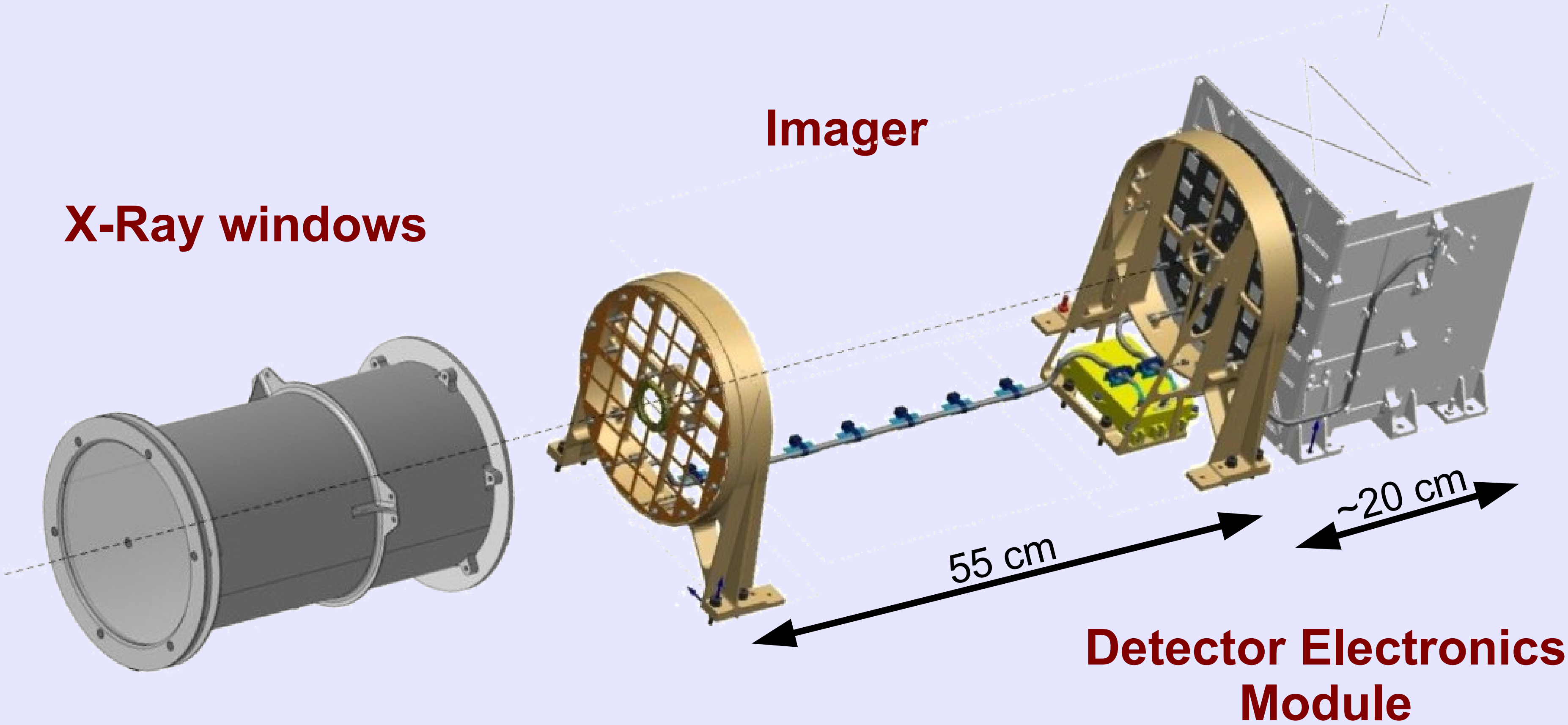
X-ray **source structures** relatively **simple**
→ simple imaging sufficient

Thermal **spectra steep**
→ need good energy resolution & low-energy attenuation

STIX Design

Instrument allocation **8 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)	Field of view	**2°** (full Sun at perihelion)

STIX imaging principle

Pairs of X-ray opaque grids with slightly different pitch and orientation

→ **Moiré transmission pattern**

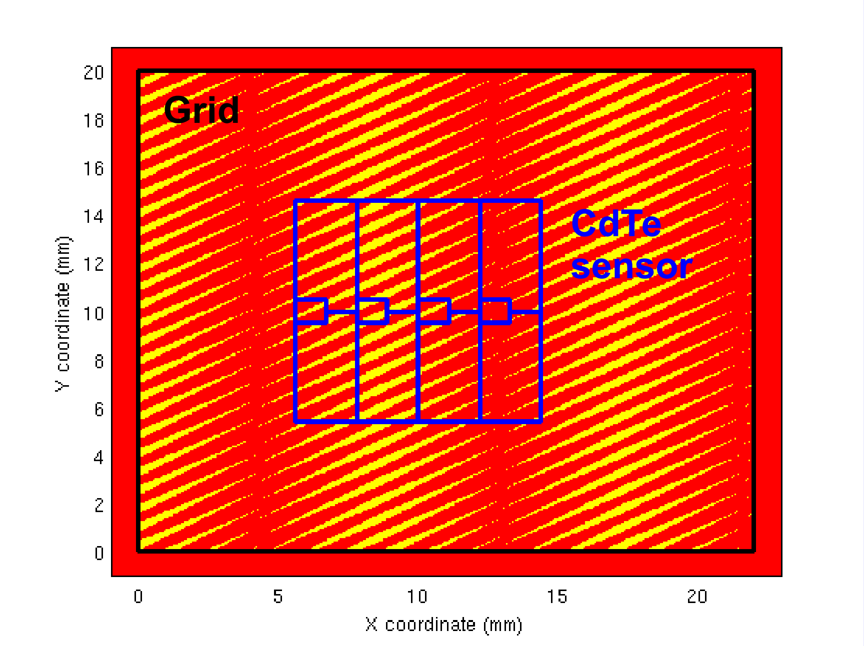
Large-scale Moiré structure encodes source direction (Fourier component)

→ **Coarse pixels** sufficient for high angular resolution

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

Example Pitch 666 / 690 μm, angle 60° / 64°
→ Moire period 10 mm

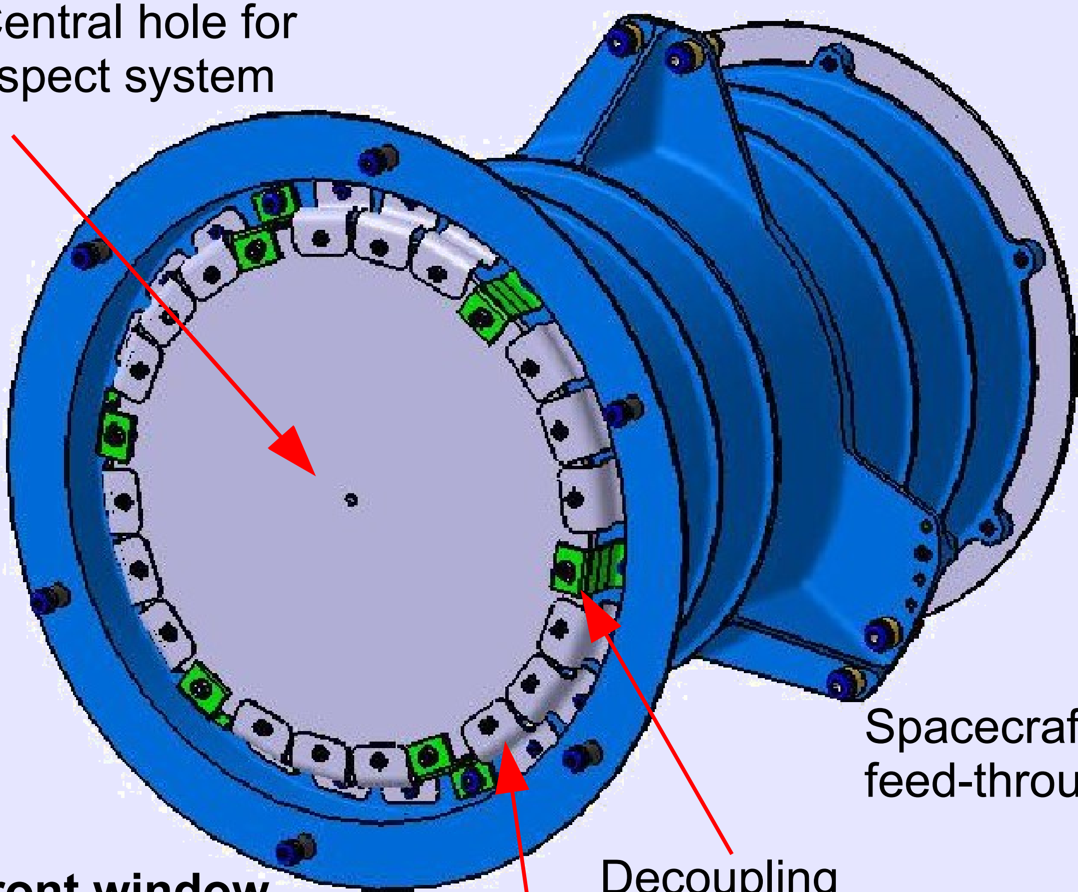
Pixel count rate differences encode source direction



Angular resolution ≈ ½ grid pitch / grid separation

Orientation of Fourier component and of
Moire pattern decoupled

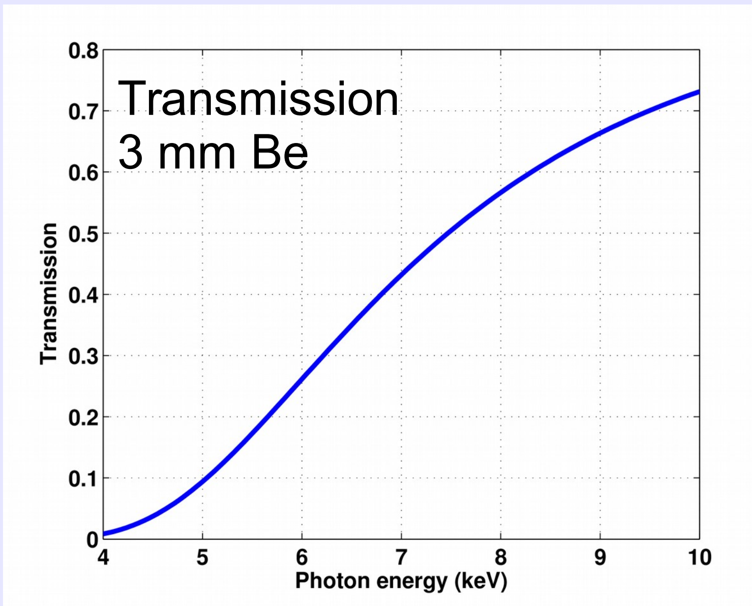
Beryllium X-ray windows



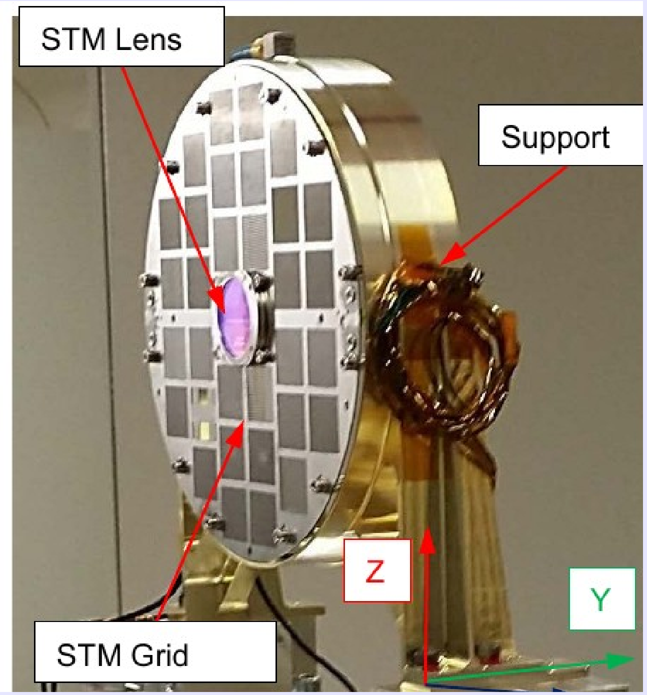
Design needs to be ***structurally stiff*** *but* ***light*** *and* ***thermally*** *well* ***controlled***

Mass 800 g (without feedthrough)

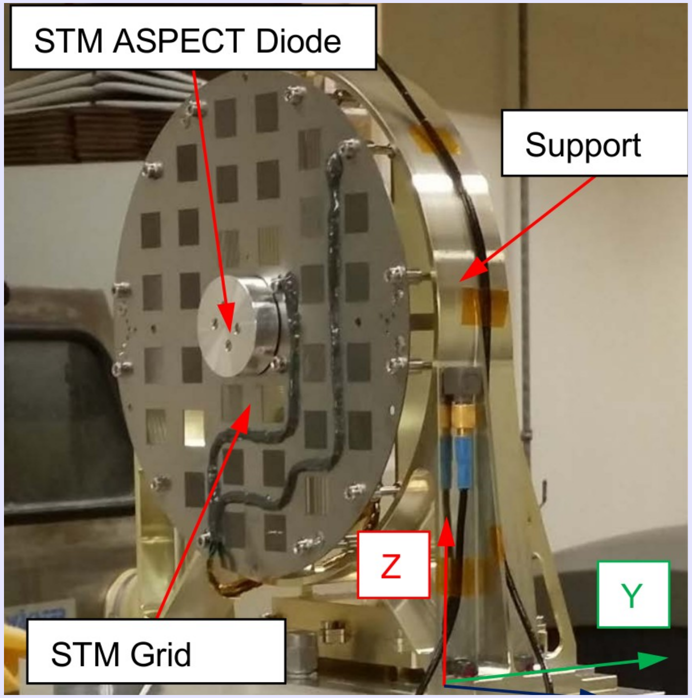
Temperatures at perihelion (17 kW/m^2)
- 500°C front
- 160°C rear



Imager



Front grid



Rear grid

Design needs to ***prevent relative twist*** *of grids, be structurally* ***stiff*** *and* ***light***

Grid separation 55 cm

Mass ~1.6 kg

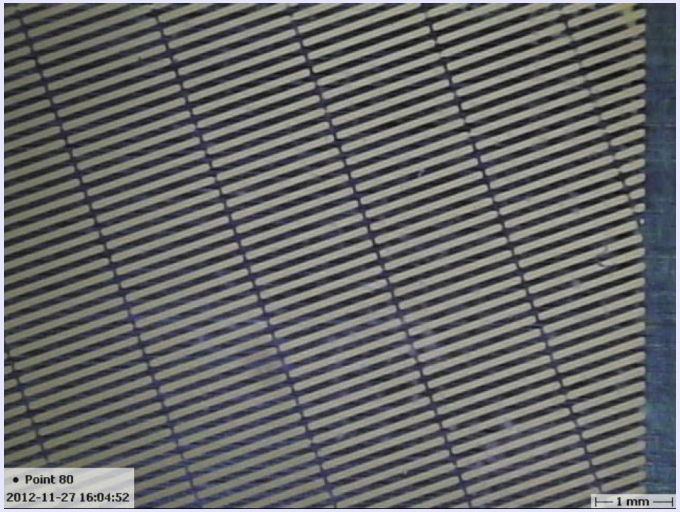
Aspect system
- images Sun onto photodiodes
- detects solar rim
- establishes line of sight to **4 arcsec**

32 Tungsten grid pairs

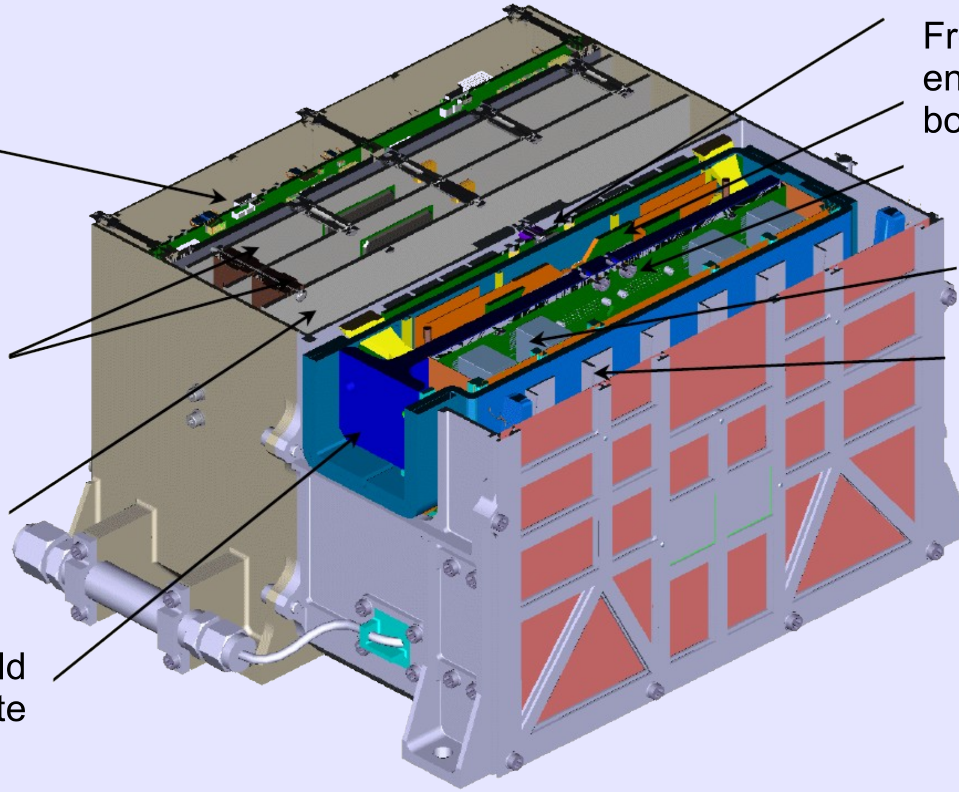
Thickness 400 µm
Pitch 38 µm – 1 mm

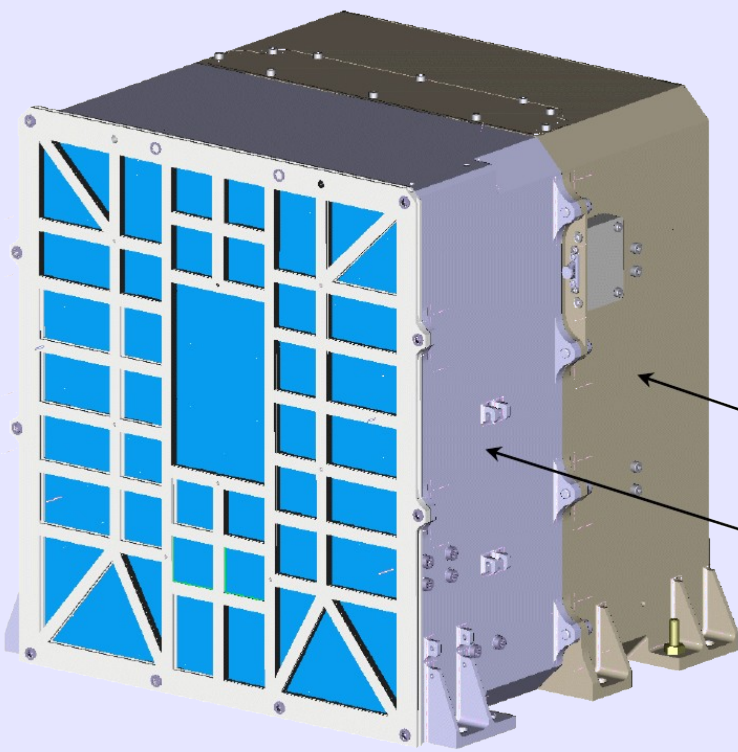
30 Fourier components/3 directions
2 special counters

Produced from etched and stacked Tungsten foils

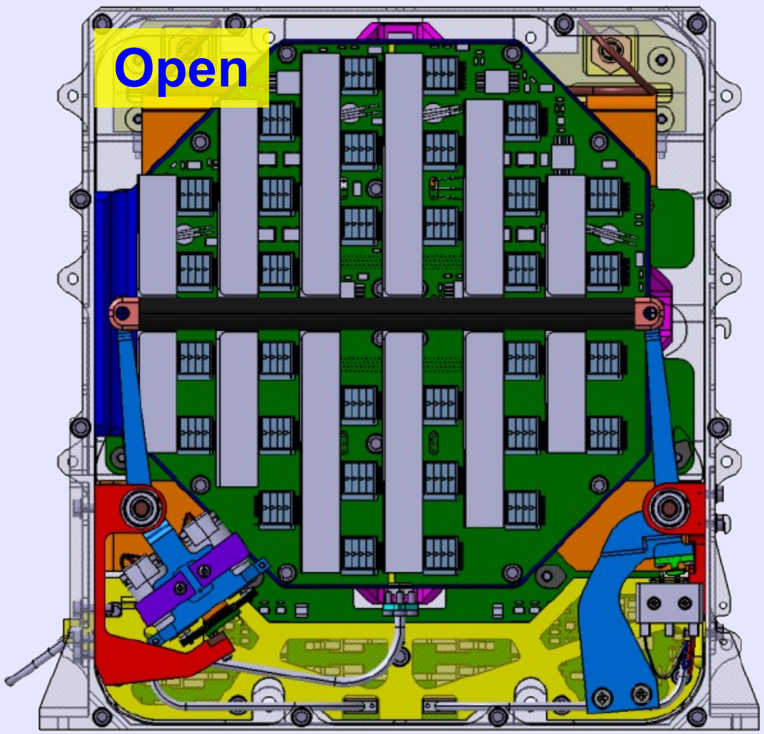


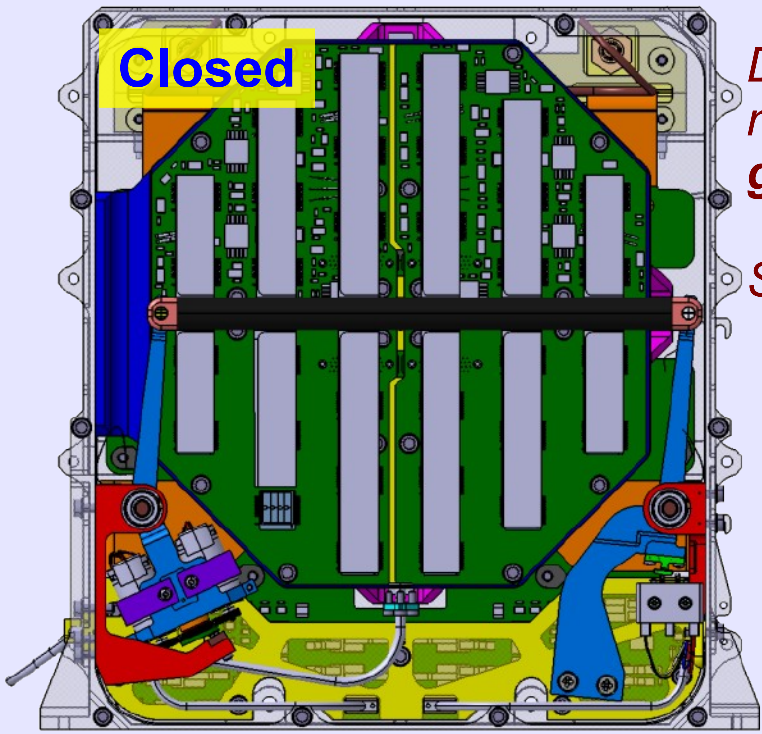
Detector Electronics Module (DEM)





Mechanical attenuator





*Design needs to reliably move the blades, **not get stuck in between***

Stiff against vibrations

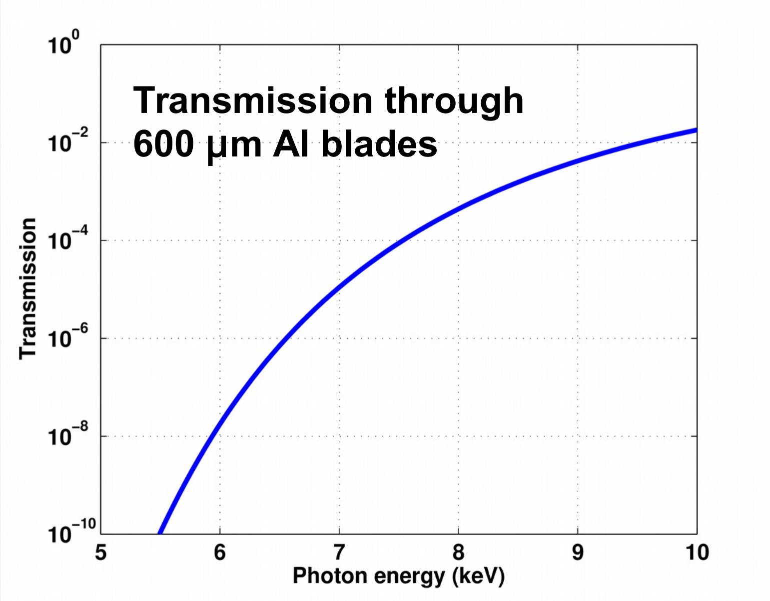
Design life 20'000 cycles

Movement open-closed 2 seconds

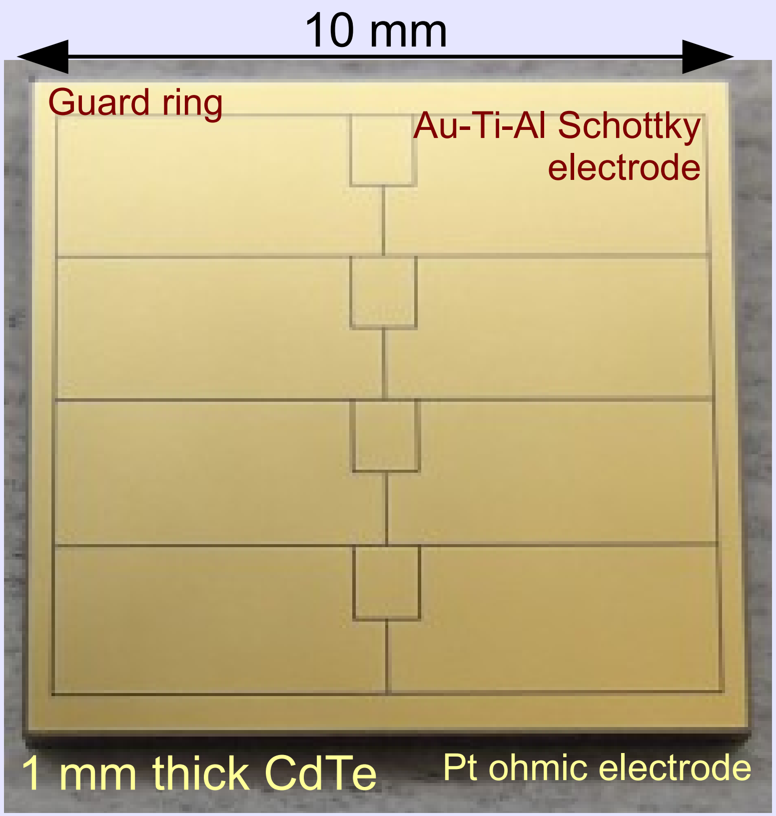
No launch lock (balanced mechanism)

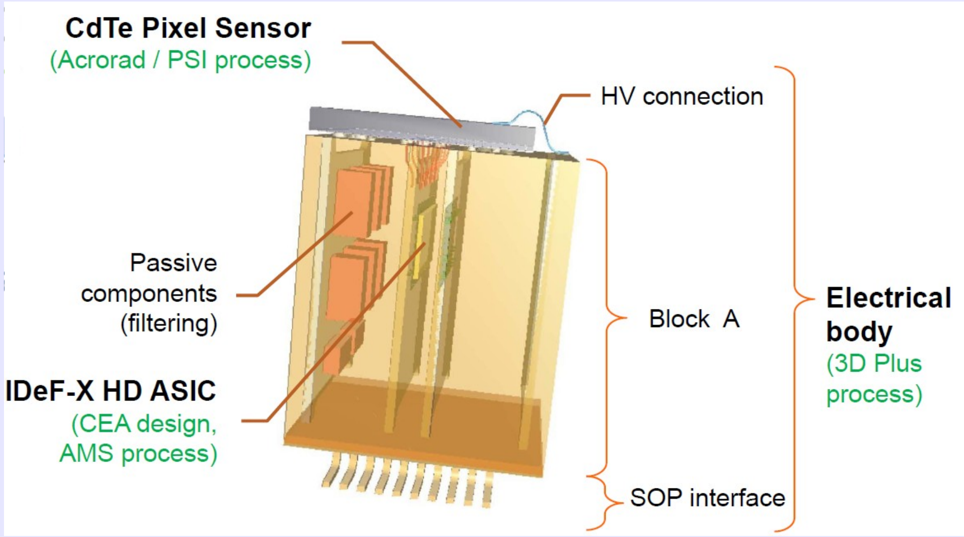
Both position stable without motor power

Autonomous insertion based on count rates



CdTe, Caliste-SO hybrid





CdTe	Pair creation energy	4.43 eV (870 pairs at 4 keV)
	Leakage current	<60 pA (large pixel, **-20ºC**, 300 V)
	Bias voltage	200 V – 600 V

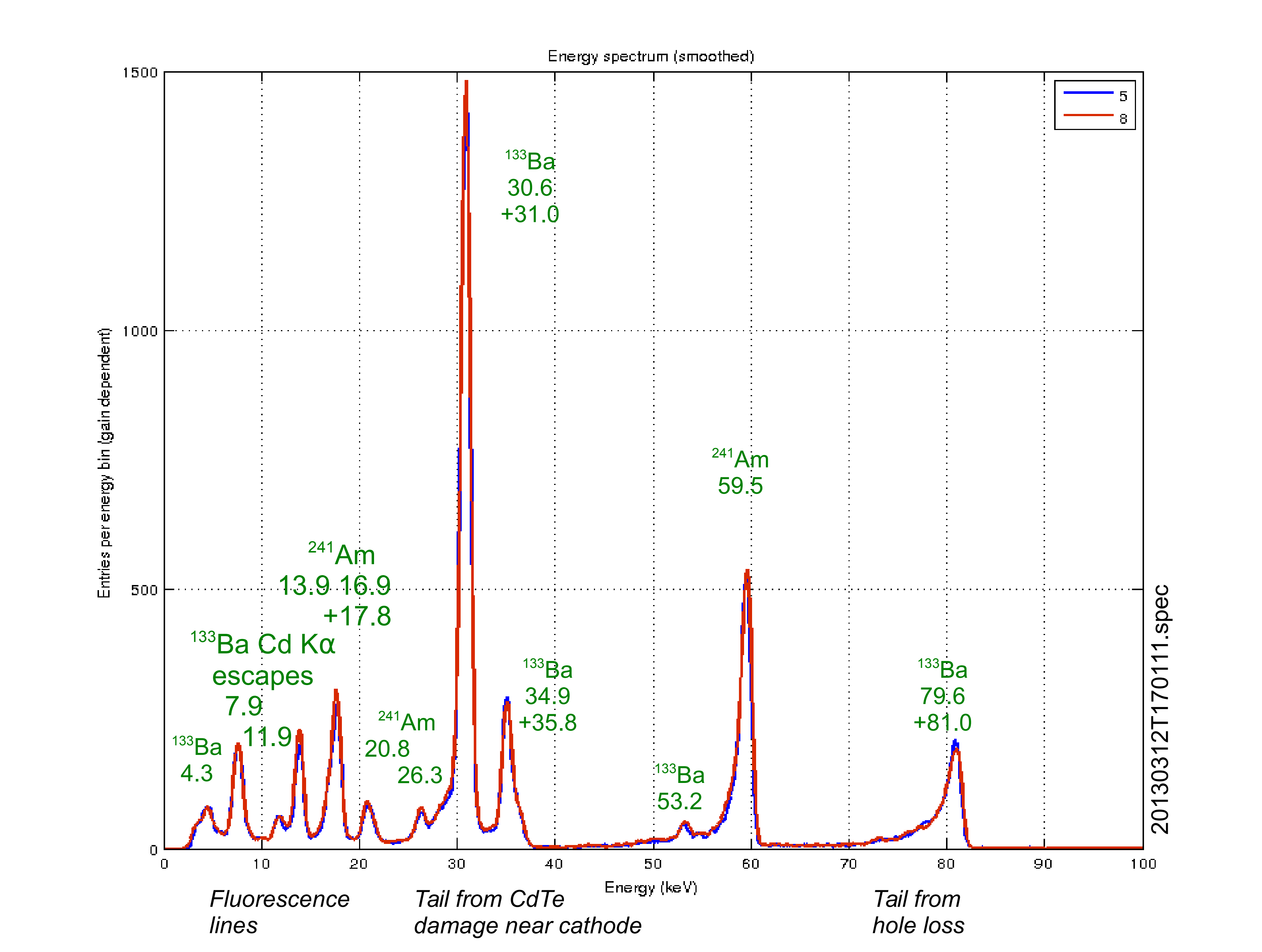
Polarization effect due to deep acceptors, degradation by solar proton flux

ASIC	32 charge-sensitive amplifiers (12 used, ENC ~80 e^-)
	multiplexed readout (~6.6 μs per hit @ 20 MHz clock)
	~1 mW (per active channel)

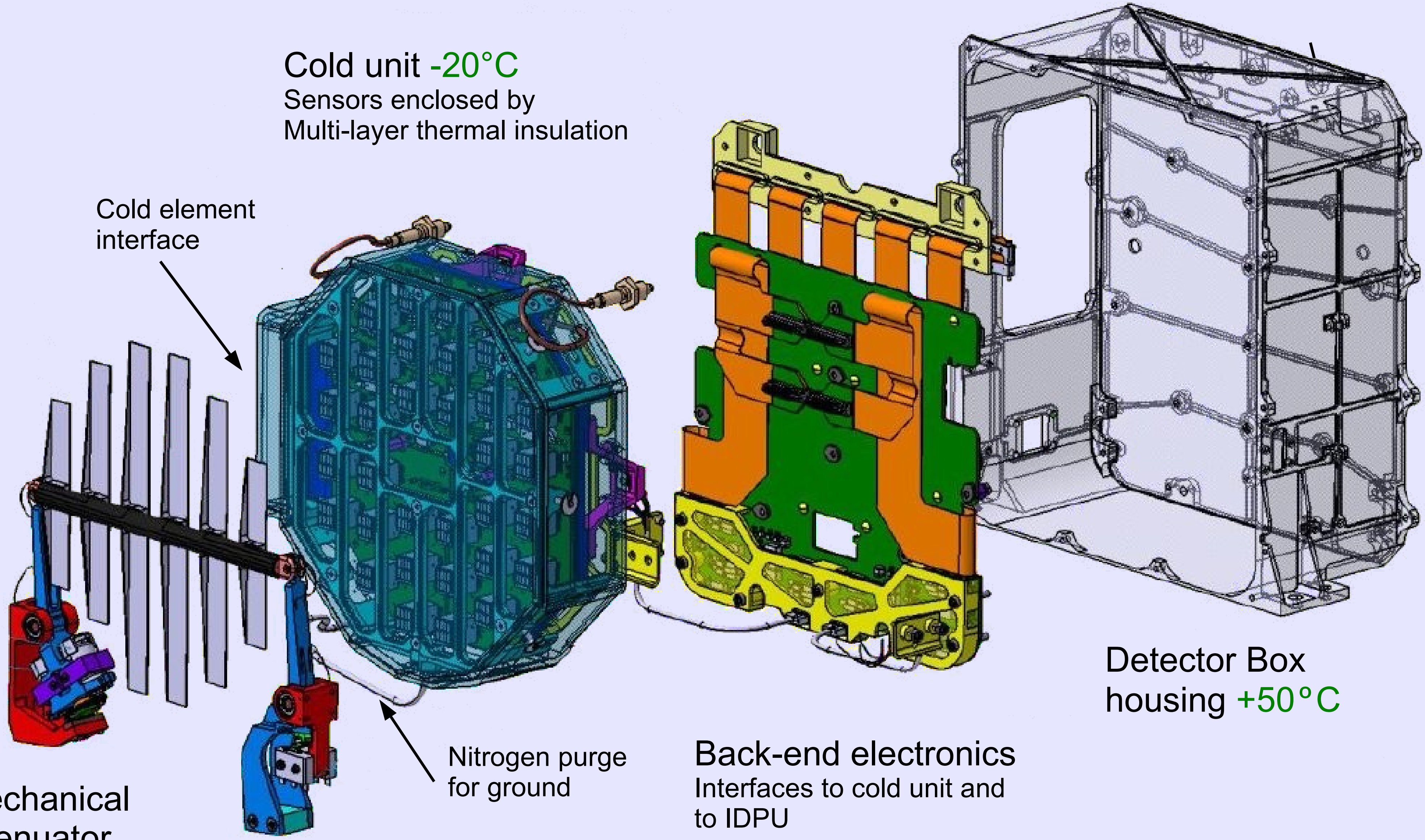
Not optimized for high-rate application in STIX

Spectrum with ^{133}Ba and ^{241}Am simultaneously

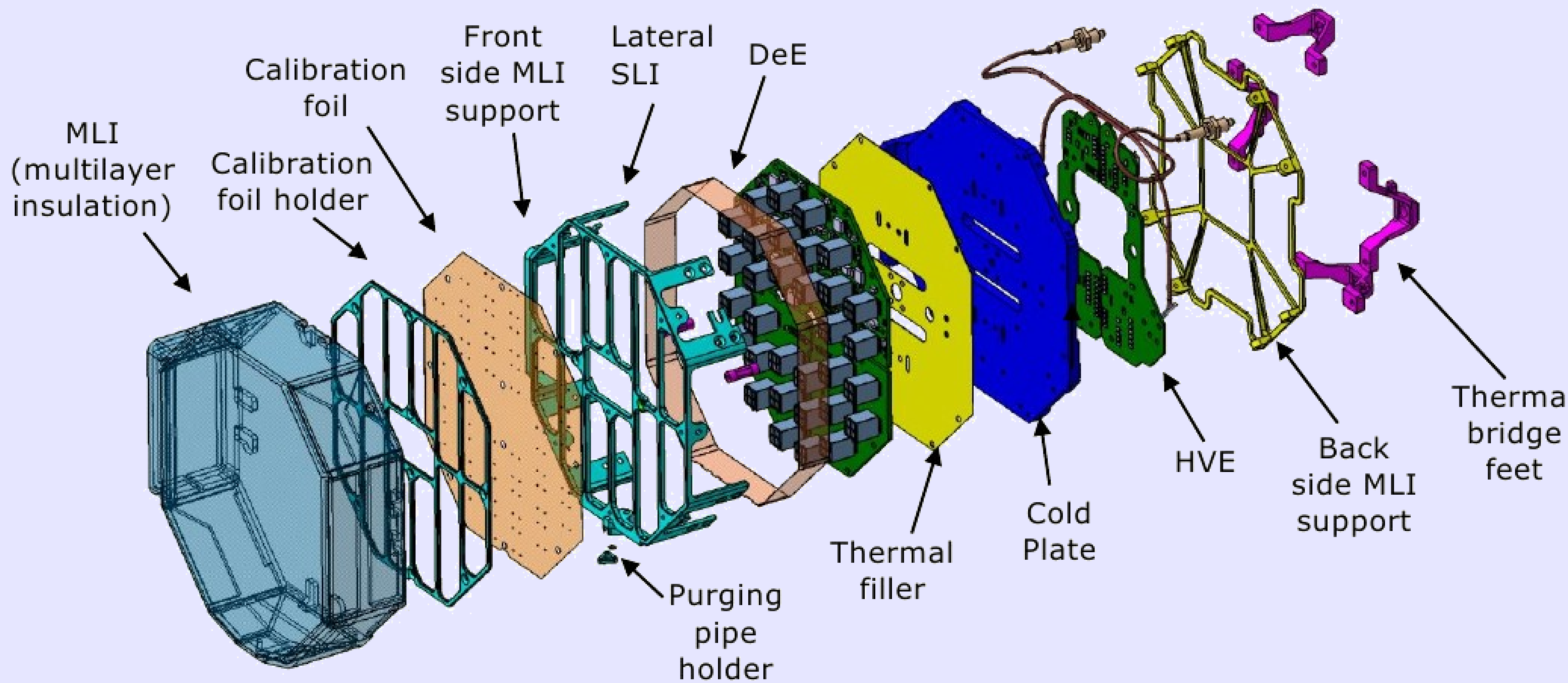
-200 V, -21°C, total leakage current 1.4 nA, threshold 1.8 keV, peaking time 4.7 µs
Energy calibration with 31 and 81 keV lines



Detector Box

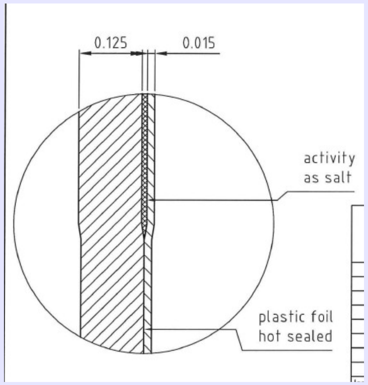


Cold unit



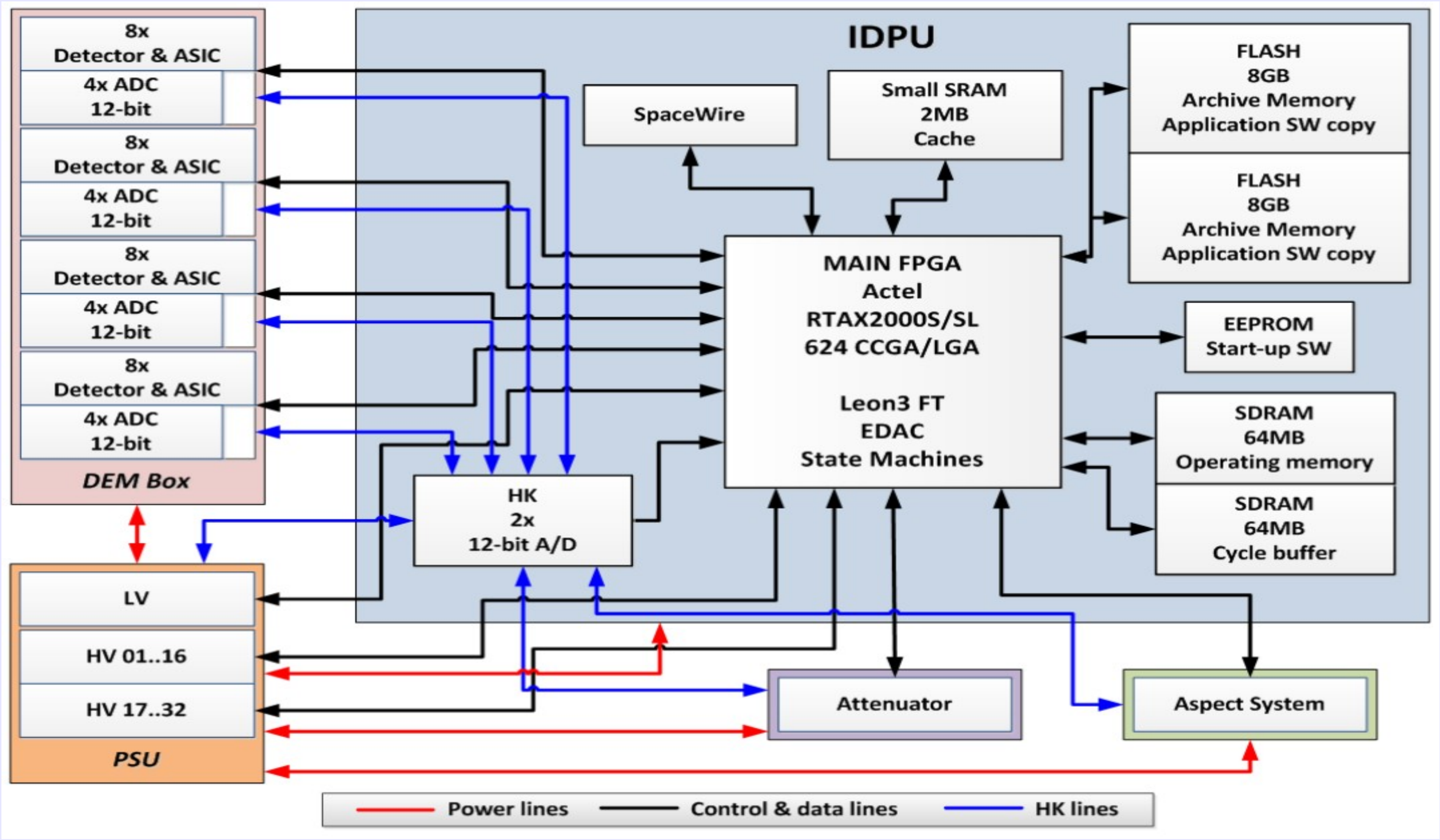
Radioactive source for energy calibration

Calibration changes due to charge collection degradion, ASIC response change with changing leakage current, ASIC gain / offset have small temperature dependence



Barium-133 (t½=10.5 years), 128 dots with ≈3 Bq activity between plastic foils
Require 100 eVrms calibration precision

FPGA instrument control



Event rates up to 10^6 s^{-1} during strong Solar flares, **700 bps** average **downlink**

Flight software runing on **LEON3 processor** synthesized on FPGA

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

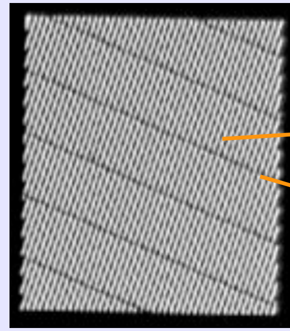
STIX at a glance

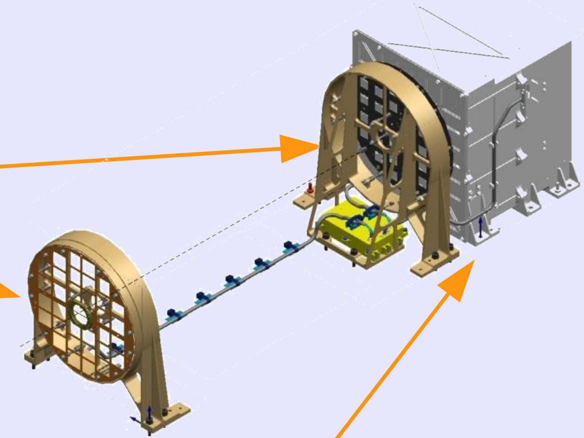
X-ray windows
Thermal protection

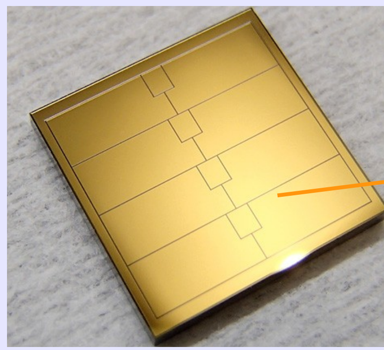
32 Tungsten grid-pairs
Pitch 38 µm – 1 mm, 400 µm thick

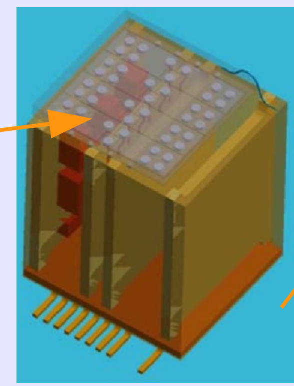
32 Caliste-SO hybrids
32 CdTe, 10x10x1 mm^3, ASIC
Cooled to < -20°C

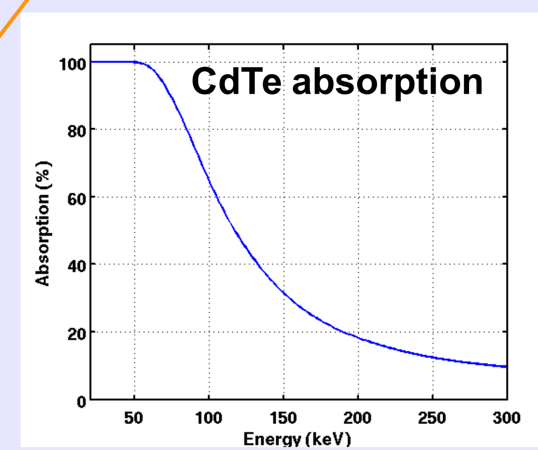
Data processing/control
Based on single FPGA











Flight instrument delivery to ESA October 2016

Launch October 2018

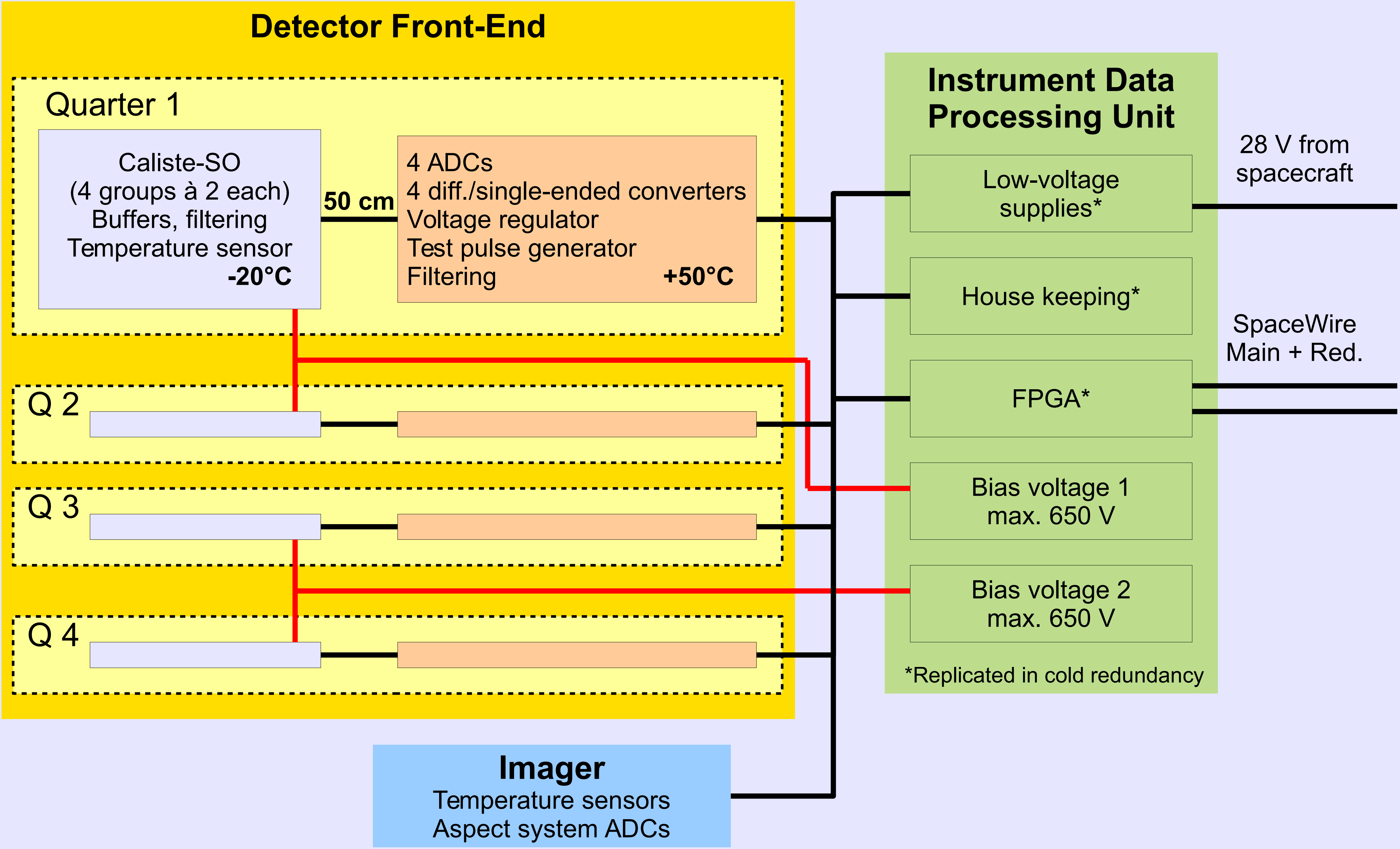
Science phase starting 2021

Extra slides

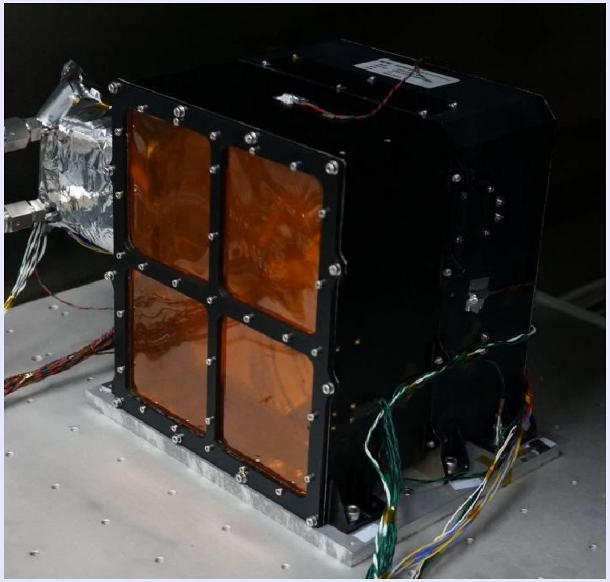
Main design challenges

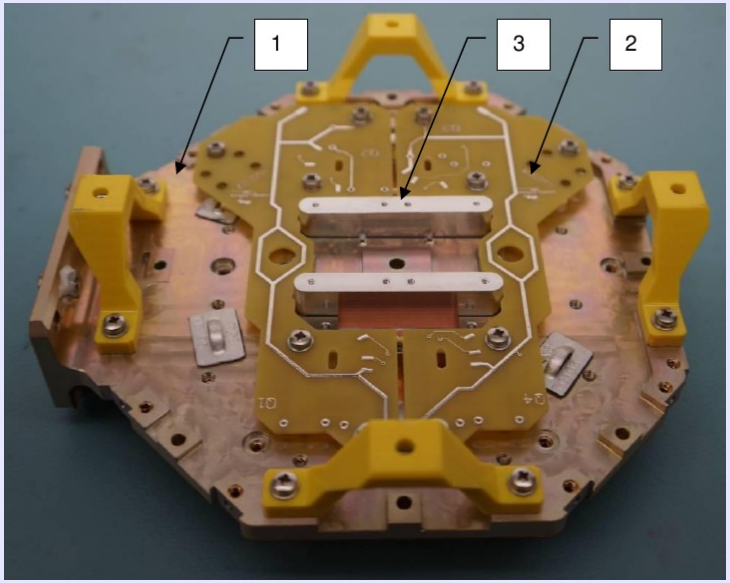
Operation under **vacuum**	→	**Thermal & electronics design** Heat transport only through conduction or radiation Incoming **solar flux 17 kW/m²** Heat rejection only by radiation to space (power limit) CdTe: need (passive) **cooling to -20ºC in +50ºC environment**
Launch environment	→	**Mechanical design** Shocks and vibration, eigenfrequencies > 140 Hz **Mass limit**
Radiation environment	→	**Component selection** 10 year mission duration Total ionizing dose (TID) ~30 krad not too severe **CdTe: Non-ionizing dose (NIEL) degrades performance**
Space-qualified design	→	**Component selection, redundancy** Limited choice, ofter larger or more power demanding
Large distance from Earth	→	**Operations concept, fault tolerance** Telemetry rate limited → data compression, selection Autonomous operation up to 80 days → failure detection

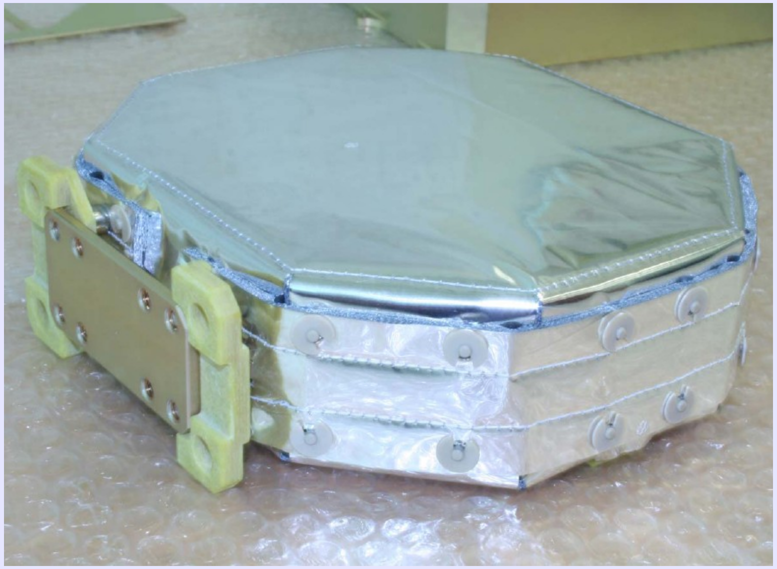
Simplified STIX block diagram



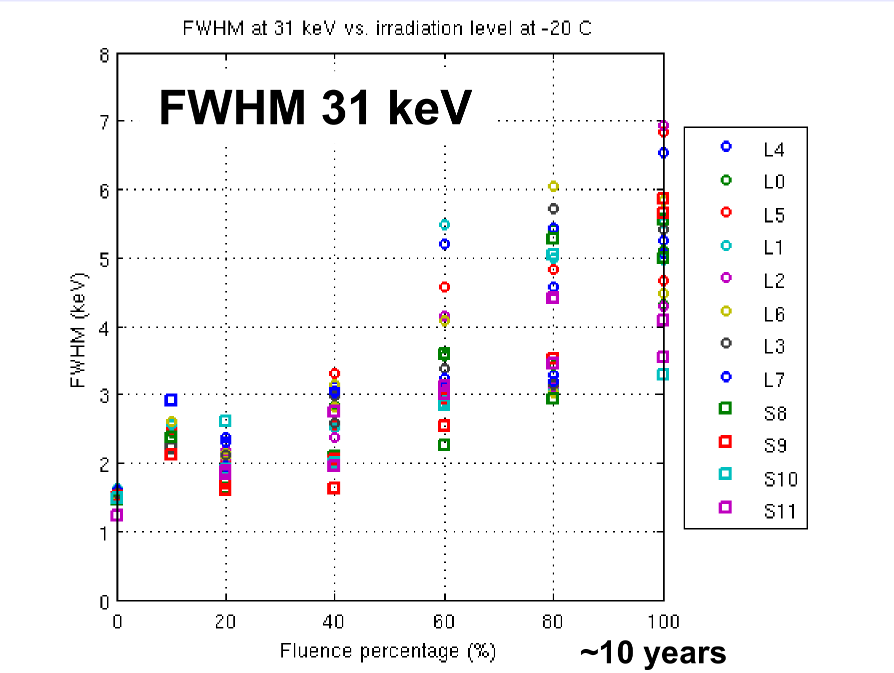
DEM structural thermal model (STM)

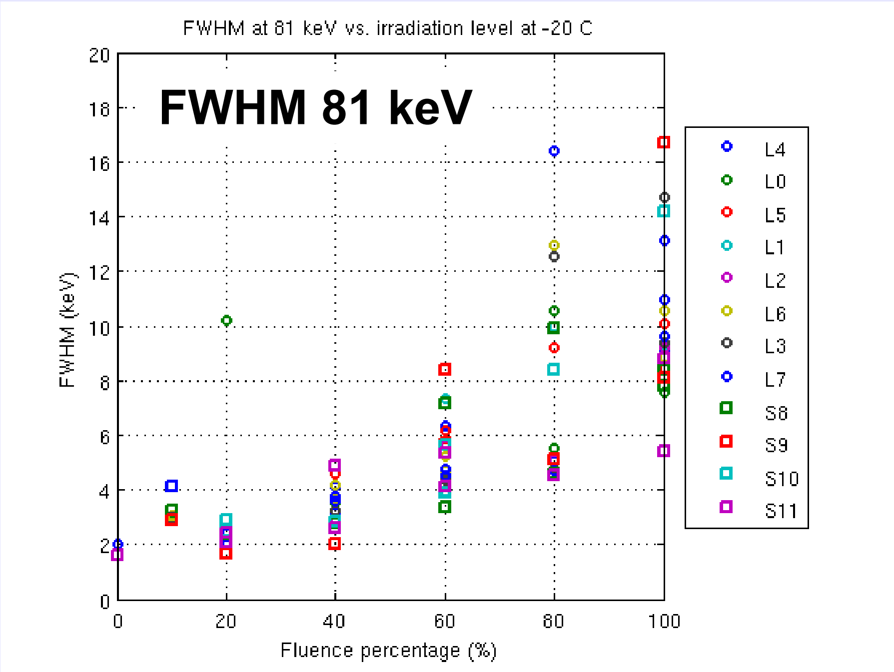


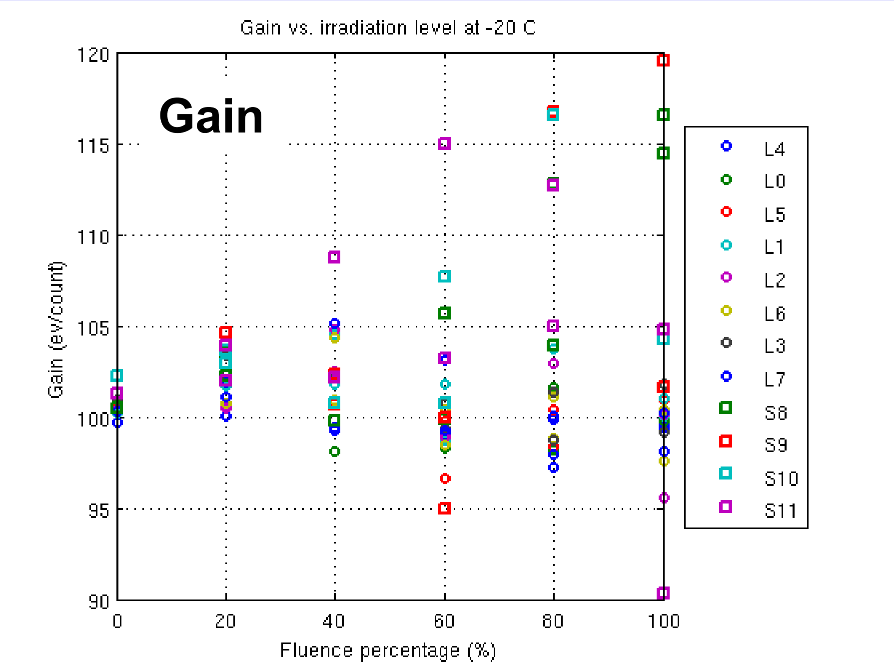


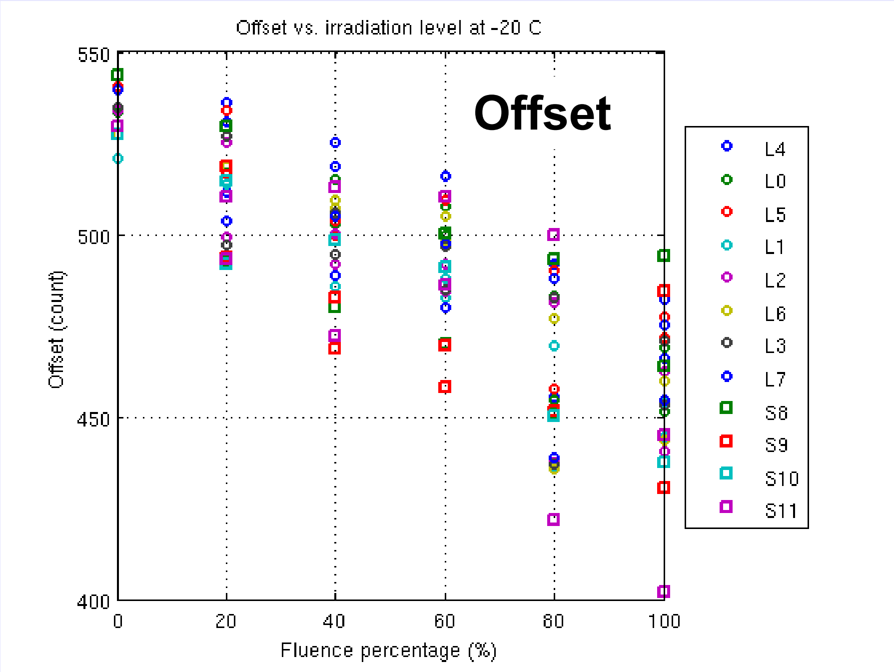


Proton irradiation: main results

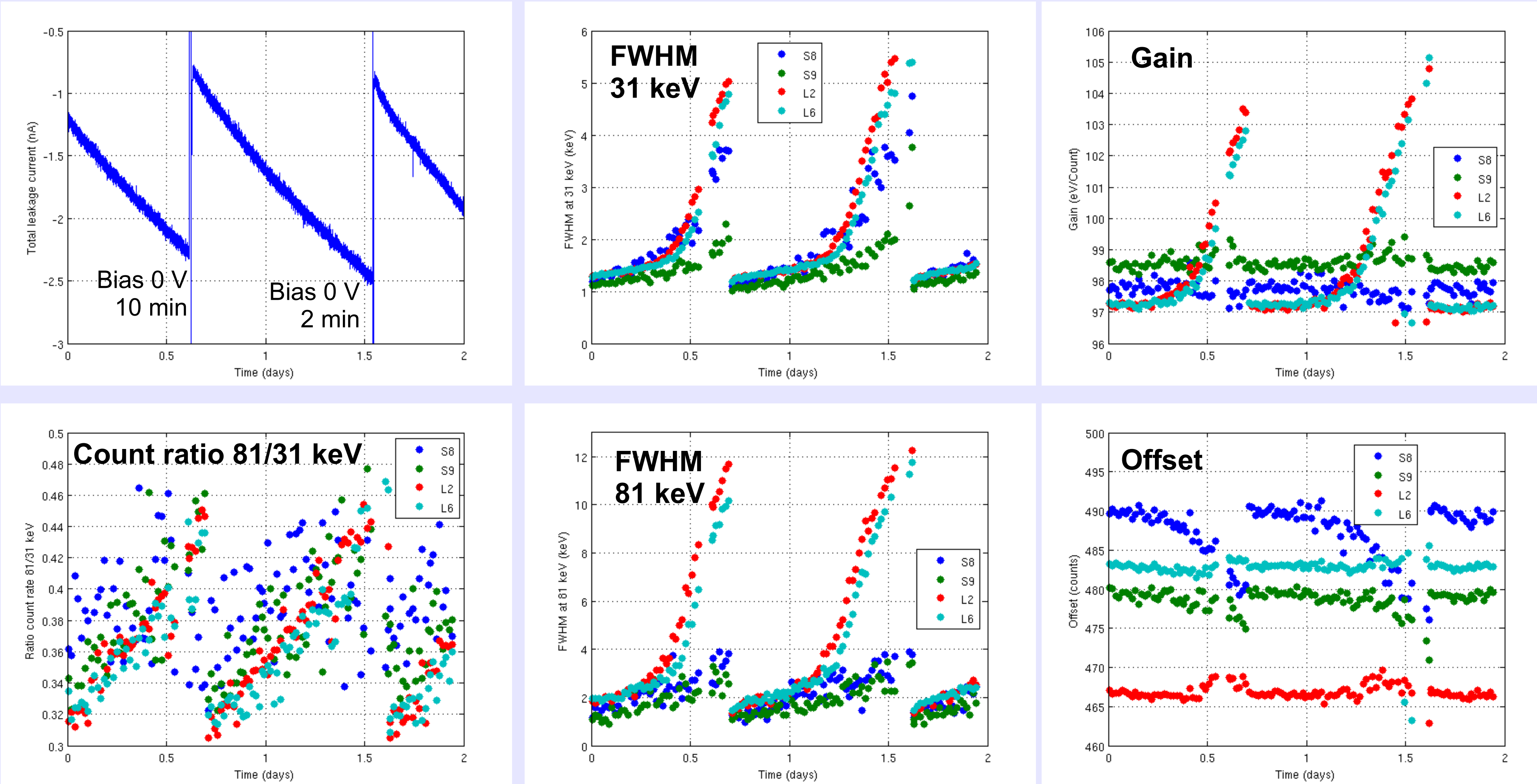








Long term stability – polarization effect



Sensor kept stable at **+4°C** and **200 V** (except bias reset), **non-irradiated crystals**

Time scale for FWHM doubling: +4°C→ ~0.5 days
-6°C → ~1 week
-17°C → ~1 month