Payload Overview following MTR

IXO Science Meeting – Paris
April 2010

Outline

1. Instrument studies
2. Model Payload
3. S/C Accommodation
4. Accommodation issues
5. Instrument Resources

Instrument studies

Assessment study schedule

Instrument studies parallel to industrial φ0/A studies

04/2009	**Request for declaration of interest**
08/2009	**Study Kick-off**
12/2009	**Instrument Definition Review**
03/2010	**Instrument Mid-Term Reviews**
07/2010	**End of Study**

Goals to be reached at Mid Term Review

1. finish trade-off analyses
2. decide on baseline design
3. updated instrument specifications
4. consolidated I/F and resource requirements
5. present approach for deriving instrument development programmatics
6. present approach for deriving radiation tolerance

MTR Review

- **Reviewed:**
  - adequacy of proposed solutions to meet the science requirements
  - relevance of the trade-offs
  - adequacy of the requirements
  - compatibility of the requirements wrt the system design(s)
  - changes wrt to the PDD v6 and its system implications

→ **Feedback to industrial system studies**

Instrument φ0/A Final Reviews (IPRR & TRR) 1/2

IPRR and TRR will be combined and held at ESTEC on 14th and 15th July 2010.

Documentation due:

- **Completely revised instrument chapter to be included in PDD version 7**
- **Instrument design reports**
- **Final trade-off(s) report**
- **Instrument assessment reports (public document)**
- **Instrument development plan**
- **Instrument cleanliness control plan**
- **Instrument programmatic and cost estimate reports**
- **Inputs to "yellow book" (few pages per instrument).**

Instrument φ0/A Final Reviews (IPRR & TRR) 2/2

Documentation due end of June:

- **Instrument technology assessment report (instrument TRL justification)**
- **Instrument technology development plan**
- **Instrument technology programmatic and cost estimate report**

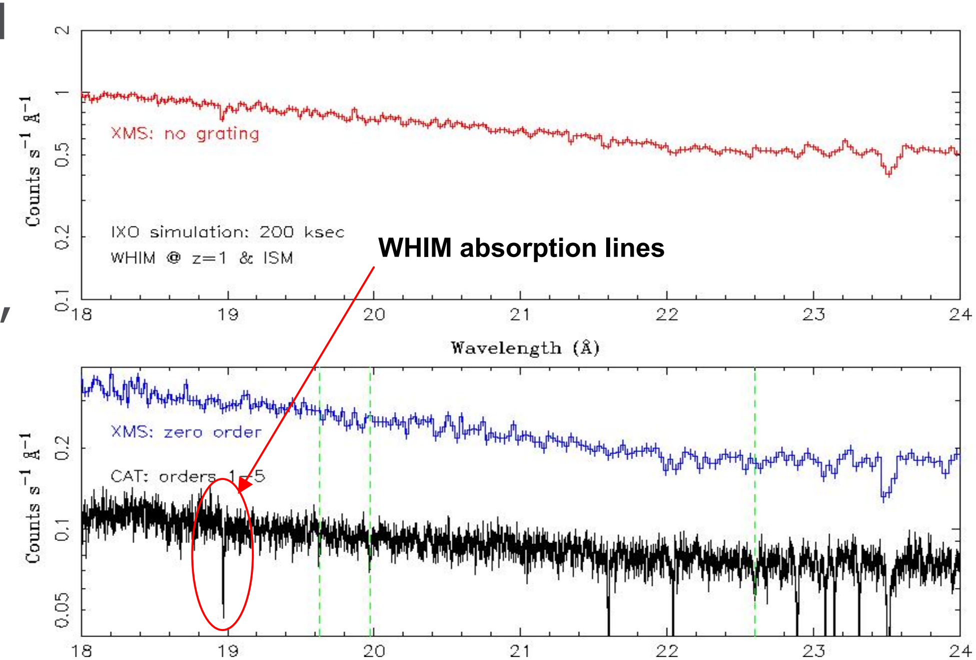
Model Payload

IXO Model Payload

6 instruments	8 Assessment Studies following call for DOI
X-ray Grating Spectrometer	CAT XGS – MIT
	OP XGS – OU
X-ray Microcalorimeter	XMS – SRON
	MIS XMS – CEA
Wide-Field Imager	WFI – MPI
Hard-X-ray Imager	HXI – ISAS/JAXA
High-Time Resolution Spectrometer	HTRS – CESR
X-ray Polarimeter	XPOL – INFN

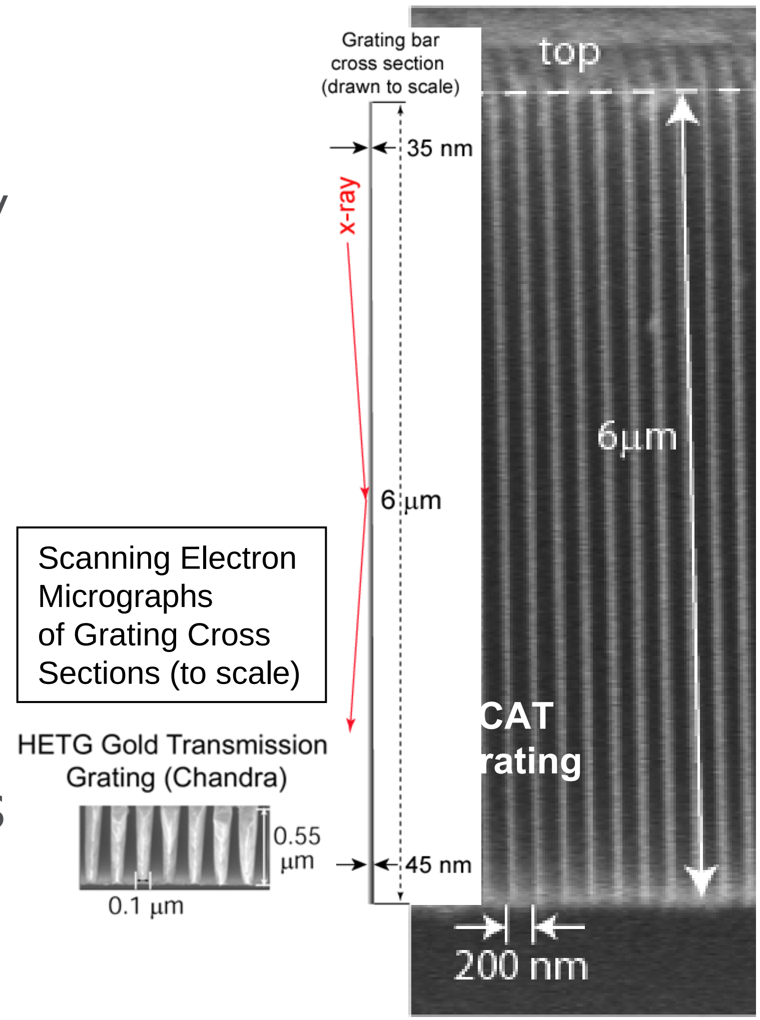
CAT-XGS Key Performance Requirements

- **Spectral resolution R = $\lambda/\Delta\lambda \geq 3000$**
  (point sources, 0.3 keV < E < 1.0 keV)
- **Effective area ≥ 1000 cm^2 (0.3 keV < E < 1.0 keV)**
- **Critical-angle transmission (CAT) gratings** combine advantages of blazed reflection gratings (efficiency, use of higher orders) and traditional transmission gratings (low mass, relaxed alignment and figure tolerances, polarization insensitivity).
- Blazing eliminates need for camera on both sides of focus.
- Gratings highly transparent at higher E.
- Camera CCDs sort orders

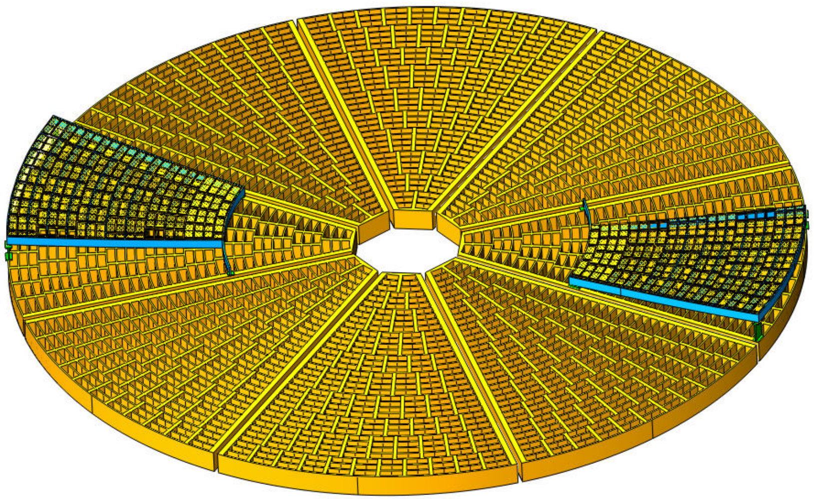


CAT-XGS Technology

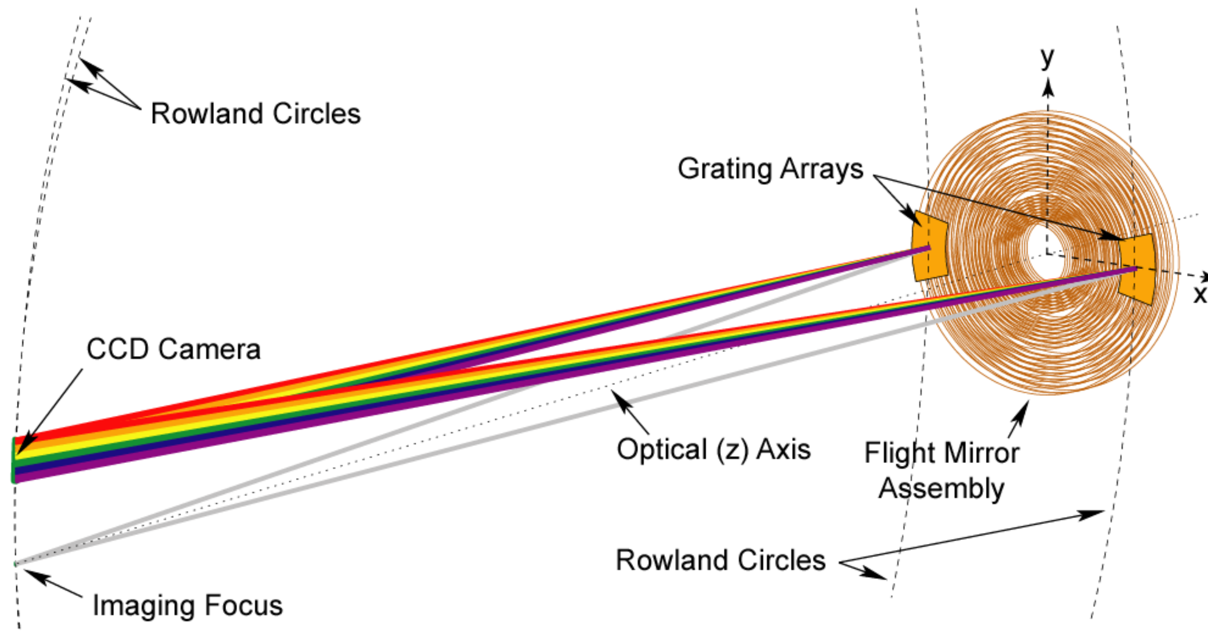
- **Critical-angle transmission (CAT) grating array:**
  - CAT gratings: prototypes with integrated support mesh tested at synchrotron, efficiency within 80-100% of theoretical.
  - New fabrication step to increase open area to design value.
- **Camera:**
  - Linear array of 32 MIT/LL CCDs with *Chandra & Suzaku* heritage
- **Optical design:**
  - Combination of *Chandra* HETGS and *XMM* RGS designs for blazed transmission gratings.
  - Subaperturing increases resolution.
  - Ongoing refinements via ray-tracing.

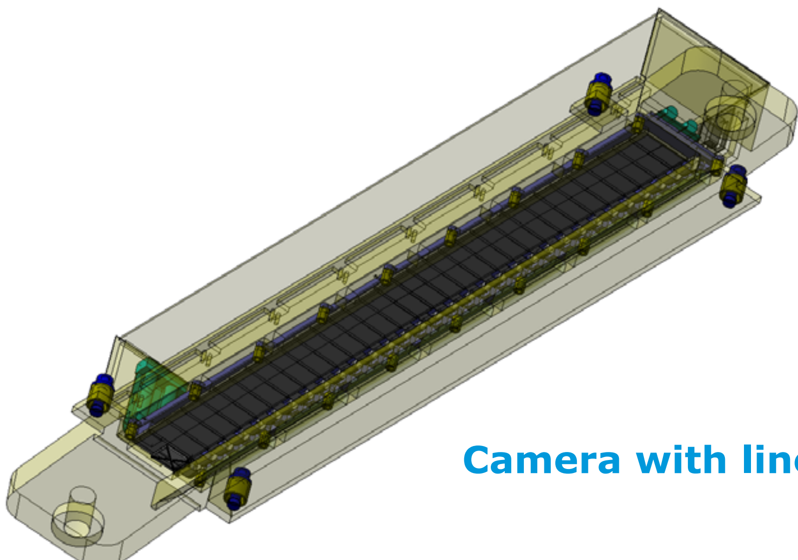


CAT-XGS Instrument configuration



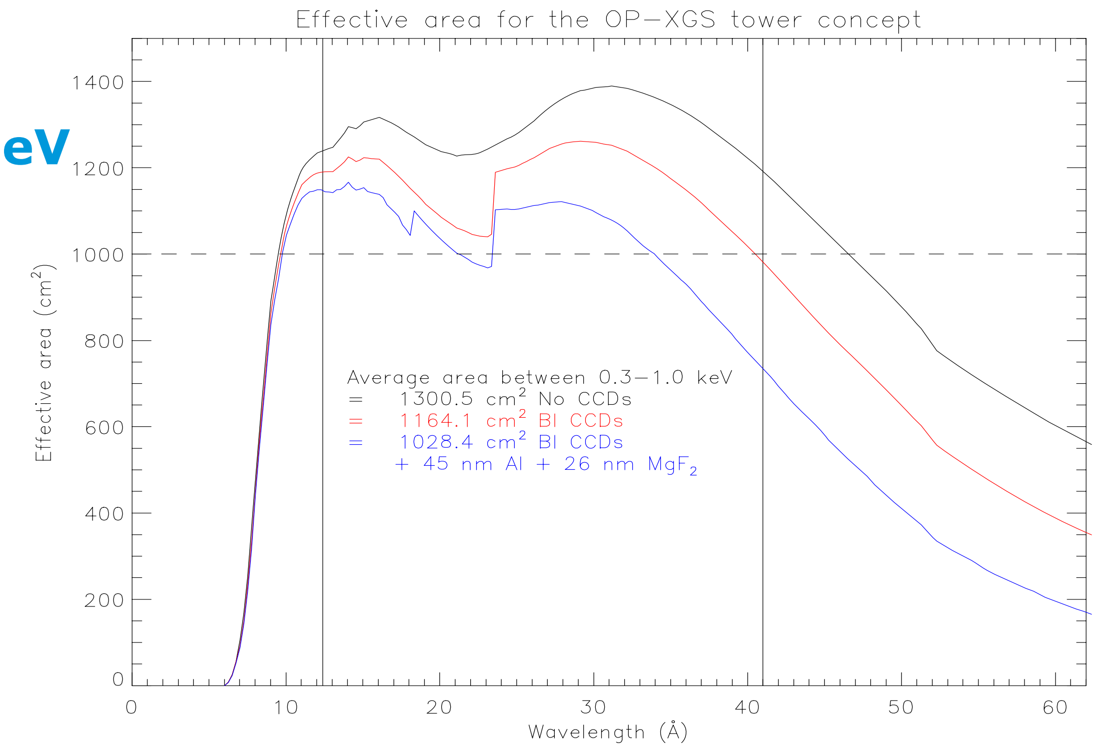
CAT grating arrays behind SPO mirrors





Camera with linear 32 CCD array

OP-XGS Key Performances - Area



Key Science Requirements:

- **Core Energy Band 300-1000 eV**
- **Effective area ~1000 cm²**
- **Resolution > 3000**

Based on Off-Plane Gratings + CCD Camera

Trade study focused on Grating location

Note: – A_{eff} and order contribution is still undergoing final optimization

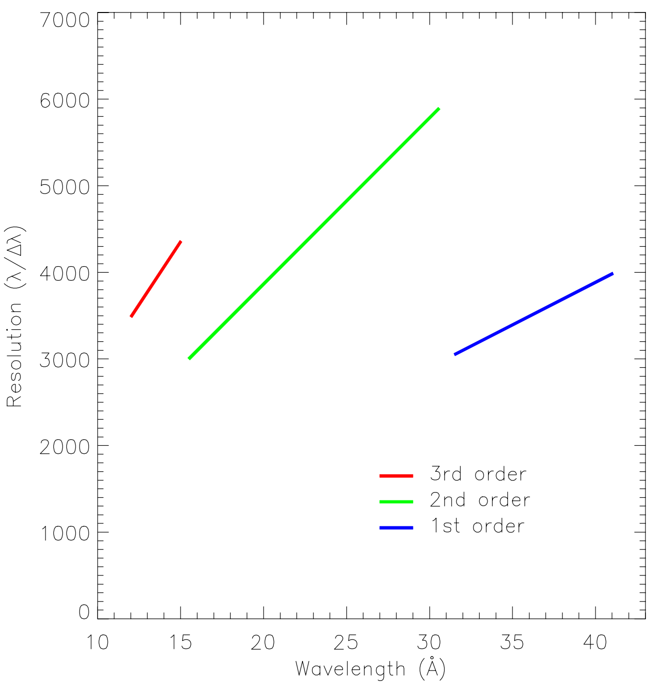
– A_{eff} estimate includes optics, gratings, light blocking filter (used on XMM/RGS) and CCD QE

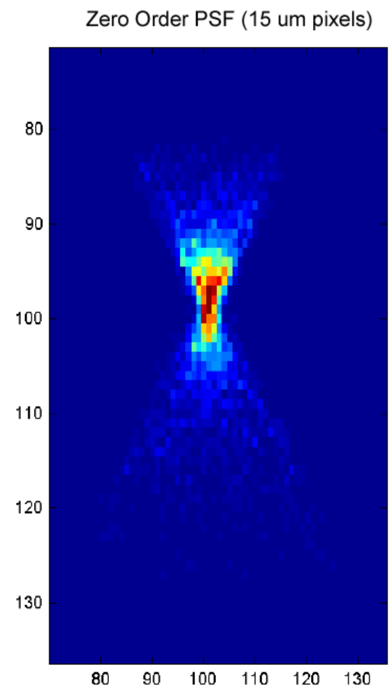
– Excludes X-ray event recognition, selection of bowtie events

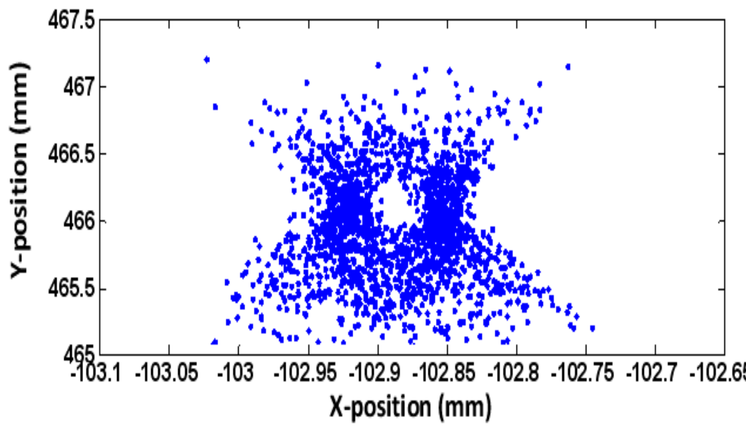
– Useable performance extends from 200-1500 eV

OP-XGS Key Performances - Resolution

- **Consortium have set an internal goal of R=3600 allowing 20% margin for grating alignment, pointing accuracy etc.**
- **Instrument performance verification has been demonstrated using detailed ray tracing**
- **Working in 1st, 2nd and 3rd orders, and utilises sub-aperturing of optics for improved resolution**

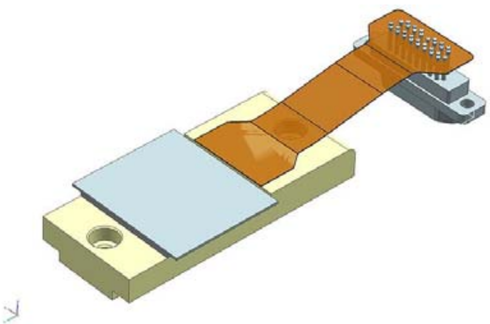


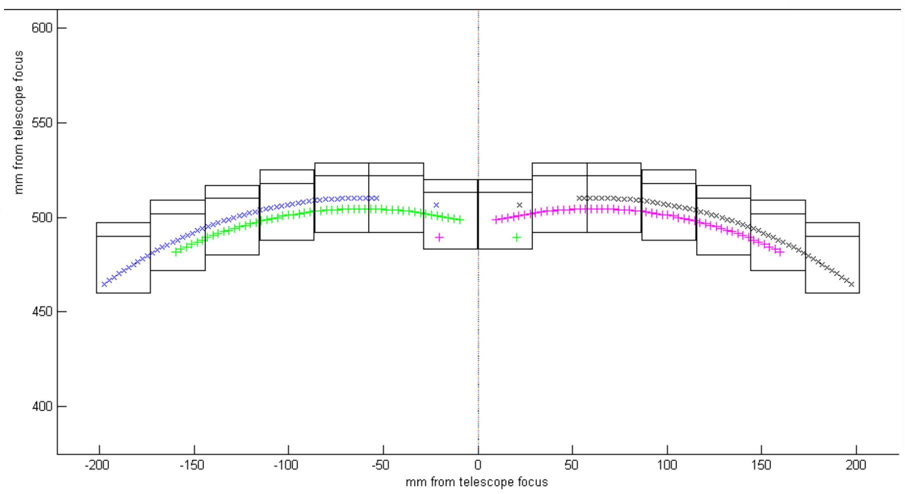


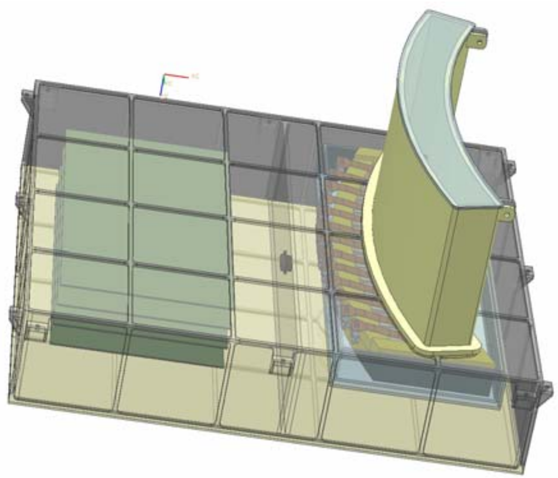


OP-XGS Camera for Spectrum Readout

- 4 grating assemblies project 4 separate spectra on CCD array
- This relaxes alignment requirements
- Zero-order beam monitors (centre CCDs) are used for wavelength scale monitoring
- CCD and array technology based on XMM RGS and EPIC heritage
- Inherent redundancy in the event of loss of single CCDs and ensures no loss across the gaps in the CCD array

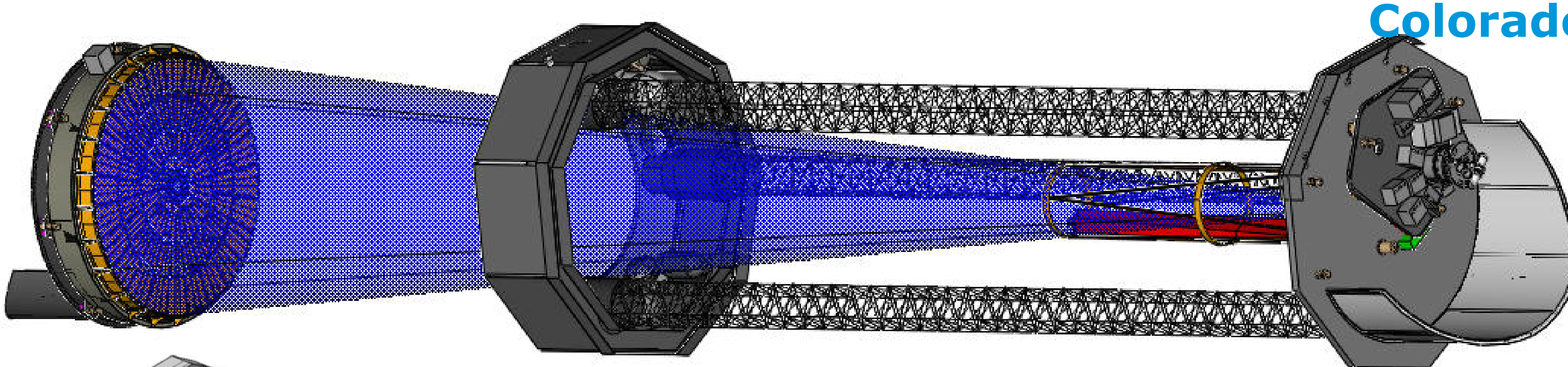


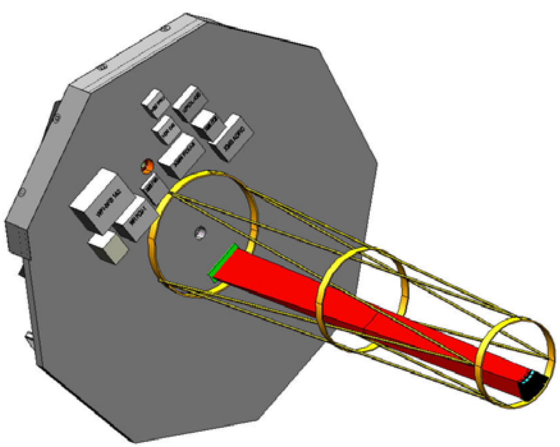


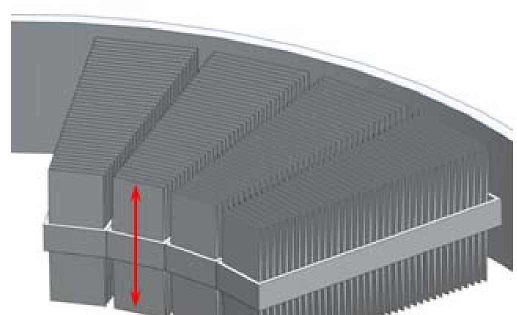


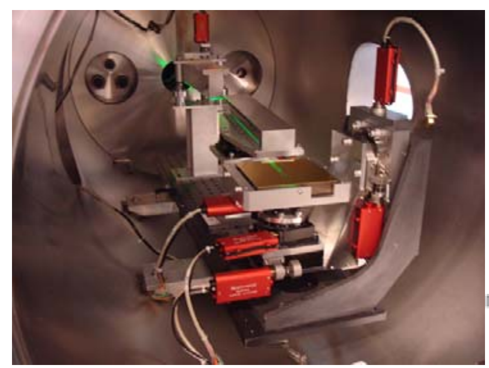
OP-XGS Instrument configuration

- Gratings: 4 identical modules held in position on a 5.16m tower
- Beryllium Grating substrates provide low mass
- IXO Beam obscuration <10% to achieve the required performance
- Representative gratings currently undergoing testing at Iowa and Colorado



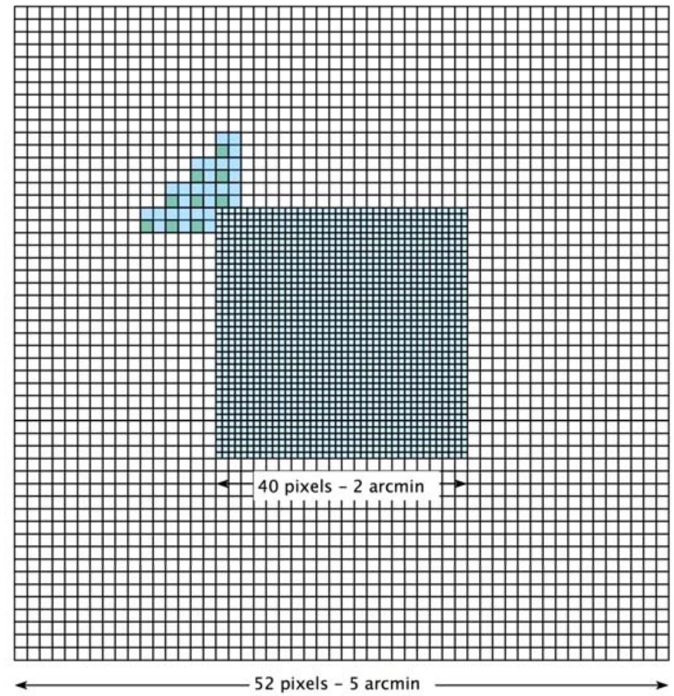






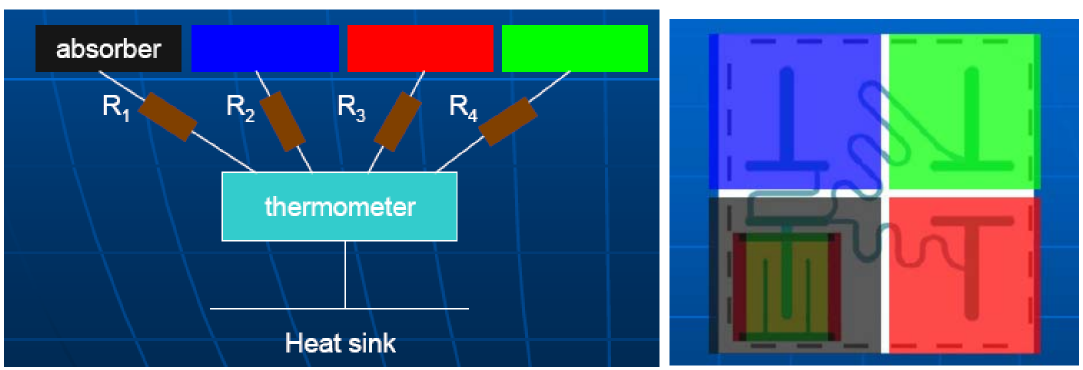
XMS Key Performance Requirements

Full detector	
Energy range	0.2 – 10 keV
QE at 7 keV	> 80%
Inner array	
Energy resolution	2.5 eV
FoV	2 x 2 arcmin
High-res events	80% at 100 counts/pixel
Energy scale	< 1 eV/h stability
Outer array	
Energy resolution	10 eV
FoV	5 x 5 arcmin
High-res events	80% at 2 counts/pixel

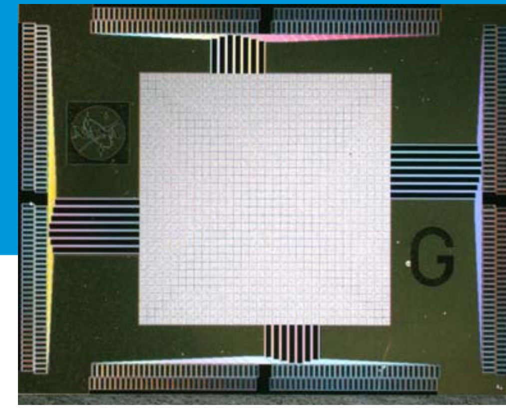


XMS Detector Design

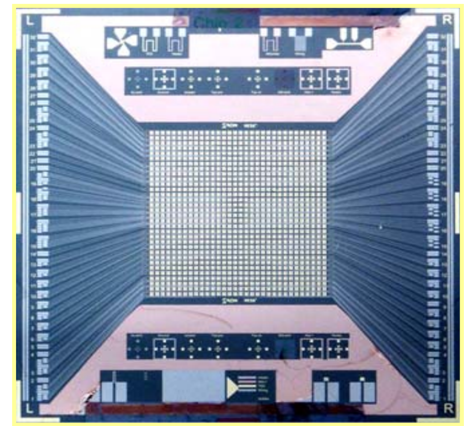
- Standard micromachining of absorbers with sensing elements (TES)
- Devices up to 32 x 32 have been produced, no show stoppers for larger devices
- To limit read-out channels different absorbers can be connected to single TES (at lower resolution and/or count-rates)



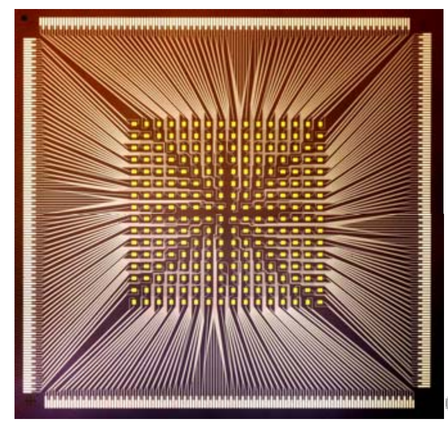
GSFC courtesy Kilbourne



GSFC courtesy Kilbourne

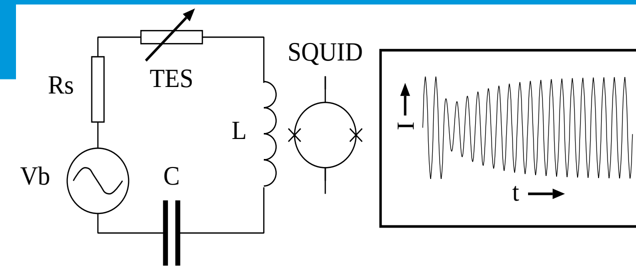


SRON

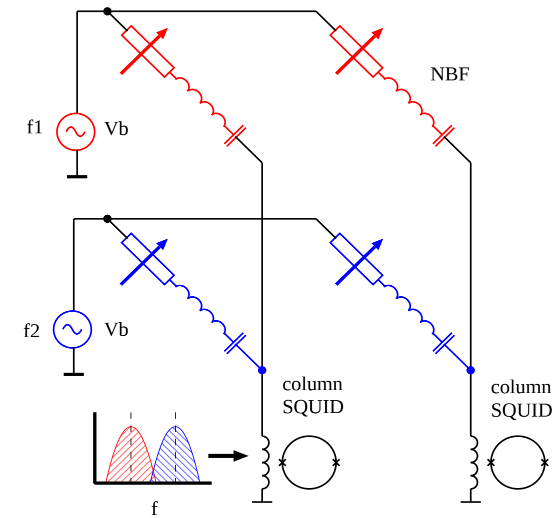


JAXA, courtesy Takei

XMS Read-out Design

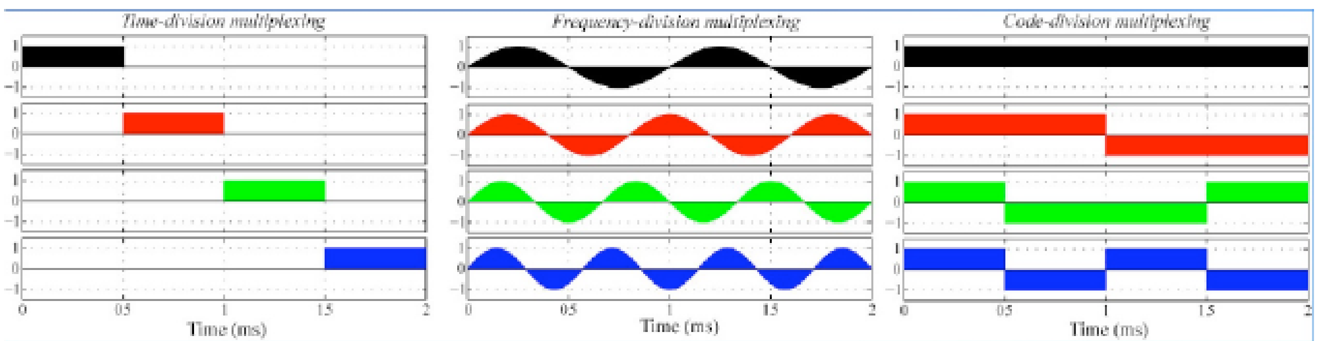


- **Read-out of cryogenic detectors requires multiplexing**
- **Cooling system of cryogenic detectors are heavy and requires a lot of power (e.g. few mW cooling at 50 mK requires ~ 200 kg and ~ 500 W)**
- **Different multiplexing schemes are being developed: TDM, FDM and CDM (typically up to 40 pixels/channel)**



1-10 Mhz frequency range

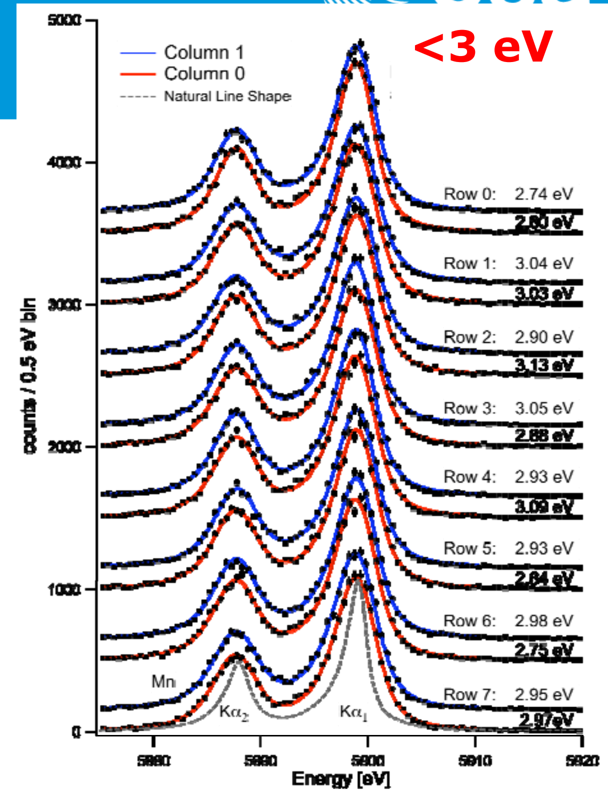
200 kHz separations: ~ 40 channels



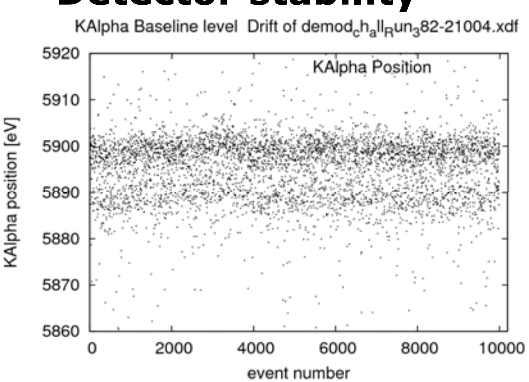
XMS Demonstrated Performance

- **32 x 32 arrays produced with intrinsic good energy resolution: < 3 eV @ 6 keV**
- **Principle for pixels with factor 16 in area (at expense of energy resolution) demonstrated**
- **Good stability of instrument demonstrated (at 4.1 eV**

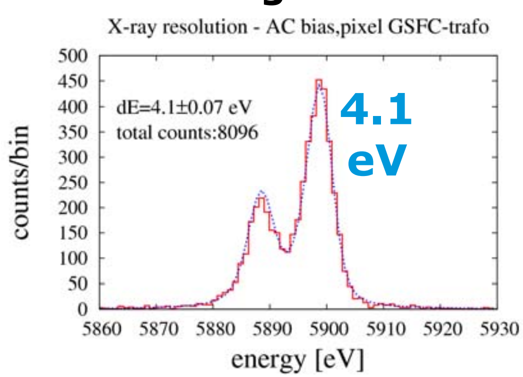
Courtesy Kilbourne



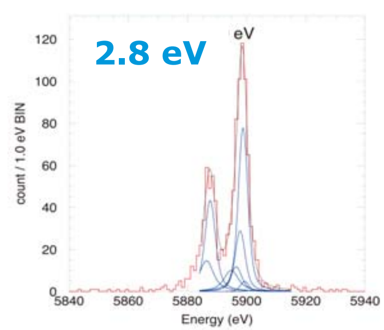
Detector stability



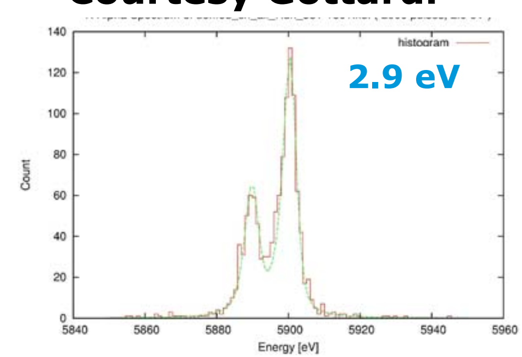
AC Biasing



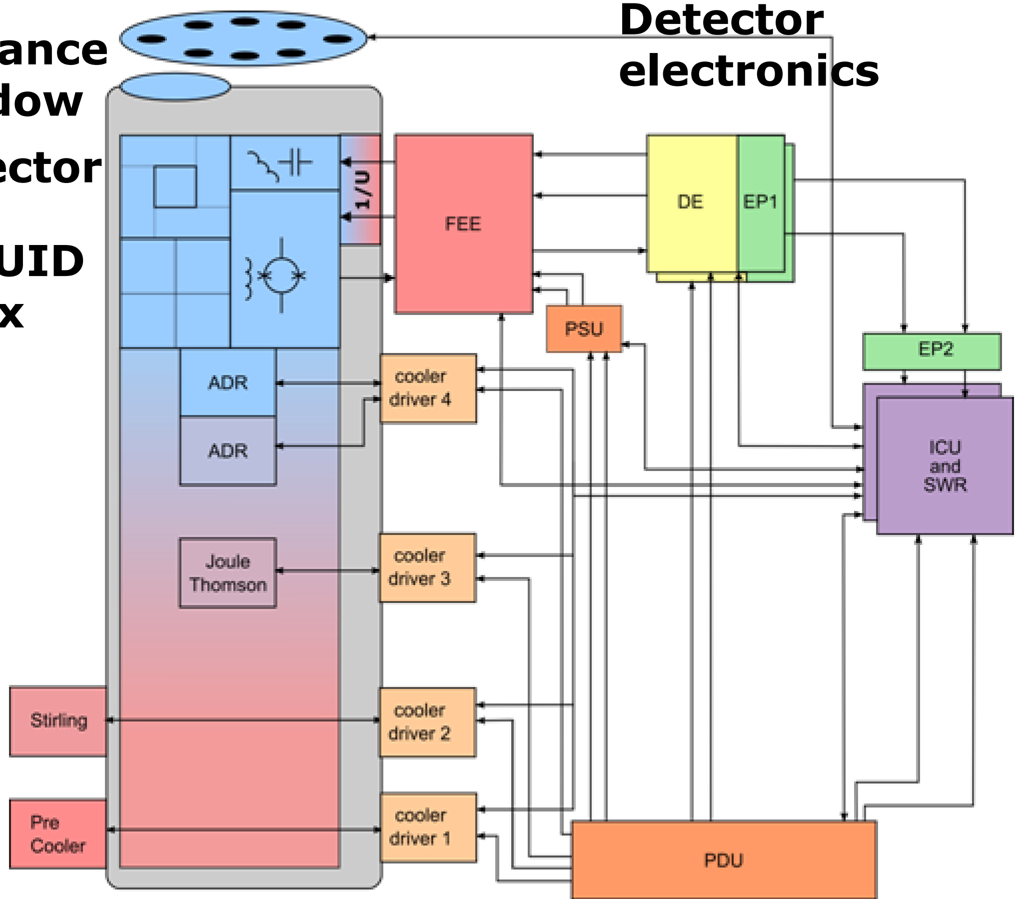
Courtesy Akamatsu

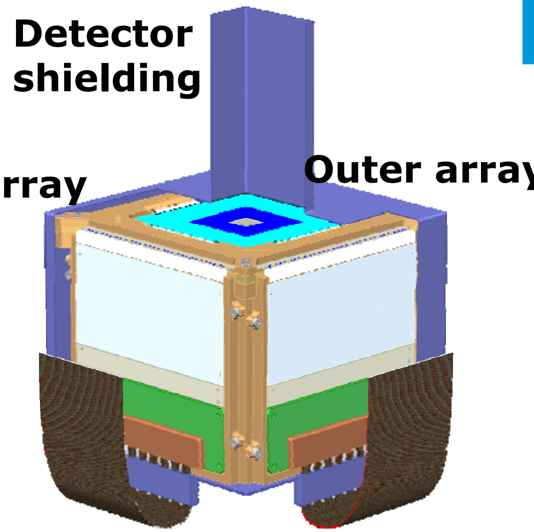


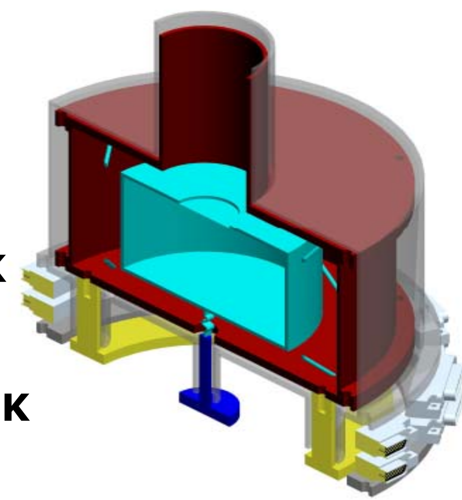
Courtesy Gottardi



XMS Instrument Configuration







XMS – MIS Key performance requirements

64x64 pixels in 4 quadrants (32x32 pixels; 2-side buttables; mux 32:1)

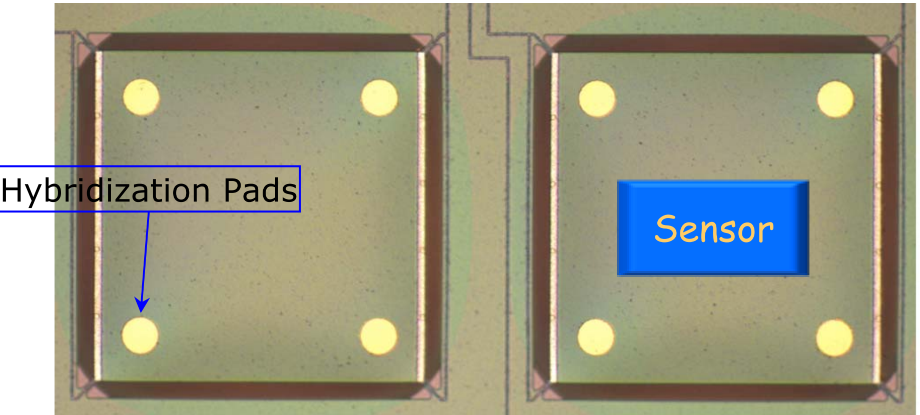
Field Of View : FOV = 6′X6′ with Pixel Size = 500µm

Energy Range : 0.3 – 10 keV

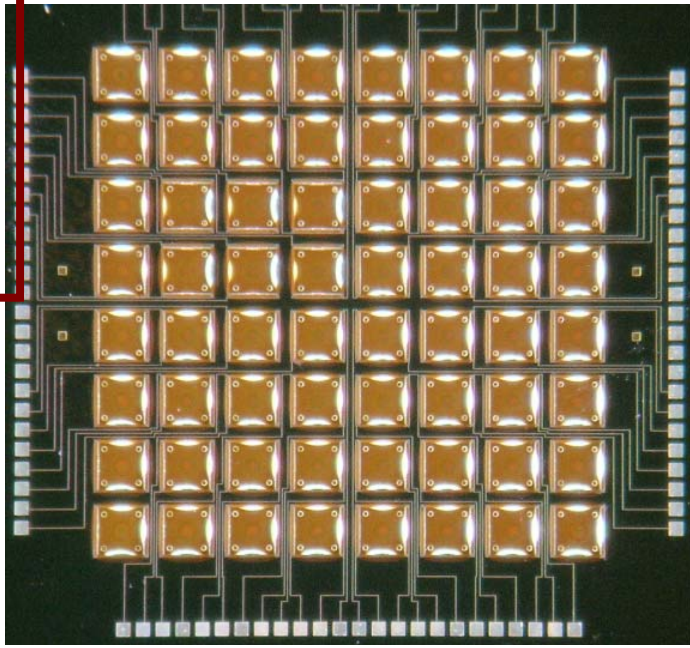
Energy Resolution : 2.5 eV @ 6 keV over <u>Full 6′x6′ FoV</u>

MIS Detector Heritage

✓MIS µcal already flown (SUZAKU/XMS 32 MIS µ-cal pixels, Astro-H soon)
✓LETI IR/Hershel PACS µ–bolometers (MIS sensors) flown
✓CEA MIS µcal are based on XMS design and built using Hershel/PACS Techno.



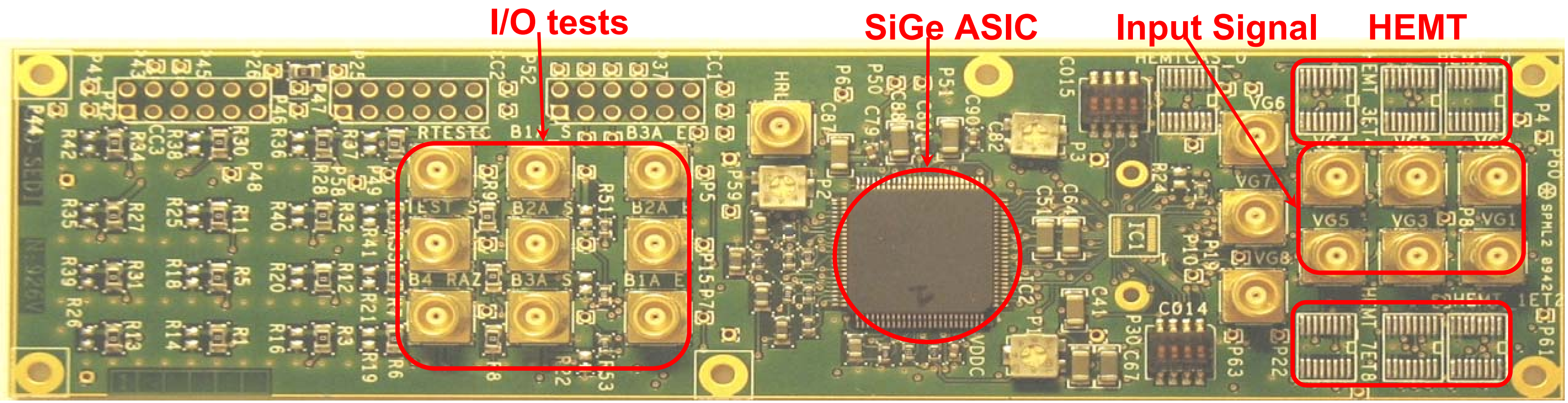
Ta pixels ready to be hybridised

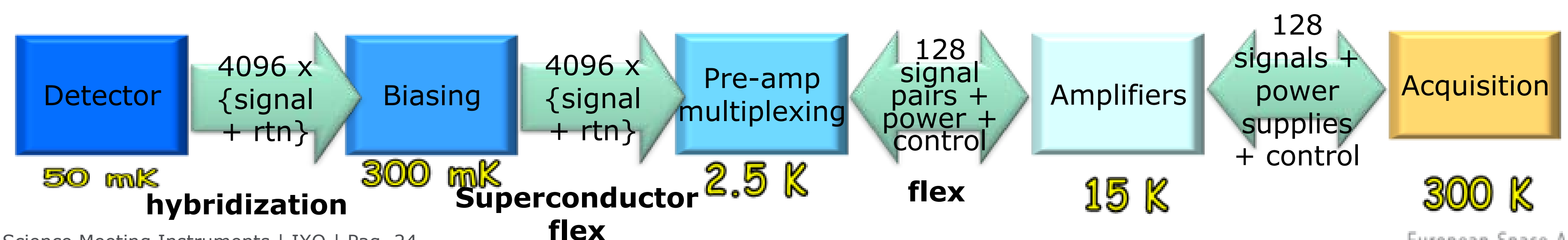


European Space Agency

XMS – MIS Proximity electronics (@2.5/4K)

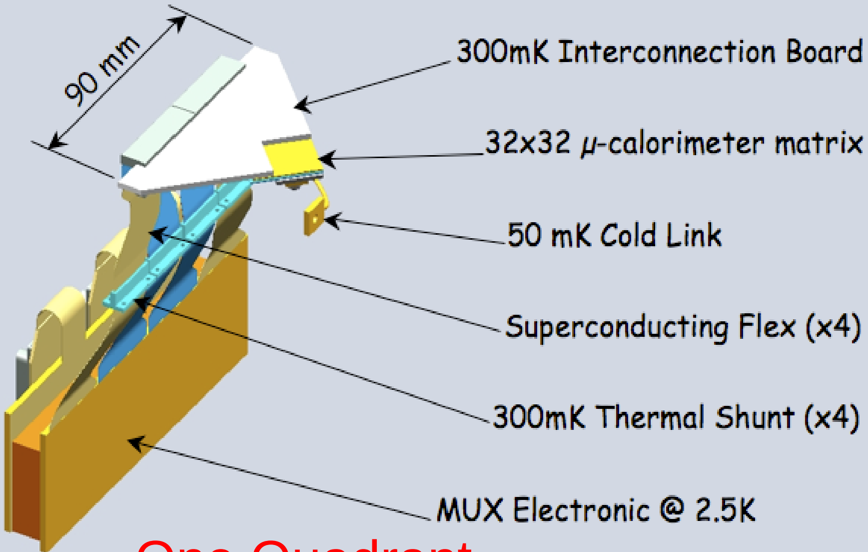
- **1st stage: HEMTs (under test) Noise ≲ 5 nV/sqrt(Hz) @ 1kHz !!**
- **2nd state: SiGe ASICs**
- **Extreme low power, allows many pixels to be mux'ed**



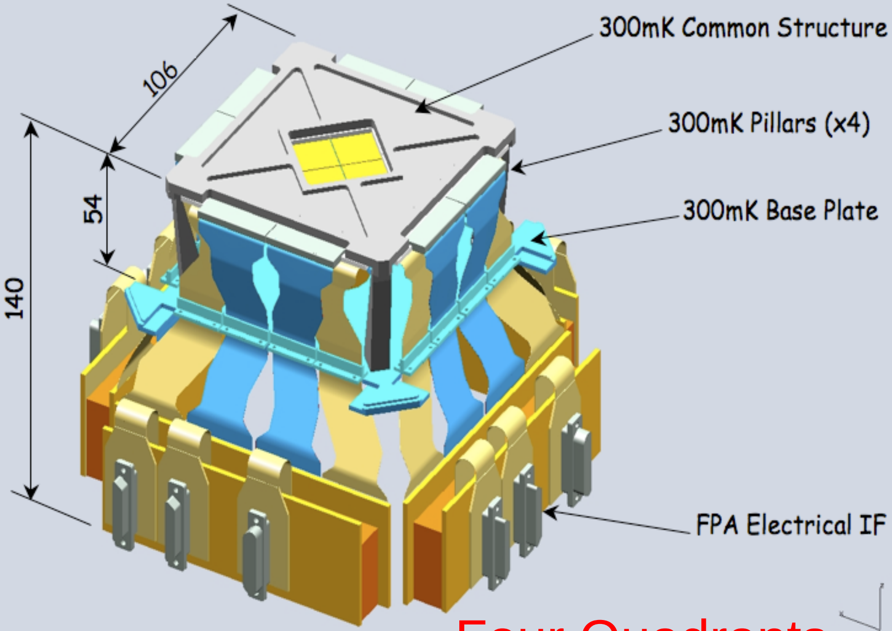


XMS – MIS Instrument Configuration

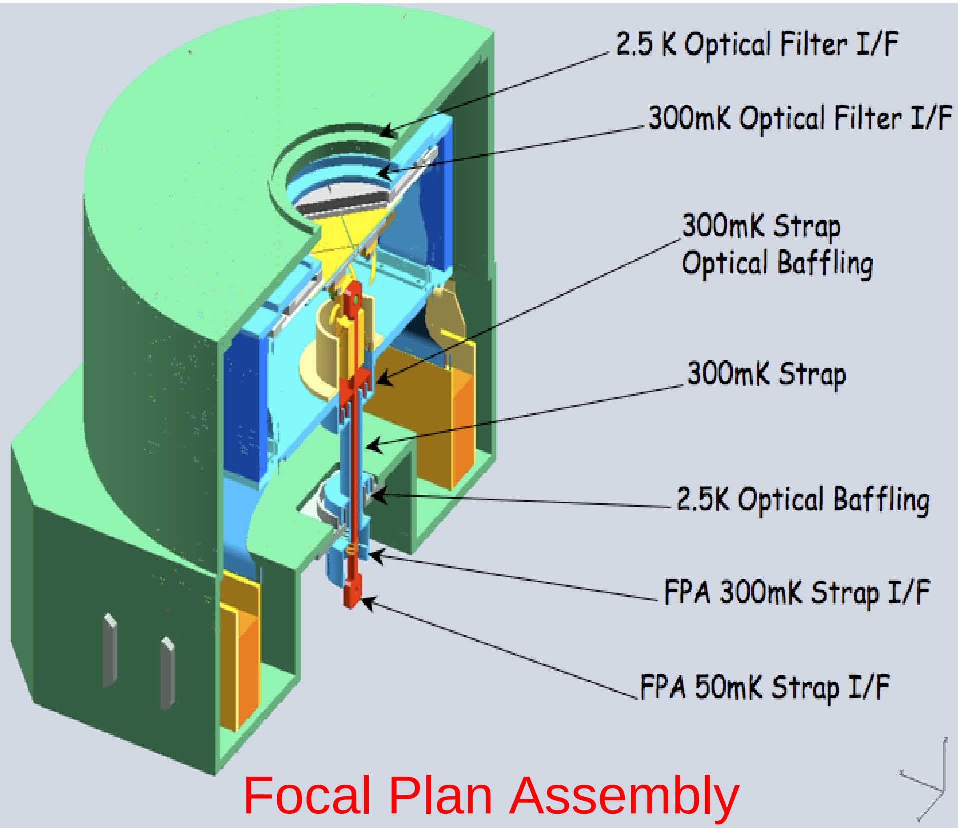
4x(32x32) MIS sensors +500μm Ta Absorbers
4K Electronic : HEMTS+SiGe ASICs& MUX 32:1
Focal Plan Assembly :
- **Volume~ 200x200x160 mm³**
- **Mass ~4.4kg**
- **P < 0.9 μW @50mK**



One Quadrant



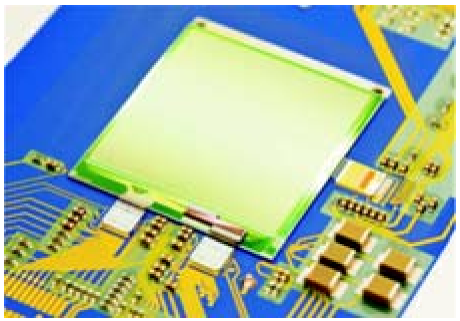
Four Quadrants

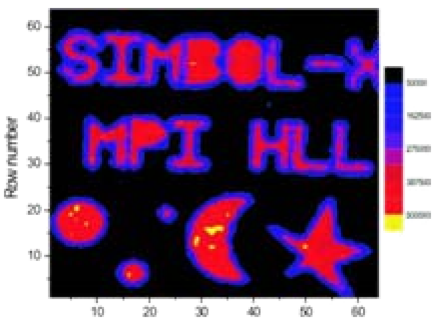


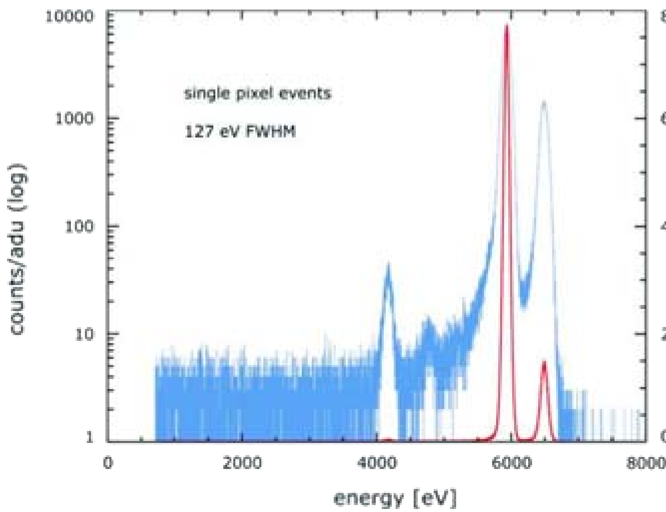
Focal Plan Assembly

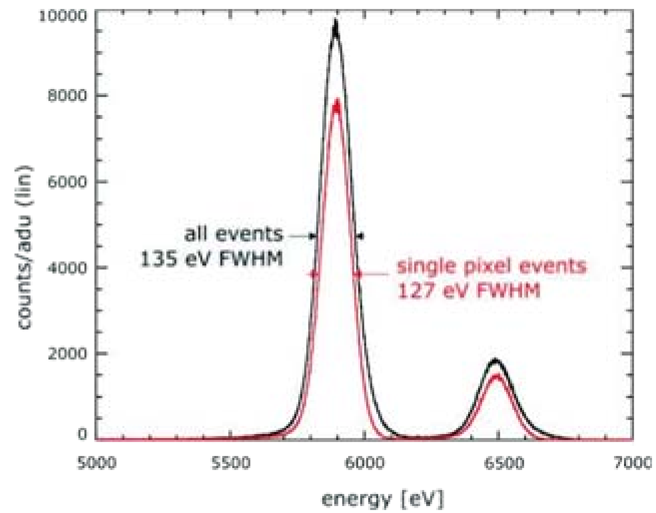
WFI Key performance requirements

- **Energy Range: 0.1 – 15 keV**
- **Energy Resolution: < 150 eV**
- **FoV: 18 arcmin**



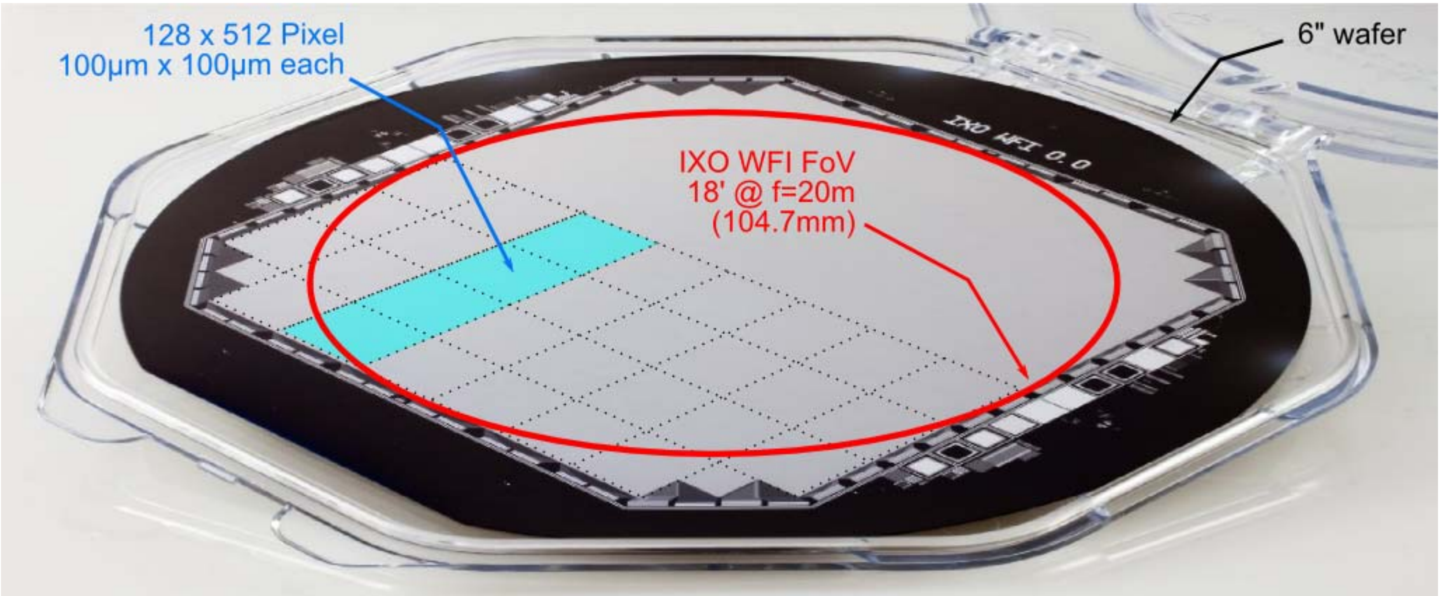






WFI Focal Plane

- **Active Pixel Sensor Array using DePFET Pixels**
- **450µm fully depleted Si**
- **Monolithic wafer-scale integration on a 6” wafer**
- **Pixel size 100x100 µm² (5-fold PSF oversampling)**
- **Array: 1024 x 1024 pixels (minus corner segments)**
- **Achievable FoV: 18' @ f=20m**



WFI DePFET Sensor Element

- **p-FET on depleted n-bulk**

  charge collected in potential minimum below FET channel steers transistor current (1 el. ~ 300 pA)

- **combined sensor & amplifier**

  low capacitance and noise

  → excellent spectroscopic performance

  complete clearing of signal charge

  → no reset noise

  non-destructive readout

  → potential of repetitive readout

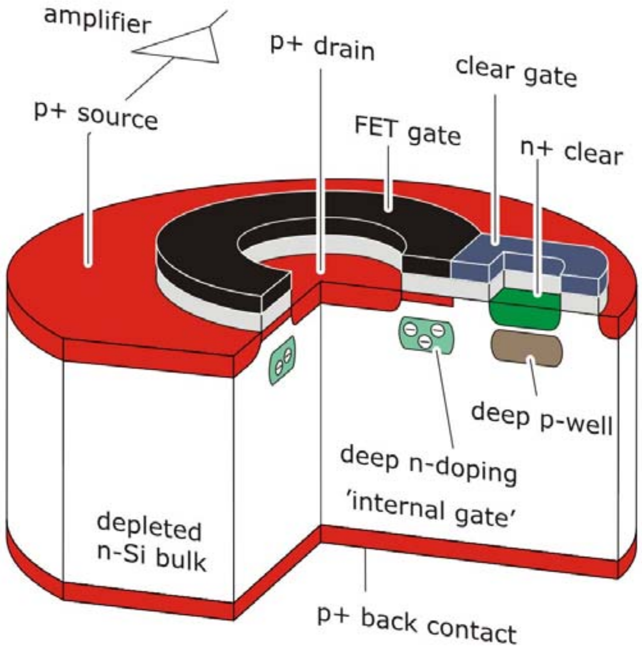
  charge storage capability

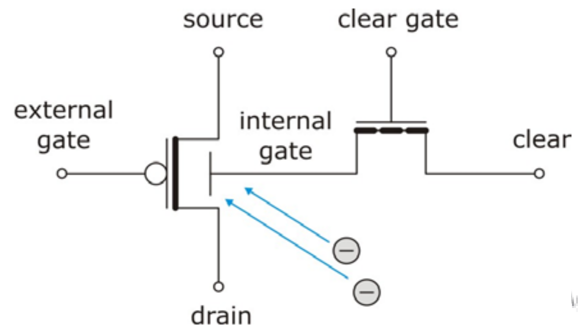
  → readout on demand

  full depletion

  → backside illumination

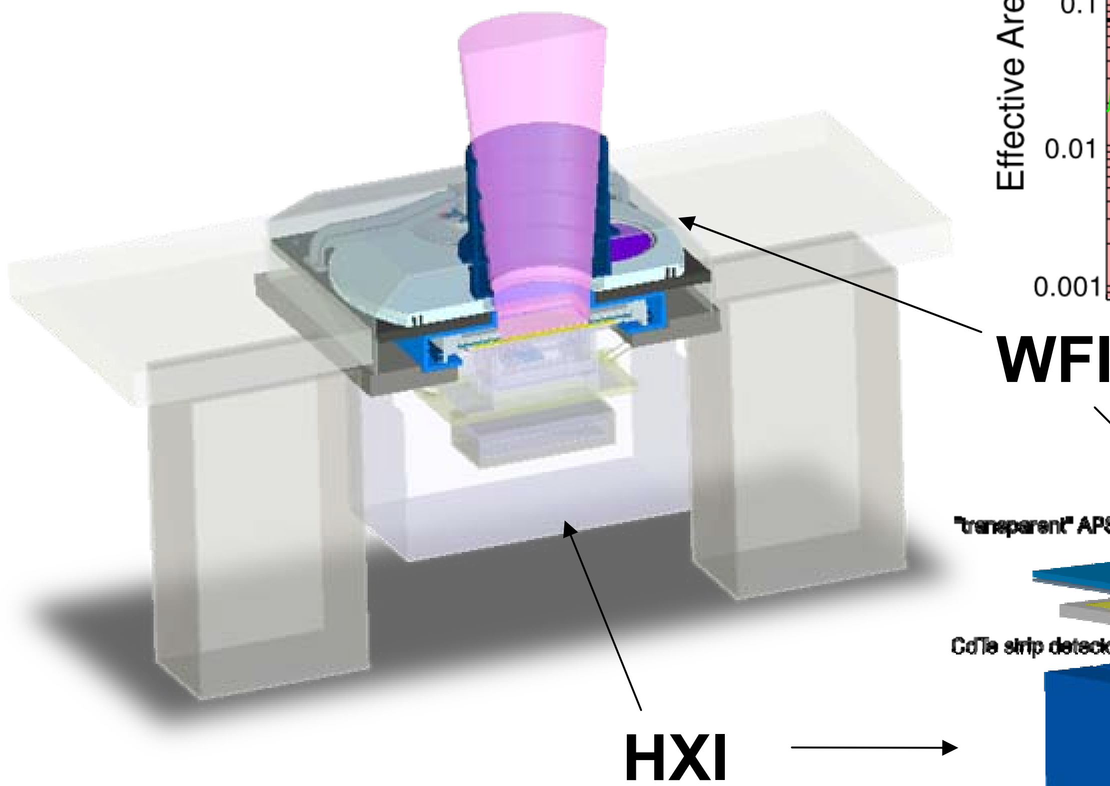
  → thin entrance window

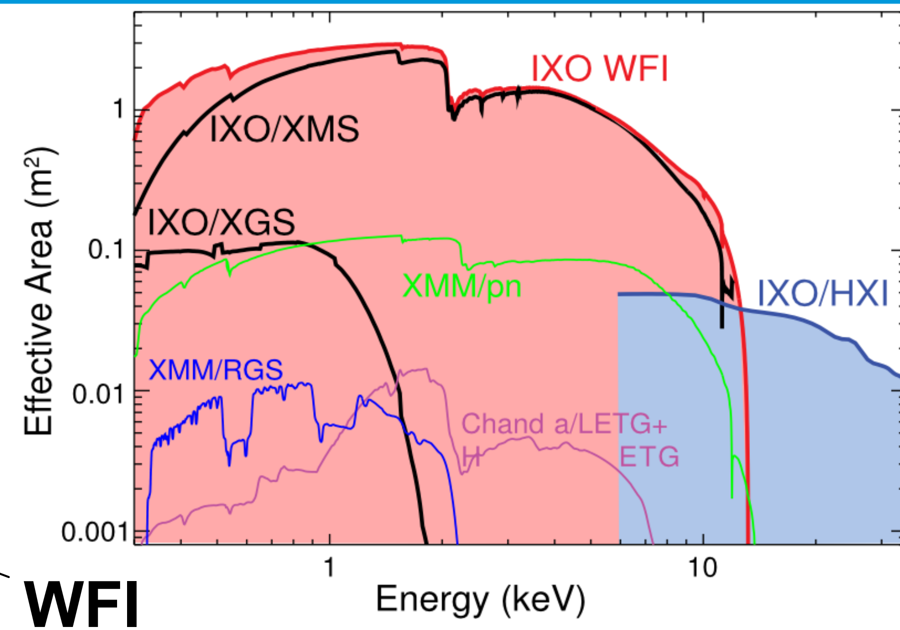


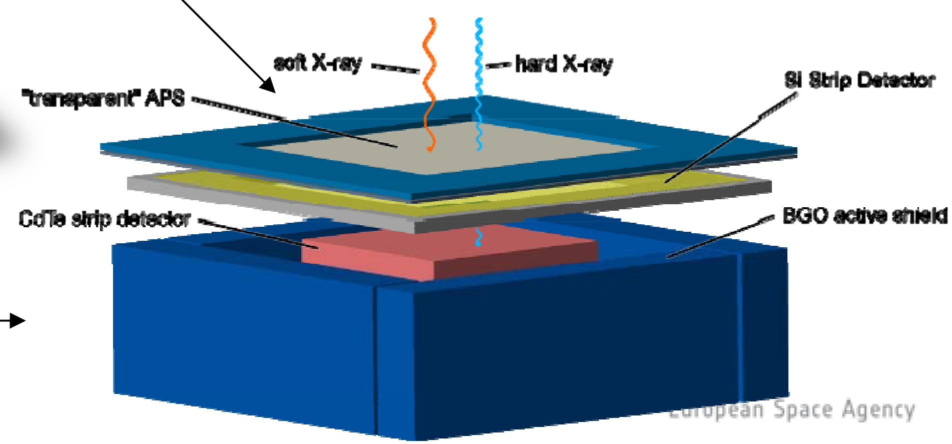


WFI – HXI Configuration

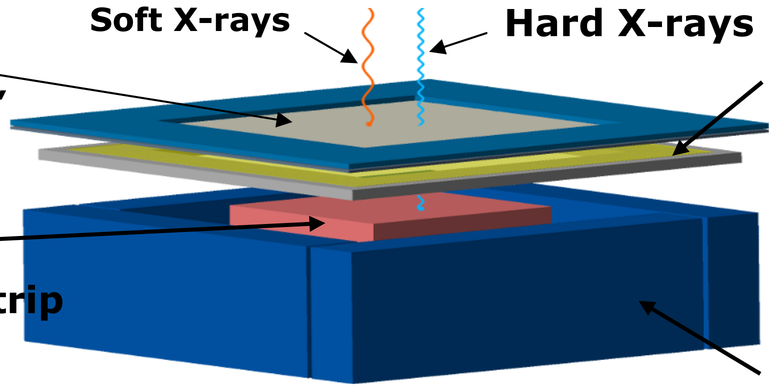
- **HXI mounted back-to-back with WFI**







HXI Key Performance Requirements



WFI/HXI Layout: The WFI soft X-ray Active Pixel Sensor (APS) is in front of the HXI CdTe detector

Detector Type	2-layers of Si and 1-layer of CdTe Schottky Diode double sided strip (c.f. CdTe pixel option)
Angular Resolution (Mirror)	30" (7-40 keV), goal of 5"
Strip pitch	250 um (~2.4" @ FL20m) (c.f. < 580 um pixel option)
Array Size	50 × 50 (mm^2) for field of view of 8 × 8 $arcmin^2$
Energy range	10-40 keV (+40-80 keV for calibration)
ΔE	< 1 keV (FWHM)
Non X-Ray Background	5×10^{-4} counts/s/keV/cm^2 roughly flat
Absolute timing	< 100 usec

HXI Instrument Technology

Double-sided Si Strip Detector

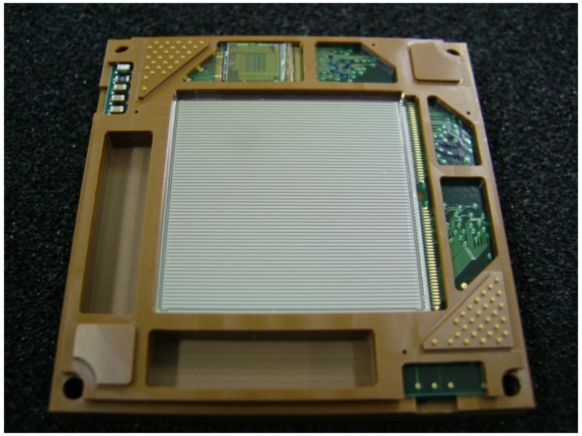
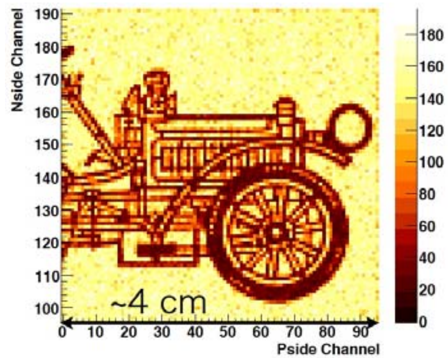


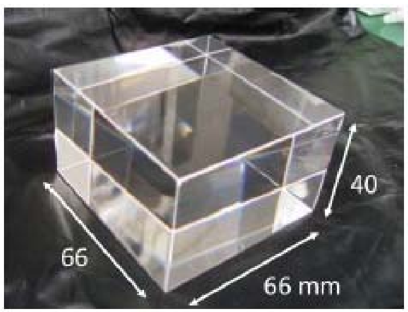
Image from 4 cm wide test DSSD device



Double-sided Strip CdTe Detector

Also CdTe pixel option dev. in progress

BGO shield technology

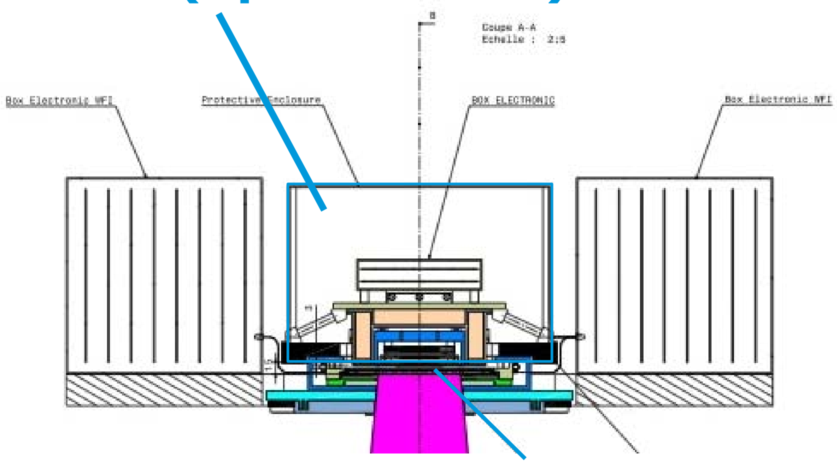


BGO scintillators read-out via APDs

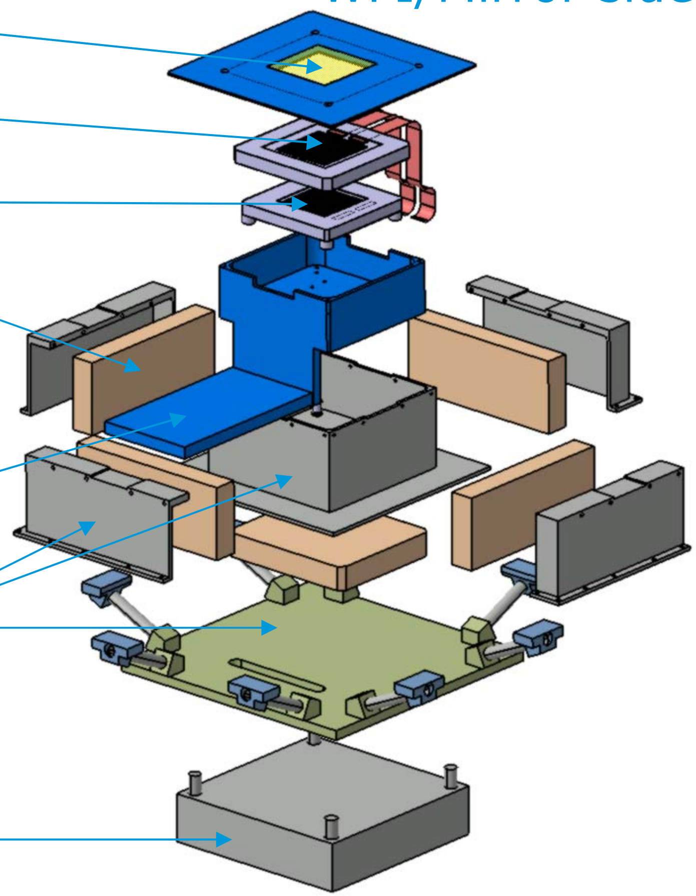
Major Detector technologies are heritages from ASTRO-H and Simbol-X activity, and well developed

HXI Instrument Configuration

HXI (upside down)



WFI/Mirror side



outer space side

HTRS Key Performance Requirements

The HTRS top level requirements for neutron star and stellar mass black hole science: Equation of state of dense matter, black hole spins and strong gravity

Parameter	Value
Max count rate (nominal)	2 Mcounts/s (~12 Crab)
Energy range	0.3-15 keV
Energy resolution @ 6 keV	<200 eV/150 eV (goal)
Minimum time resolution	10 microseconds
Deadtime @ 1 Crab	<2%
Pile-up @ 1 Crab	< 2%

HTRS key technology

Silicon Drift Detectors (SDDs): small capacitance and integrated FET:

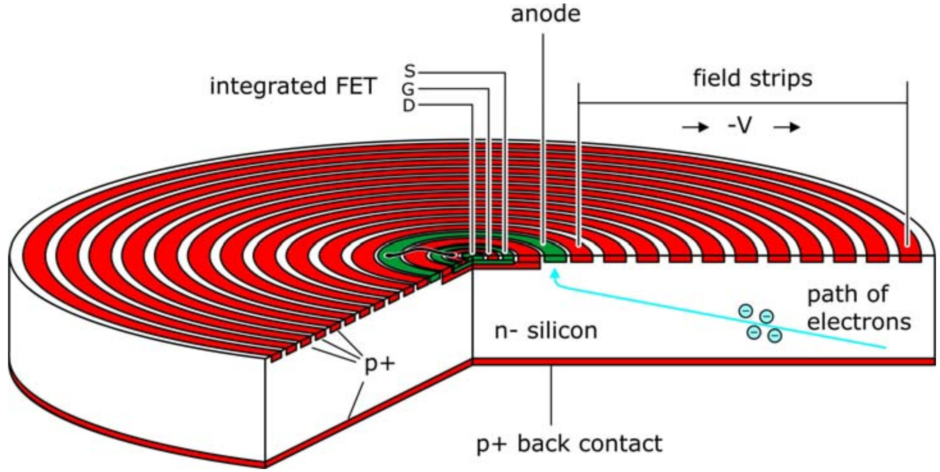
➔ Perfectly suited for high count rate and moderate spectroscopy applications

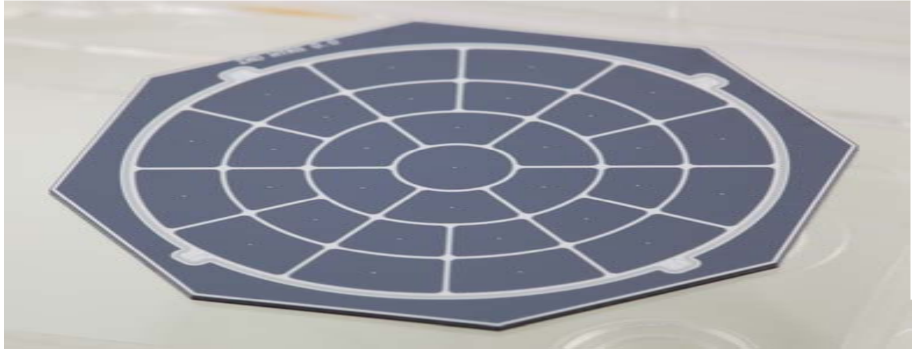
Low leakage current:

➔ Require moderate cooling (-40 C)

Flexible in shape and size: disks, squares

The HTRS is an array of 31 SDDs operated out of focus (-10.4 cm) so that the focal beam gets dispersed quasi-uniformly over the 31 detectors





Courtesy Peter Lechner

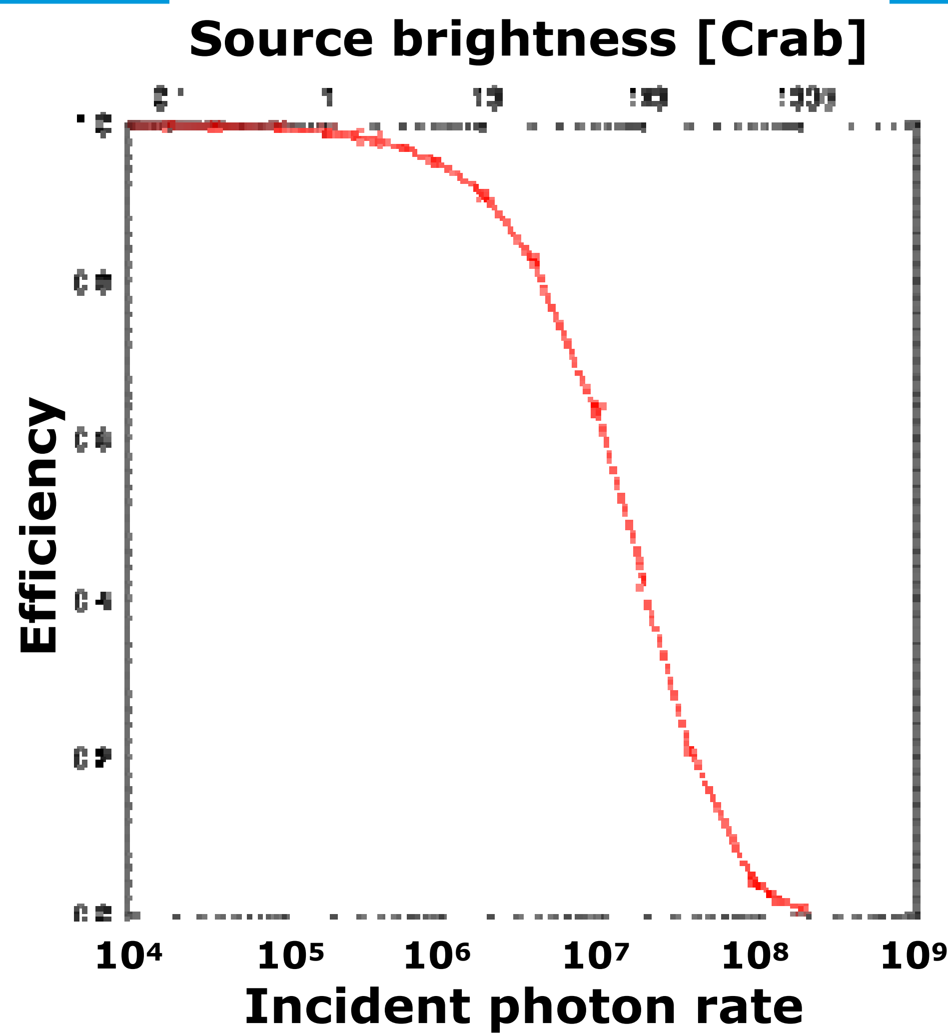
HTRS performance simulations

Detection efficiency computed using analytical modeling and numerical simulations of time variable or constant light curves

Take into account the detector geometry and performance of the readout electronics

Assume realistic energy spectrum, e.g. Crab-like spectrum

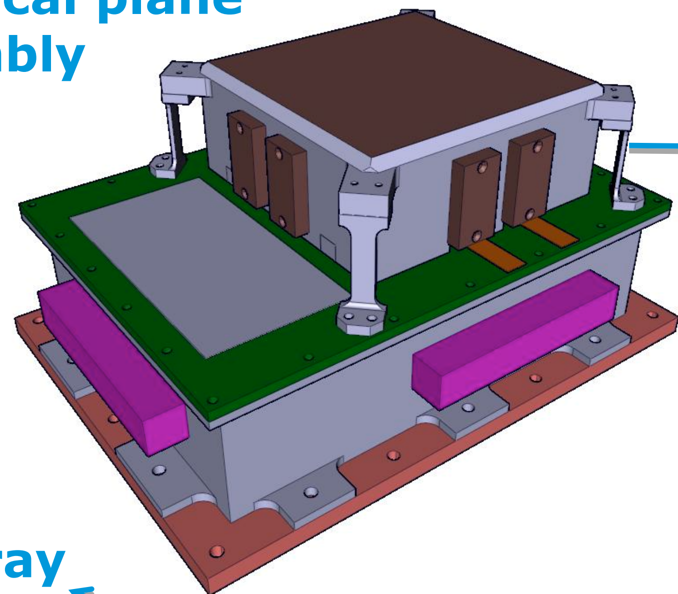
Data mode by default: Binned spectral mode with data rate reduced to less than 0.84 Mbits/s by on-board compression

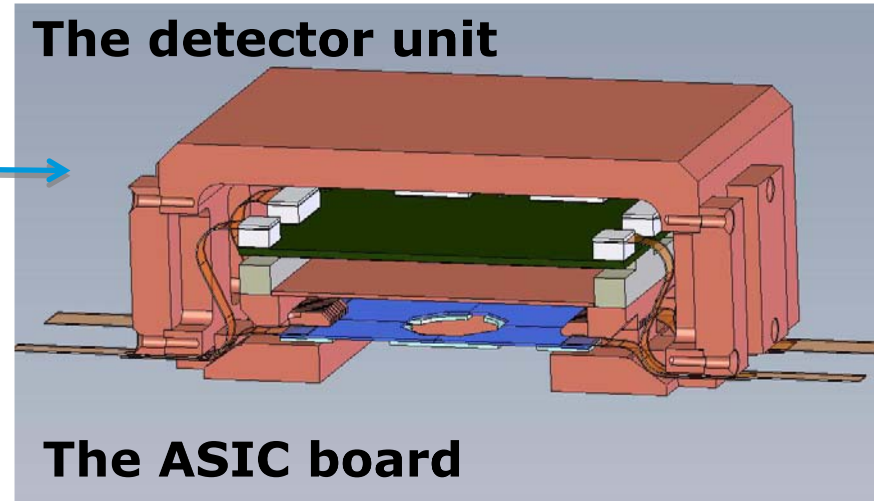


Courtesy Christian Schmid & Joern Wilms

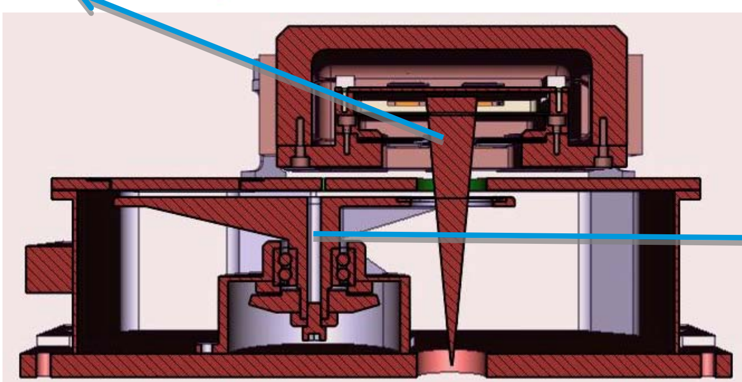
HTRS configuration

The focal plane assembly

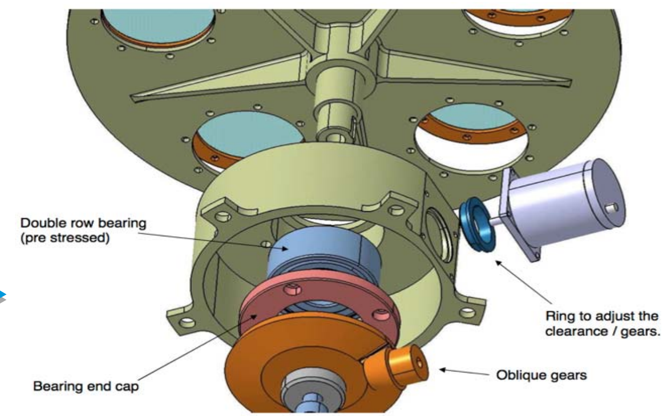




SDD array



The filter wheel

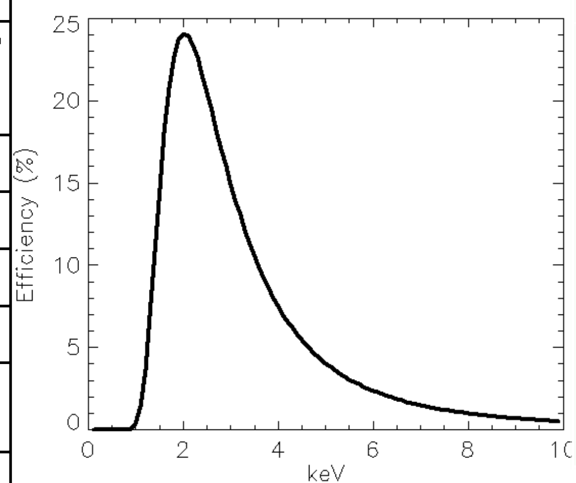


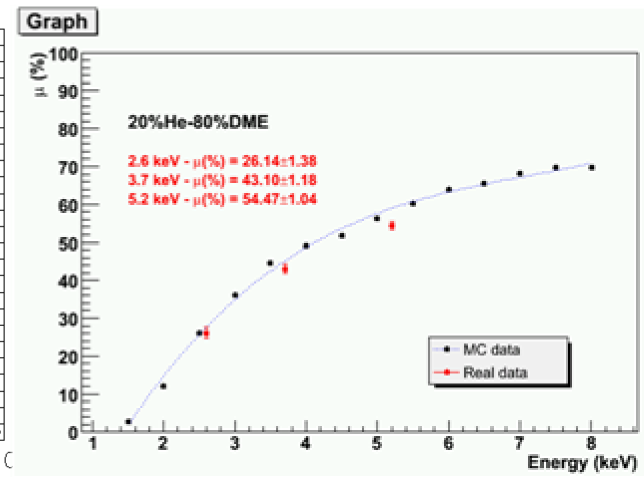
Courtesy Franck Cadoux & Stéphane Paltani

XPOL Key Performance Requirements

- Enable Polarimetric measurements to 1% Minimum Detectable Polarization (3σ) for 1mCrab source in 10^5s
- Specs for He-DME 20-80 at 1bar, 50 μm Be window, 1cm drift region in Table and Figure

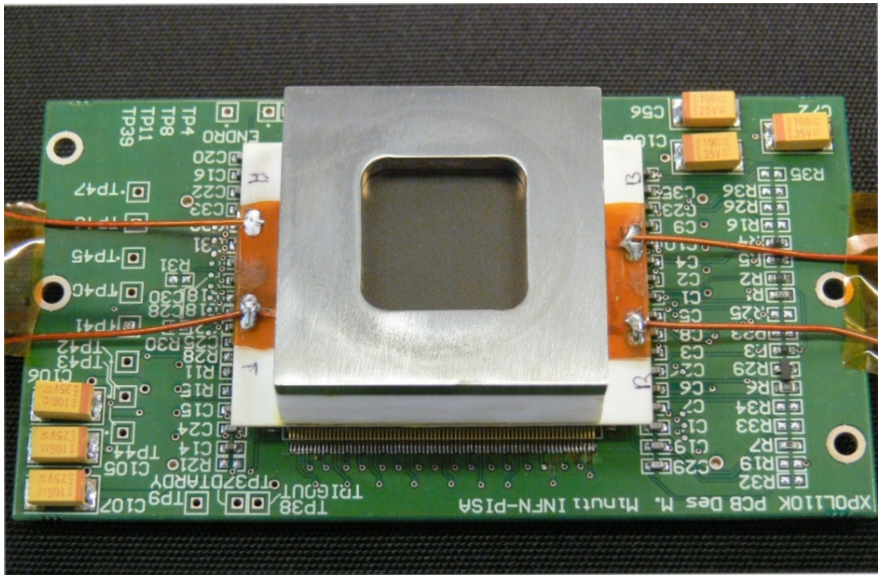
Detector size	15x15 mm^2
Polarizazion sensitivity	1% MDP (3σ) for 1mCrab source
Energy range	2 – 10 keV
Energy resolution	20 % at 6 keV
Angular resolution	5″
Pixel size	50 μm
FOV	2.6x2.6 arcmin square
Timing resolution	5 μs
Efficiency	See Figure
Modulation factor	See Figure
Polarization angle resolution	~ 1 deg
Dead time	10 μs





(Left) Efficiency. (Right) Modulation factor measured at 2.6 keV, 3.7 keV and 5.2 keV compared with the Monte Carlo previsions.

Key XPOL technology and status



➢XPOL is aimed to the polarization study and is based on a Gas Pixel Detector (GPD)

The GPD is a finely subdivided counter with proportional multiplication that is able to precisely reconstruct the photoelectron track and thence to derive its ejection direction thanks to the low noise, autotriggering, pixel readout ASIC

Synopsis of development history and status:

–The GPDs have been tested with polarized and non polarized X-ray sources to measure all the performance. The performance are in agreement with theoretical predictions. An upgraded ASIC (speed, trigger level) is under design. Gas optimization (pressure, mixture) is going on.

Environment in which the technology has been demonstrated:

–Thermal test at ambient pressure and Thermo-vacuum test at P ≤10^{-5}mBar in the T range -15°, +45°C.

–Random vibe test at GEVS acceptance levels +4dB. First resonance >3000Hz, GPD is a very compact and robust device.

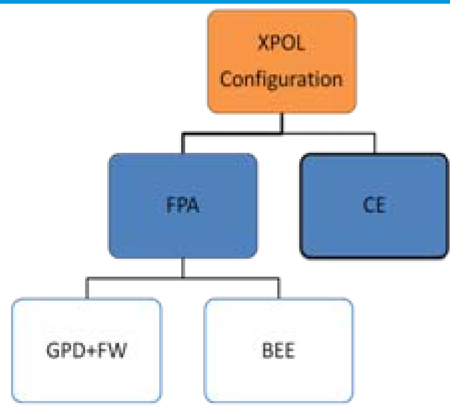
–One detector overcame a survival test to Fe ions, at 500MeV/nucleon

TRL:

–GPD TRL= 5 : GPD was demonstrated in relevant environment

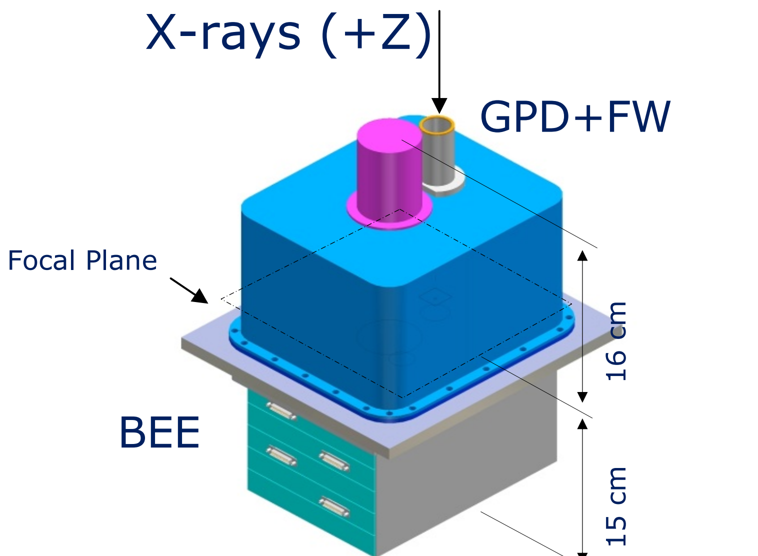
–Associated electronics/mechanisms TRL=7/6: breadboards exist, standard space components are foreseen, no relevant technologic R&D are needed.

XPOL configuration and resources requirements

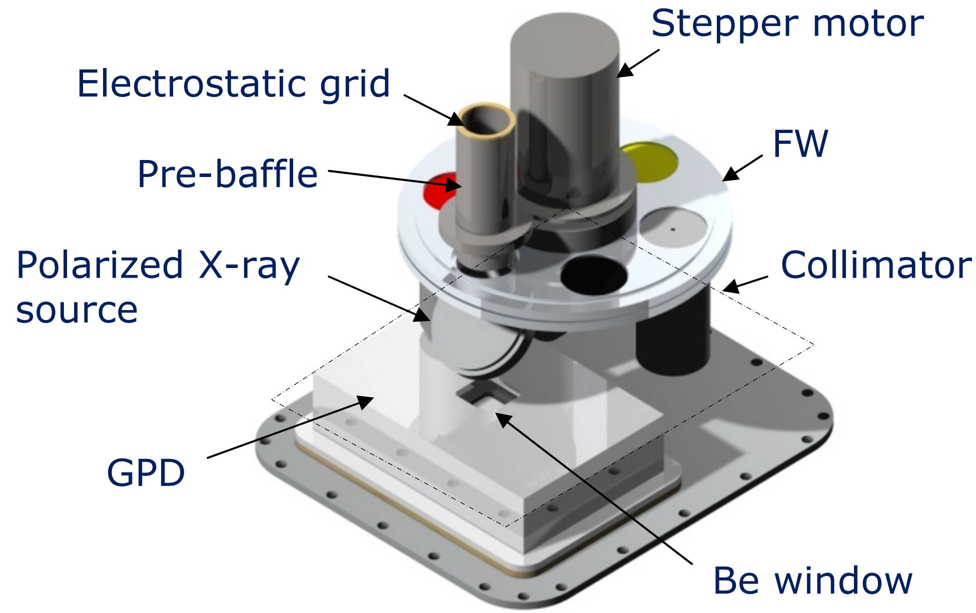


- **Focal Plane Assembly (FPA)**
  located on MIP
  - GPD and Filter Wheel assembly (GPD+FW)
  - Back End Electronics unit (BEE)

- **Control Electronics unit (CE)**
  located anywhere on MIP or FIP



FPA in back-to-back config



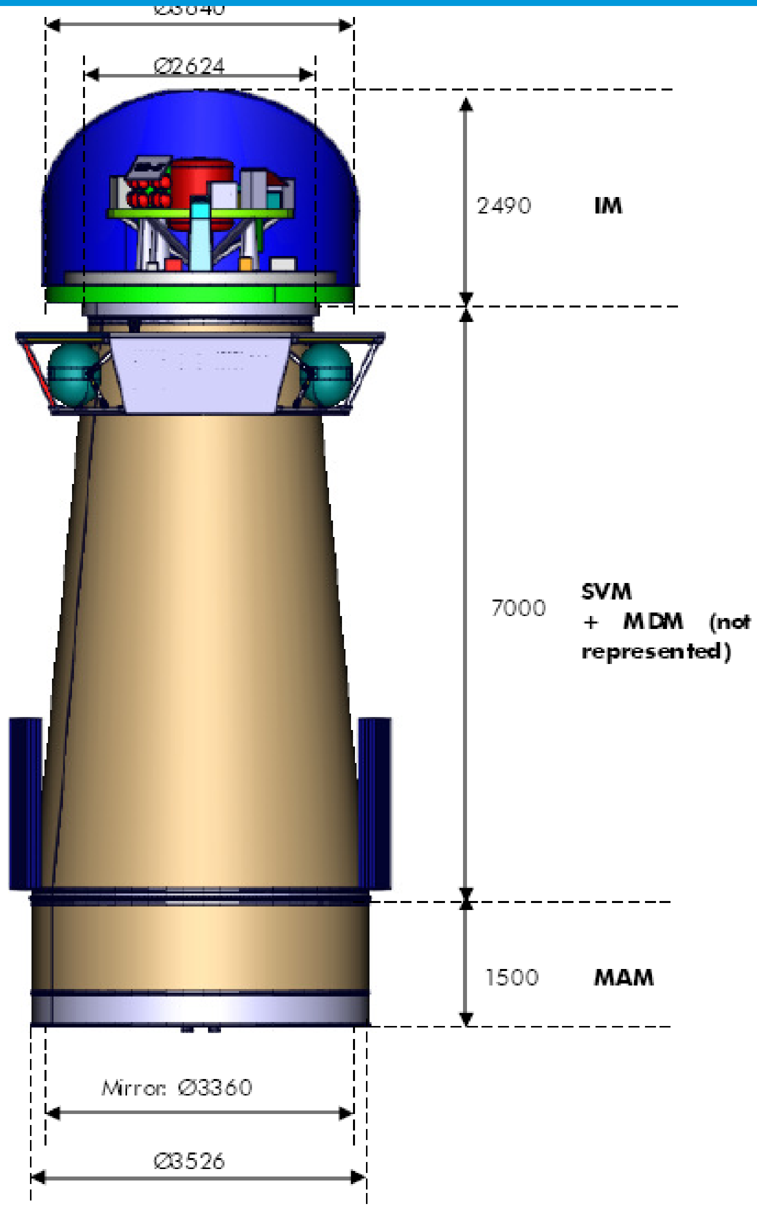
GPD+FW

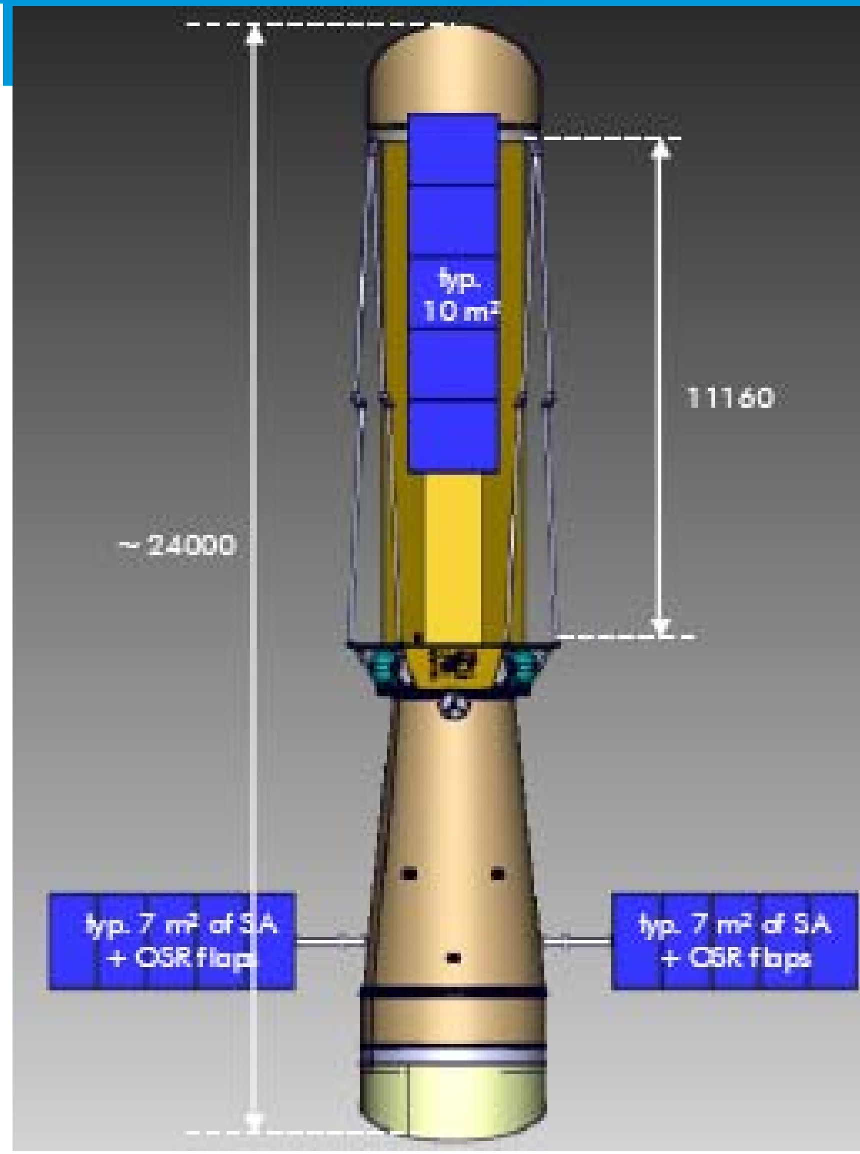
Accommodation on S/C

Instrument Accommodation on S/C

- Instrument platform is on boom, deployed after launch
- Concept consists of a
  - "Fixed" platform (FIP), which accommodates the XGS camera
  - "Moveable" platform (MIP), accommodating all other (imaging) instruments
- Single aperture mirror concept requires the moveable platform to place the relevant instrument in focus
- Instrument platform requires metrology to measure its precise position wrt X-ray beam to:
  - Maintain optical quality (5")
  - Accurately reconstruct pointing (1")

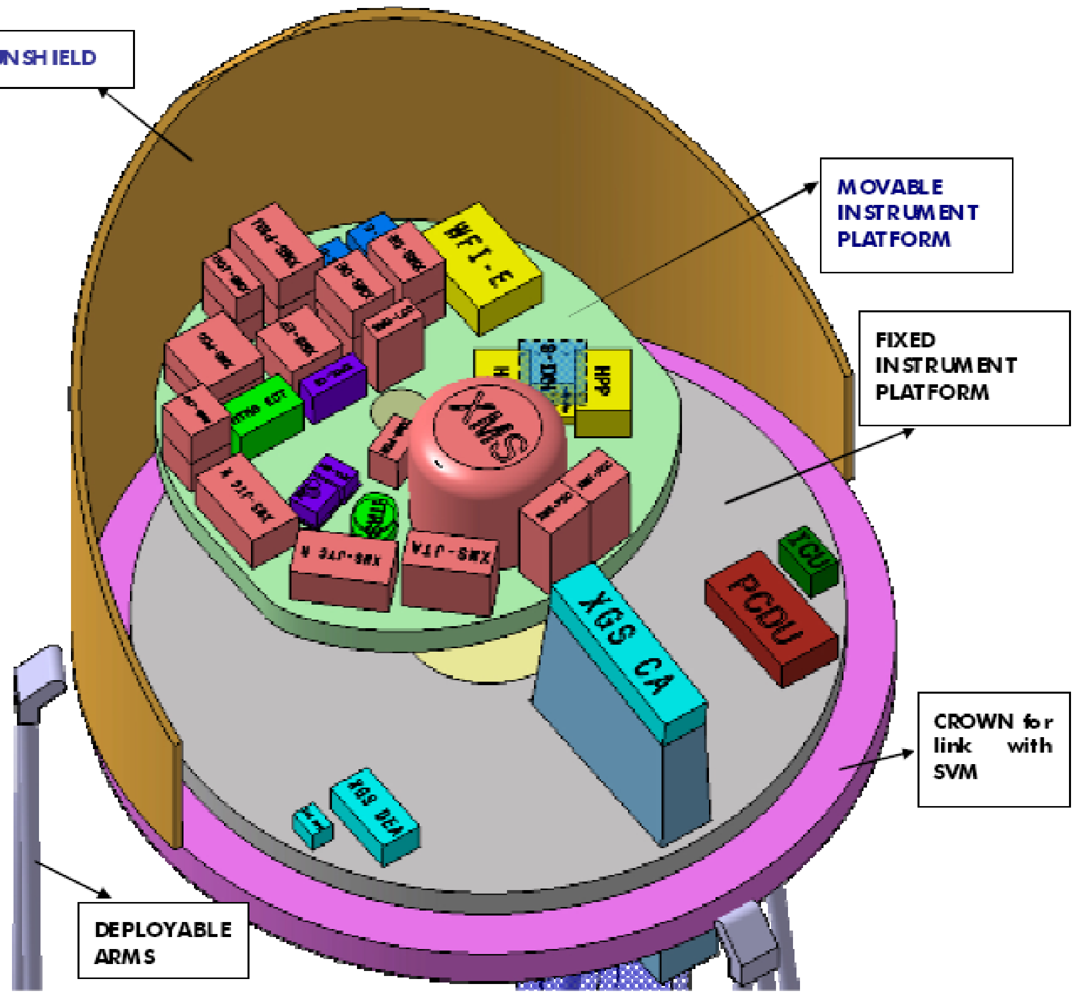
TAS S/C concept

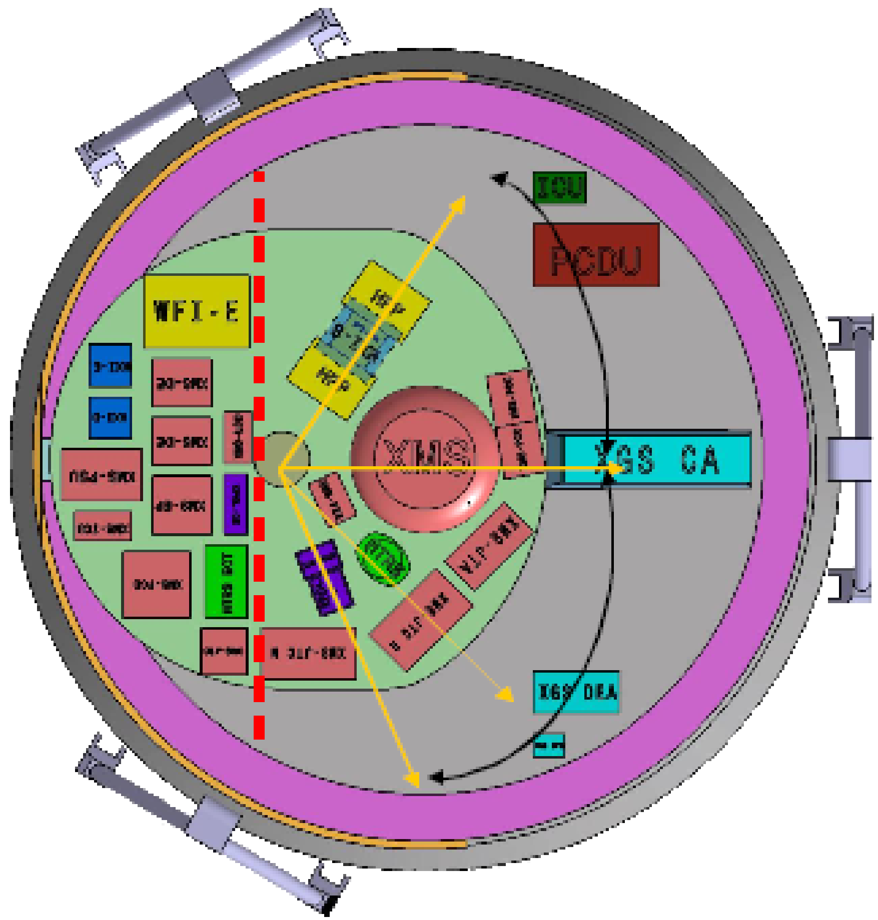




Launch and deployed config

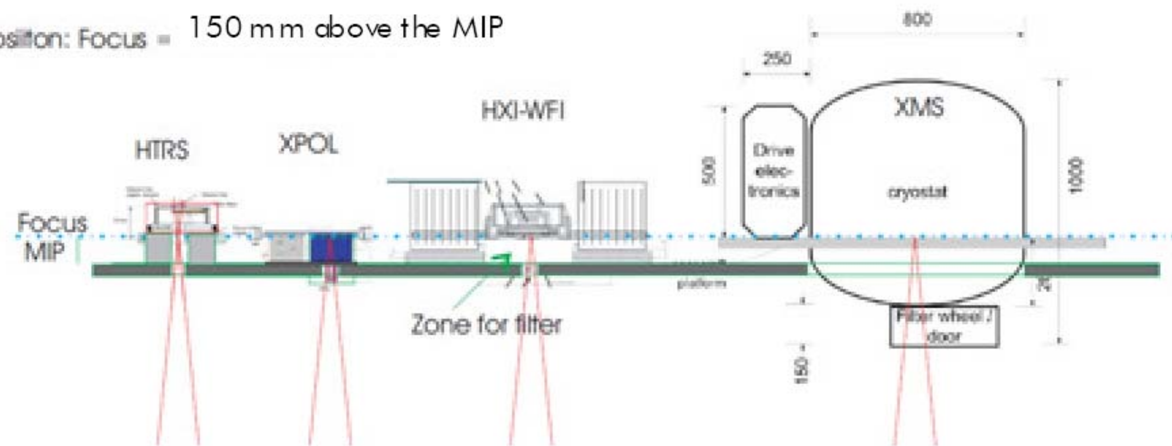
TAS Instrument platform concept





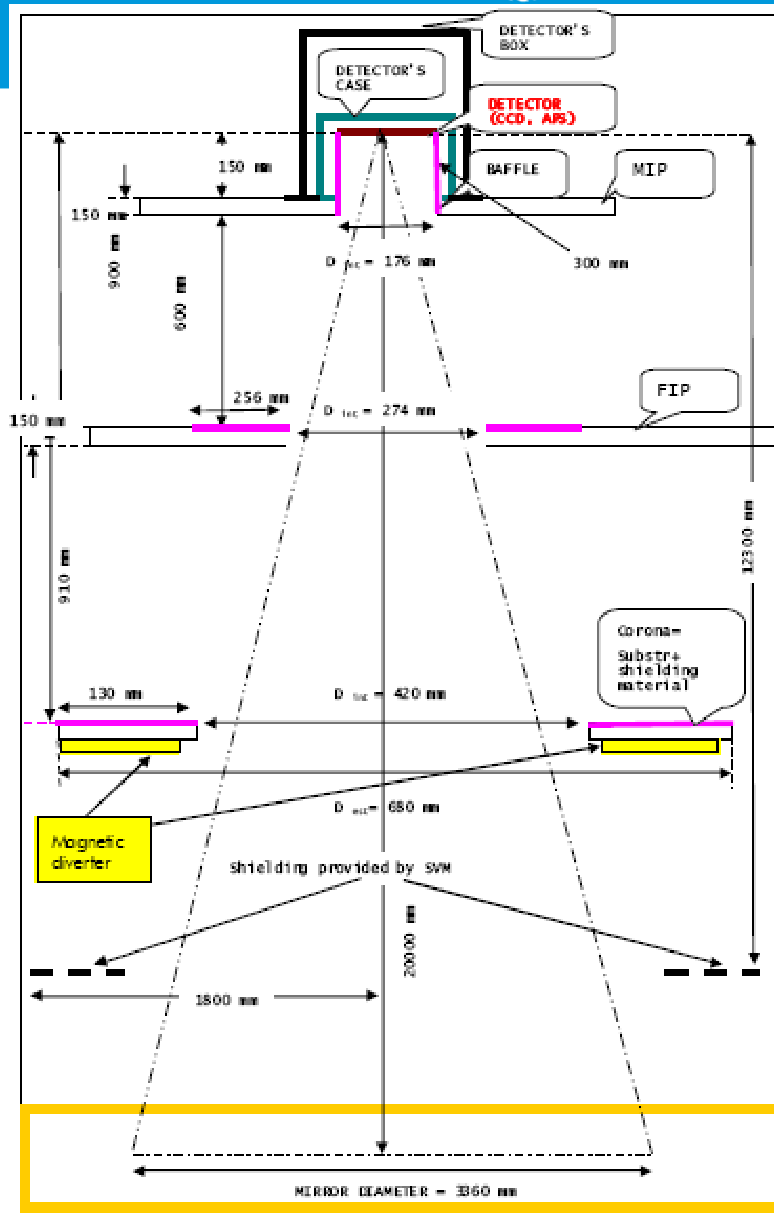
TAS Instrument platform concept

Proposition: Focus = 150 mm above the MIP

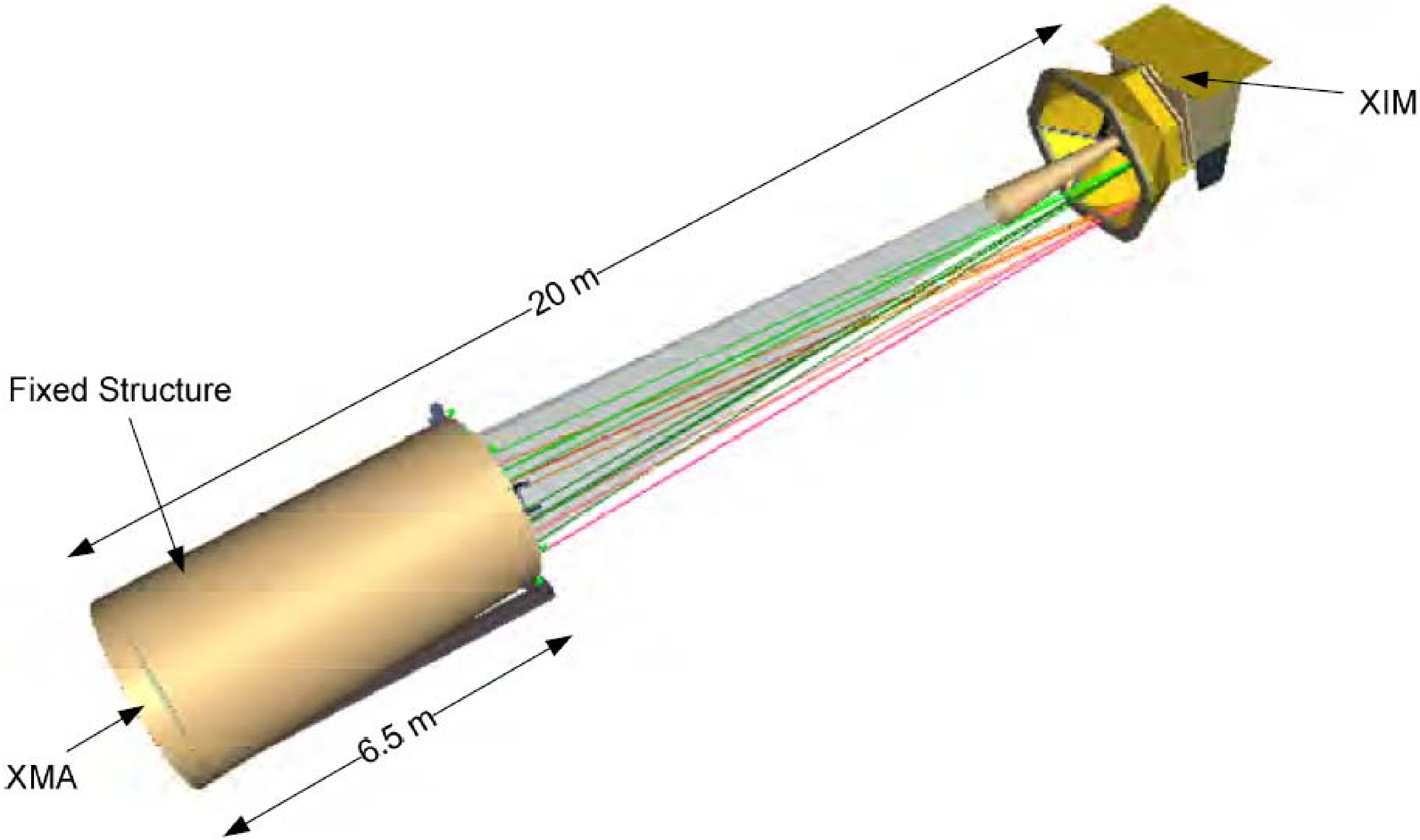


Alternative Focus position

Baffling

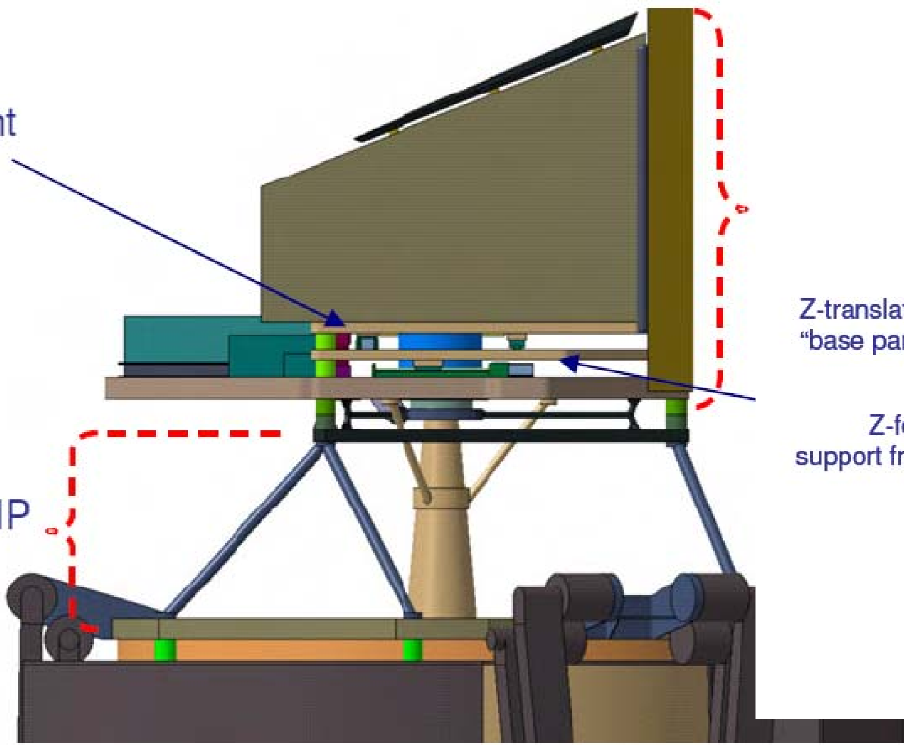


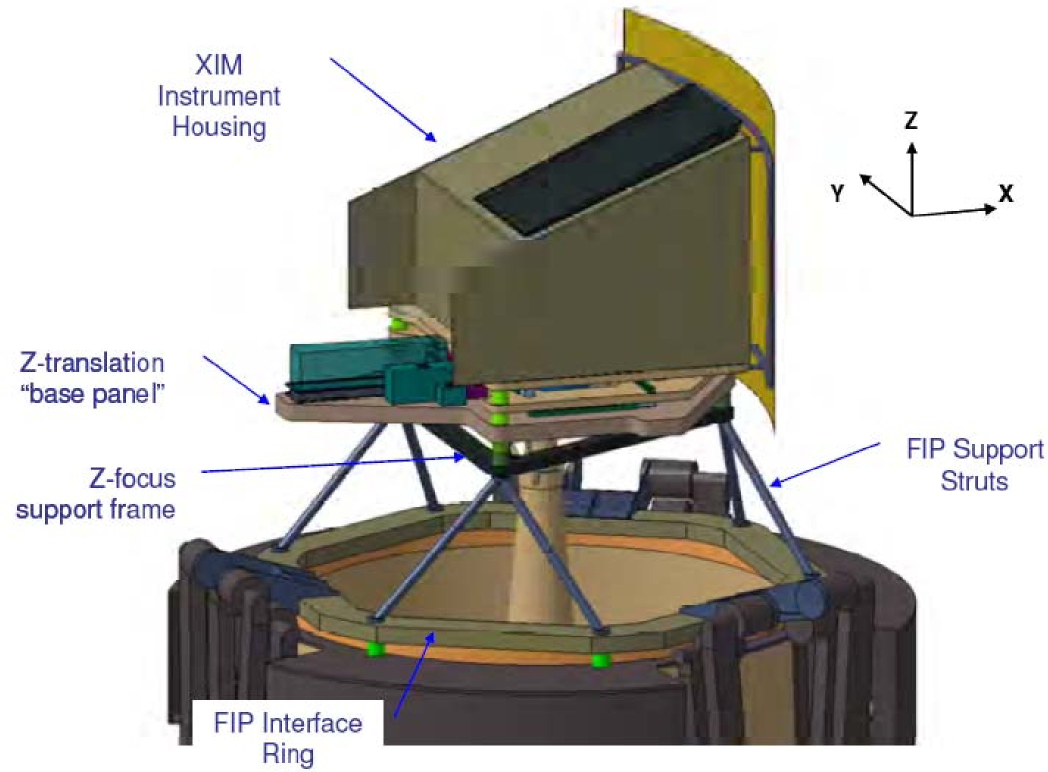
ASU S/C concept



Deployed config, w/o shroud and SAs

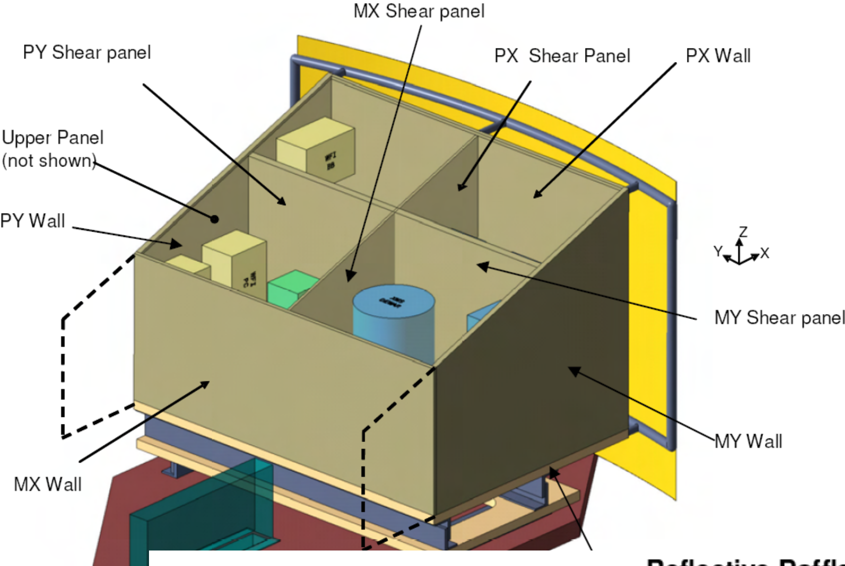
ASU Instrument platform concept

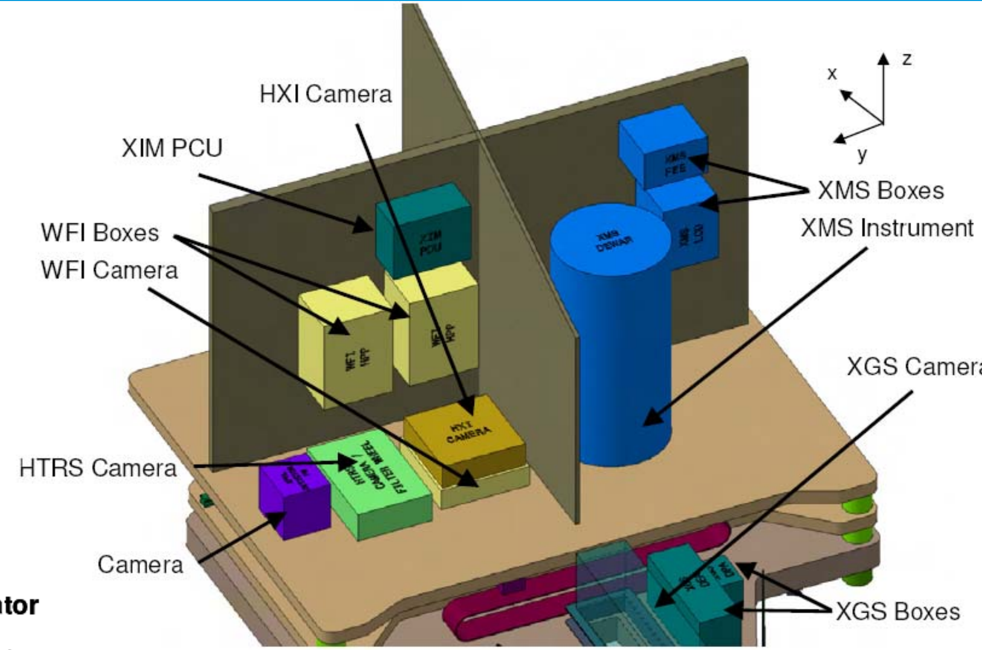


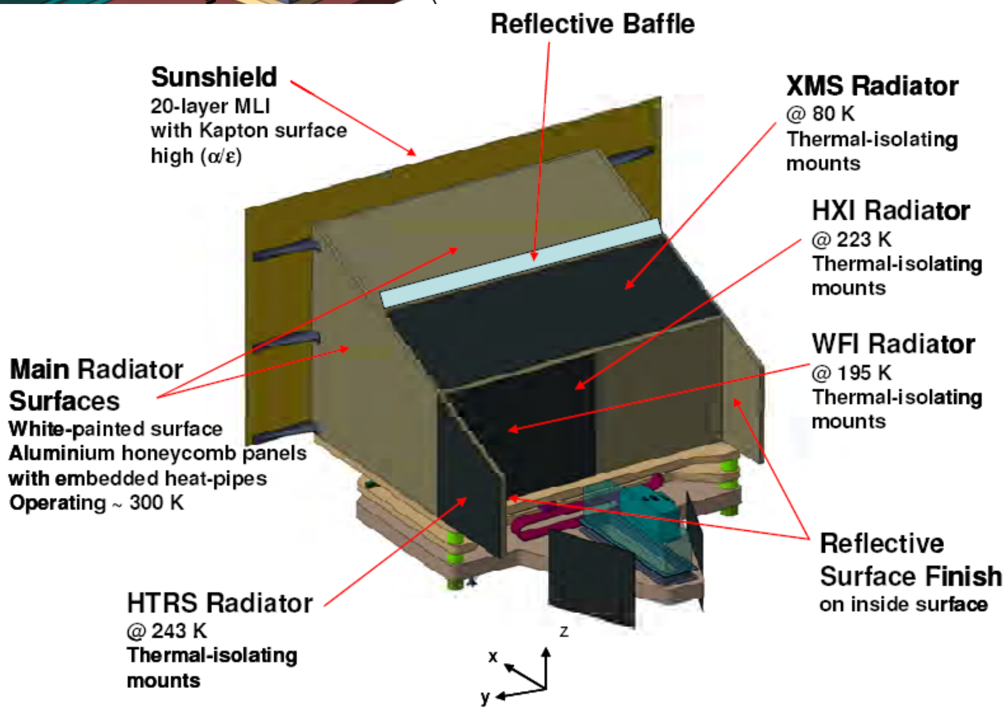


Instrument Platform

ASU Instrument platform concept







Instrument Platform

Accommodation Issues

Accommodation issues

- Mass, Mass, Mass
- Pointing/alignment (deployment, stability)
- Accommodation on MIP (space, thermal)
- Cryogenics
- Straylight (external, alignment monitor)
- Contamination

Instrument Resources

Instrument Resources

instrument	acronym	Mass (kg)	Power (W)	Data rate (kbit/s)	
				typical	Max
Wide Field Imager	WFI	100.9	283.1	45	450
Hard X-ray Imager	HXI	28.0	55.9	11	256
Cryogenic Spectrometer	XMS	113.1	520	64	840
	Cryo-chain#	278.4	497	na	na
Grating Spectrometer	CAT-XGS	121.7	115.2	128	840 (1280)
	OP-XGS	90.7	86.4		840
High Time Resolution Spectrometer	HTRS	30.2	145	840	840
Polarimeter	X-POL	15.3	55.2	840	840

Mass and power including design margins
 # ESA CDF design