The Imaging X-ray Polarimetry Explorer (IXPE)

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INAF/IAPS
on behalf of the IXPE Team

Why X-ray Astrophysical Polarimetry ?

Polarization from celestial sources may derive from:

- Emission processes themselves: cyclotron, synchrotron, non-thermal bremsstrahlung

(Westfold, 1959; Gnedin & Sunyaev, 1974; Rees, 1975)

- Scattering on aspherical accreting plasmas: disks, blobs, columns.

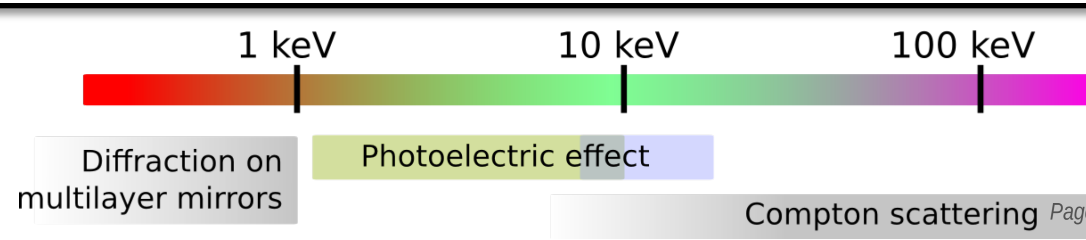
(1975; Sunyaev & Titarchuk, 1985; Mészáros, P. et al. 1988)

- Vacuum polarization and birefringence through extreme magnetic fields

(Gnedin et al., 1978; Ventura, 1979; Mészáros & Ventura, 1979)

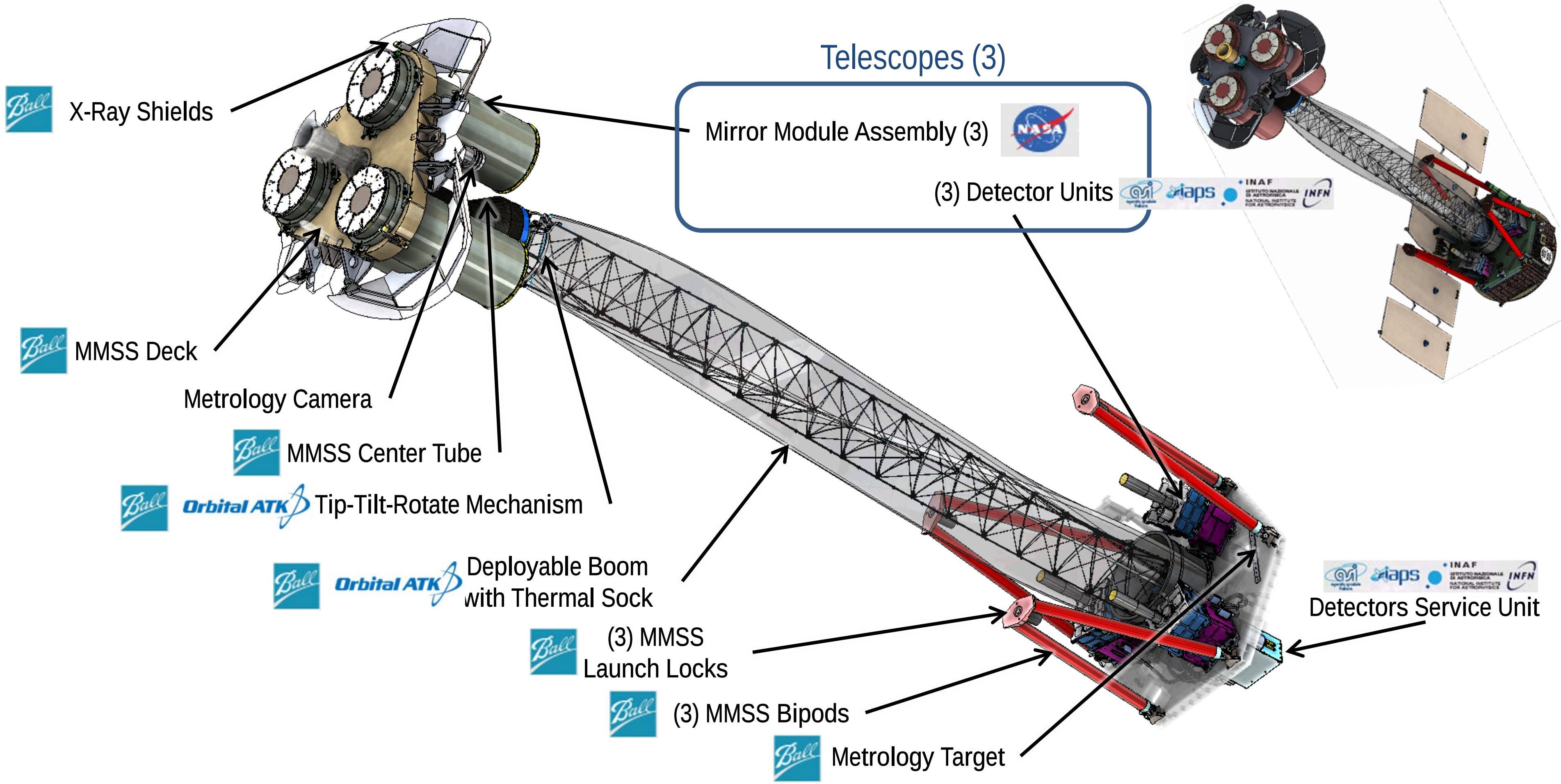
Why X-ray Polarimetry in 1-10 keV energy band

Scientific goal	Sources	< 1 keV	1–10	> 10 keV
Acceleration phenomena	PWN	yes (but absorption)	yes	yes
	SNR	no	yes	yes
	Jet (Microquasars)	yes (but absorption)	yes	yes
	Jet (Blazars)	yes	yes	yes
Emission in strong magnetic fields	WD	yes (but absorption)	yes	difficult
	AMS	no	yes	yes
	X–ray pulsator	difficult	yes	yes (cyclotron)
	Magnetar	yes (better)	yes	difficult
Scattering in aspherical geometries	Corona in XRB & AGNs	difficult	yes	yes (difficult)
	X–ray reflection nebulae	no	yes	yes
Fundamental Physics	QED (magnetar)	yes (better)	yes	no
	GR (BH)	no	yes	no
	QG (Blazars)	difficult	yes	yes
	Axions (Blazars, Clusters)	yes ?	yes	difficult



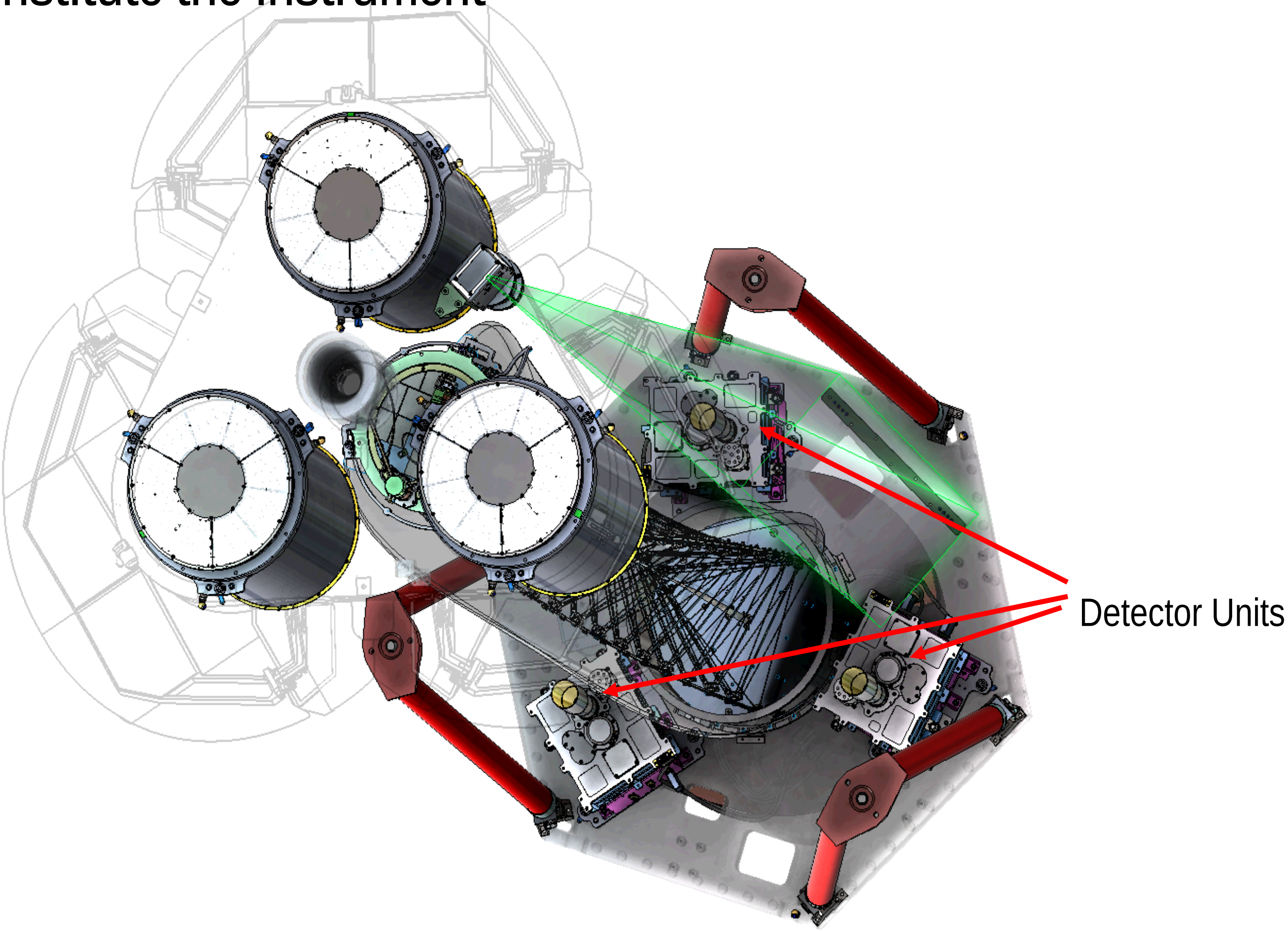
Payload Components

Accomplish the science through integrated system of Telescopes and structure alignment components.



Architecture of the Instrument

- Three Detector Units and a single Detectors Service Unit (on underside of deck) constitute the Instrument

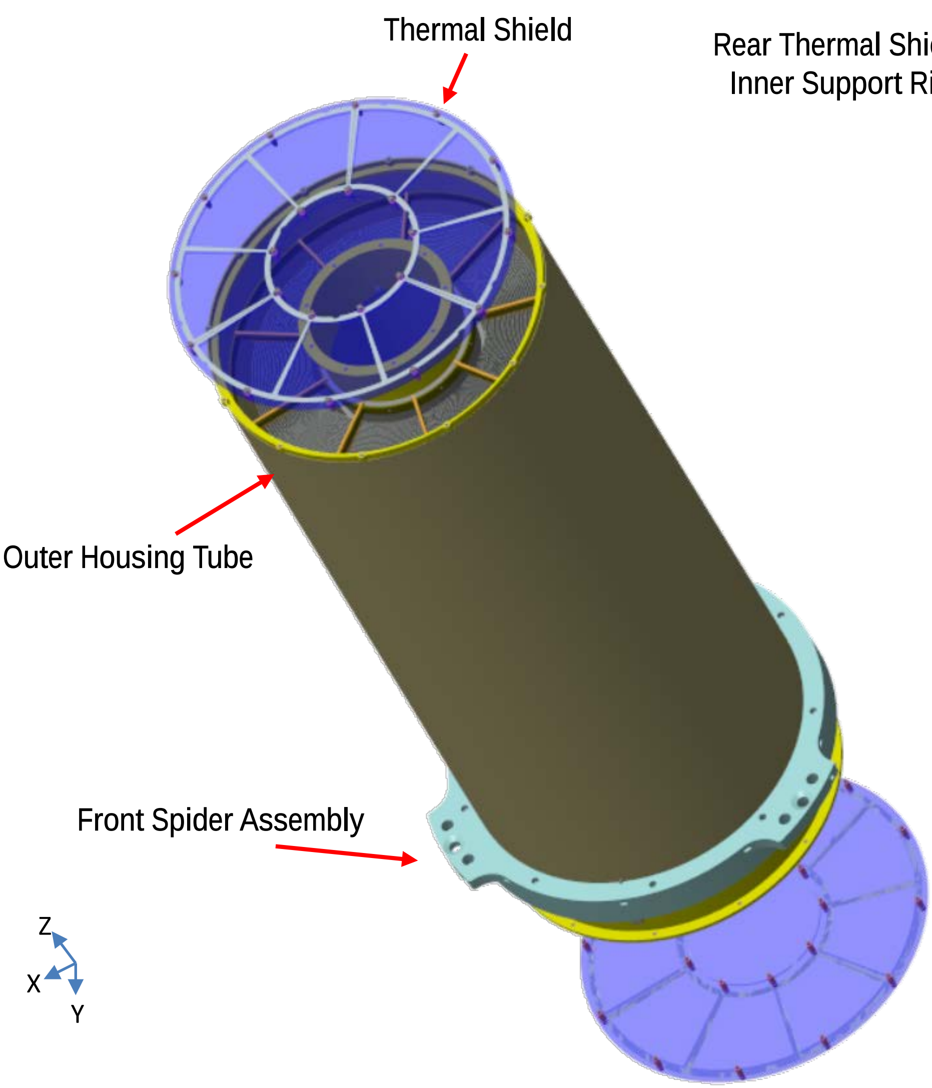


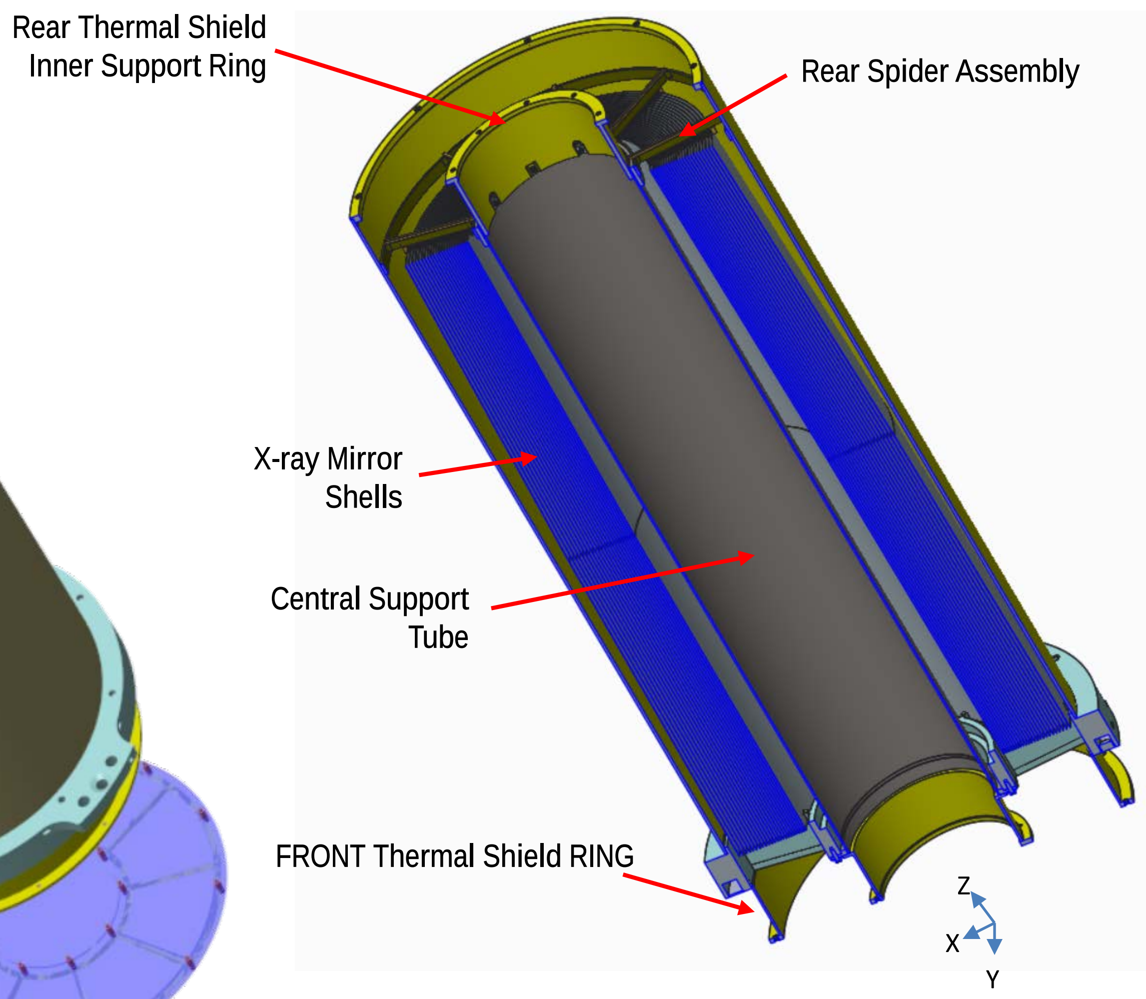
Institutions and Companies Involved

Institution	Role	Institution	Role
NASA Marshall Space Flight Center	PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving	IAPS, INAF (Istituto Nazionale di Astrofisica / National Institute for Astrophysics), INFN, OAC, OHB Italia	Polarization-sensitive imaging detector systems
		CU / LASP	Mission operations
ASI (agenzia spaziale italiana)	Detector system funding, ground station	Roma Tre Università degli Studi, Stanford University	Scientific theory
		McGill	Co-Investigator
Ball	Spacecraft, payload structure, payload, observatory I&T	Massachusetts Institute of Technology	Co-Investigator

Science Advisory Team

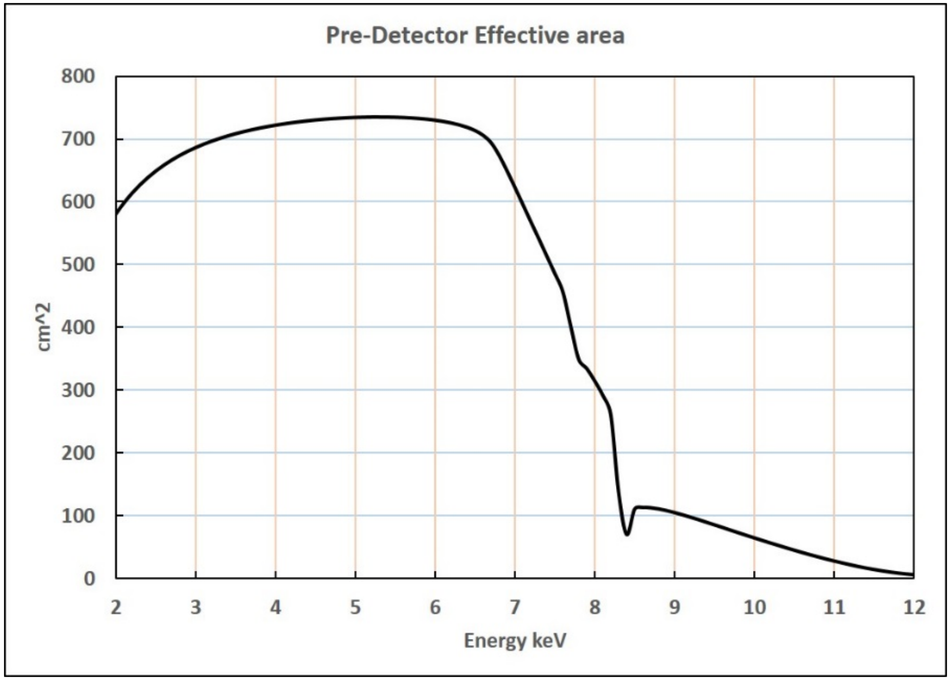
MMA Flight Configuration



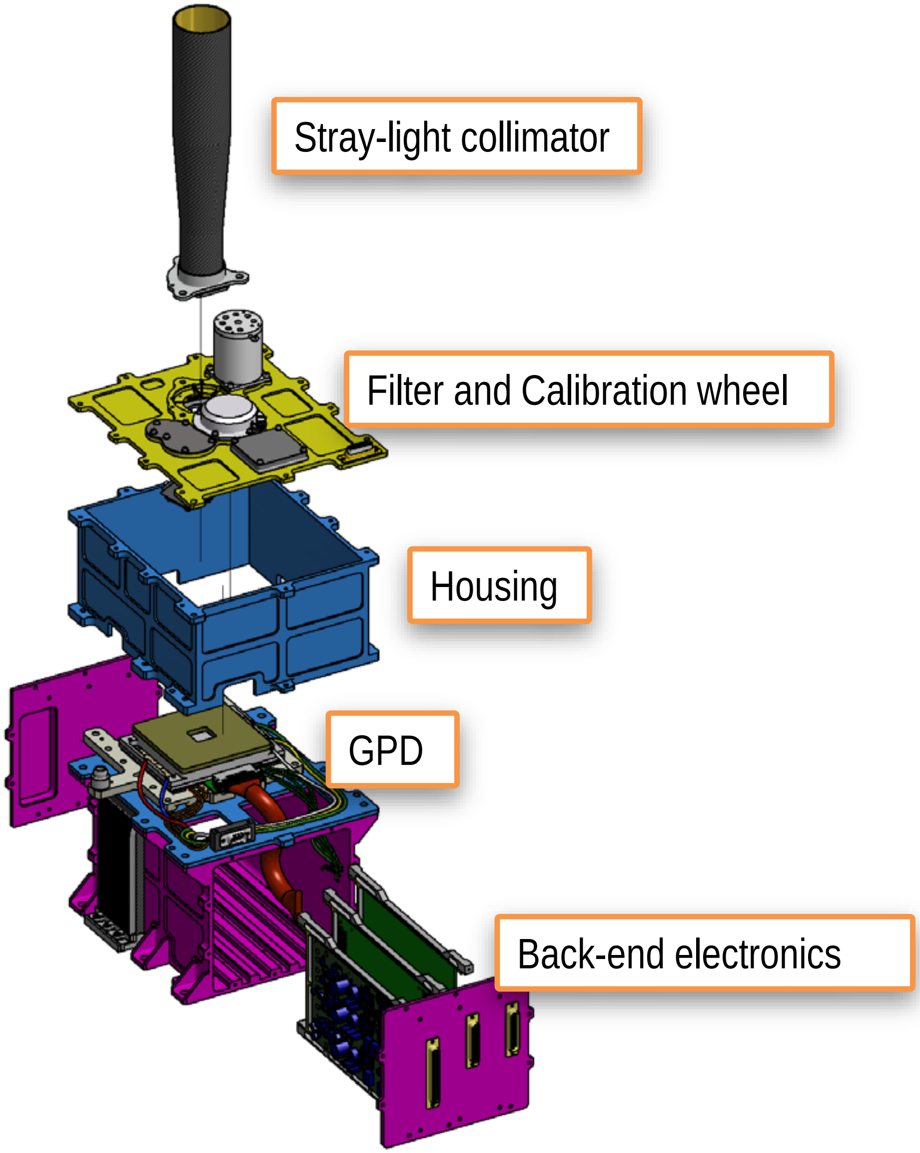


Mirror Module Assembly Properties

Property	Value
Number of modules	3
Mirror shells per module	24
Inner, outer shell diameter	162, 272 mm
Total shell length	600 mm
Inner, outer shell thickness	180, 260 μm
Shell material	Nickel cobalt alloy
Effective area per module	210 cm^2 (2.3 keV) > 230 cm2 (3-6 keV)
Angular resolution	≤ 25 arcsec HPD
Detector limited FOV	12.9 arcmin
Focal length	4 m
Mass (3 assemblies)	95 kg with contingency



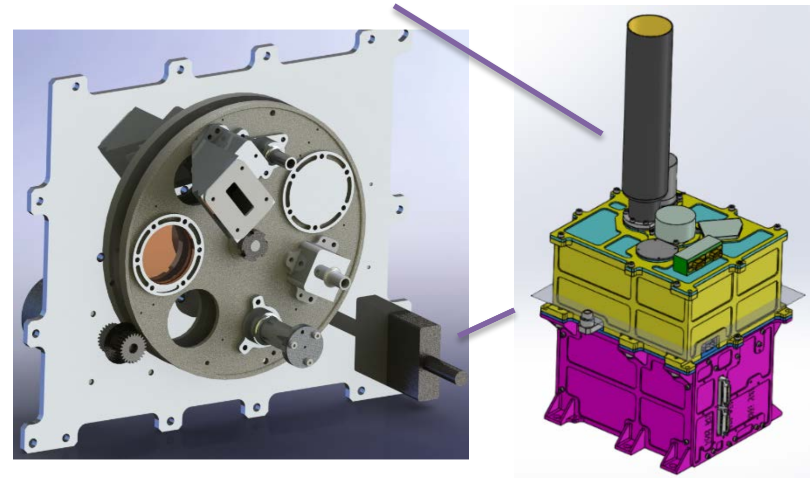
Detector Unit: Grand Summary

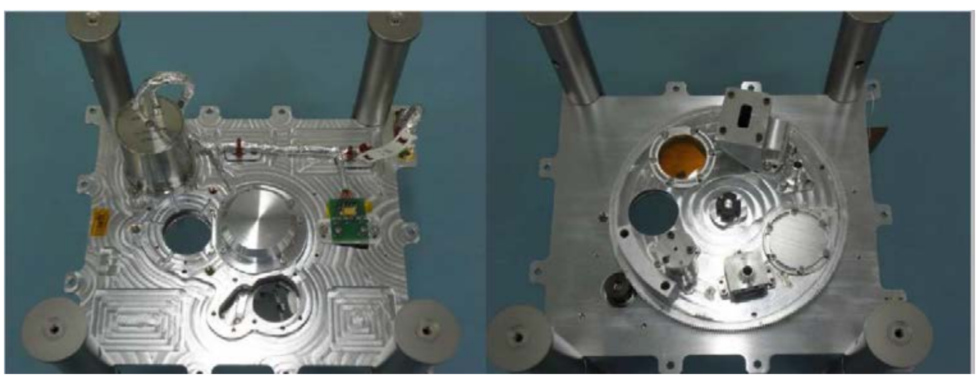


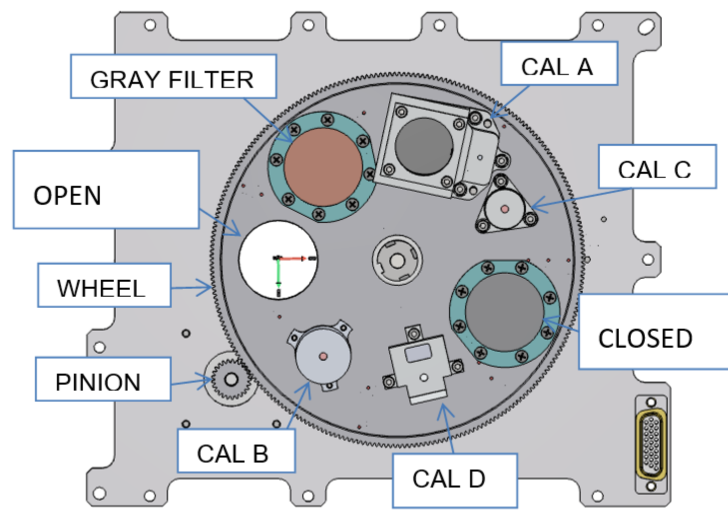
- INFN
  - GPD and associated thermal ctrl
  - DAQ and low-voltage boards and associated backplane (through OHB-I)
  - Stray-light collimator
- IAPS
  - Calibration set
  - UV filter
- OHB-I
  - High-voltage board
  - Filter and calibration wheel

In-Flight Calibration System

- Each DU includes a Filter & Calibration Wheel (FCW)
  - Heritage eRosita FCW (Spectrum X-Gamma)
  - Filters, for specific observations
    - Open position (normal observation mode)
    - Closed position (background measurement)
    - Gray filter (very bright sources, >2 Crab)
  - x4 calibration sources based on radioactive nuclides (^{55}Fe)
    - Cal A: polarized X-rays at two energies (2.9 and 5.9 keV).
    - Cal B: unpolarized X-rays on a spot at 5.9 keV
    - Cal C: full illumination of the GPD at 5.9 keV
    - Cal D: full illumination of the GPD at 1.7 keV





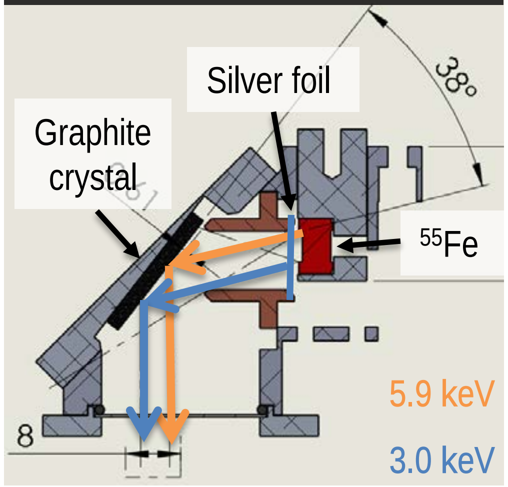


On-Board Calibration Sources: Cal A – Design & Testing

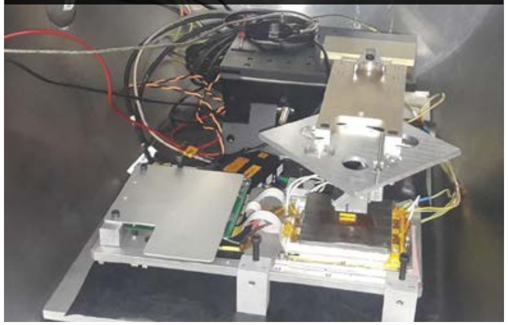
- Powered by a single ^{55}Fe source emitting at 5.9 and 6.5 keV
- A thin silver deposit (1.6 µm), deposited between two thin polyimide layers (4+8 µm), is used to produce Ag fluorescence at 2.9 keV
- 2.9 and 5.9 keV incident at 38.5 deg on graphite crystal are diffracted at first and second order
- Polarization is 67%
- Counting rate (with flight source, ^{55}Fe 100 mCi)
  - 6 c/s @ 2.9 keV
  - 80 c/s @ 5.9 keV
- Design tested in vacuum chamber
  - Silver (1.6 µm) deposited on a 6 µm polyimide
  - The image of the source is a strip, rotating the FCW we can map the modulation factor at two energies

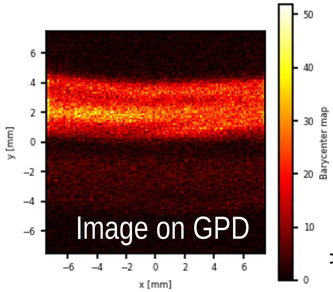
Poster by Muleri F., et al., [10699-189]

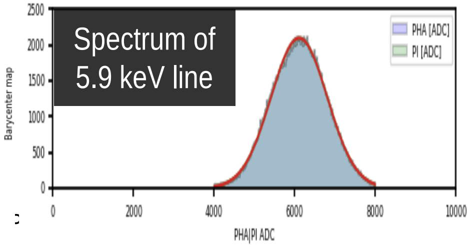
Cal A design

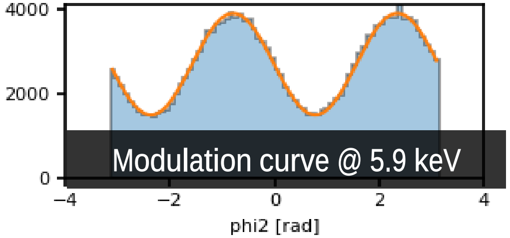


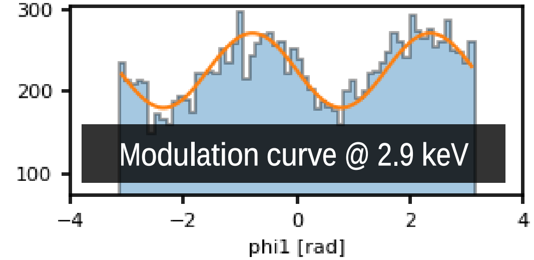
GPD and Cal A in vacuum chamber









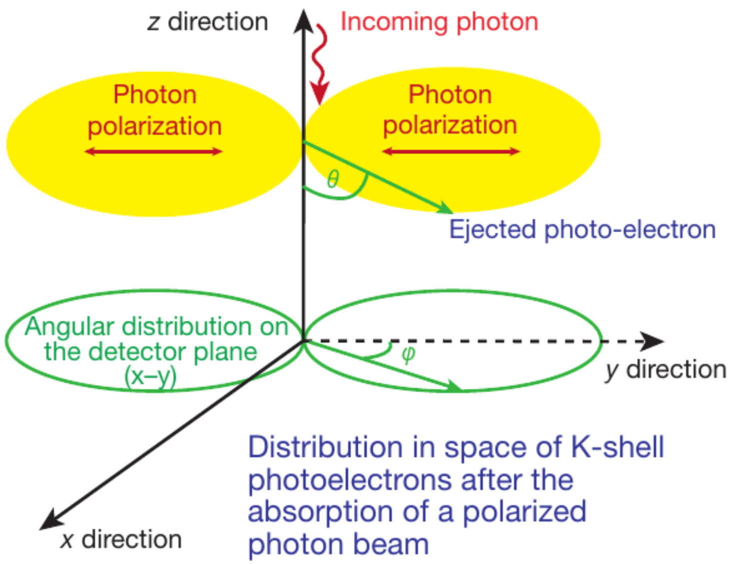


The Gas Pixel Detector

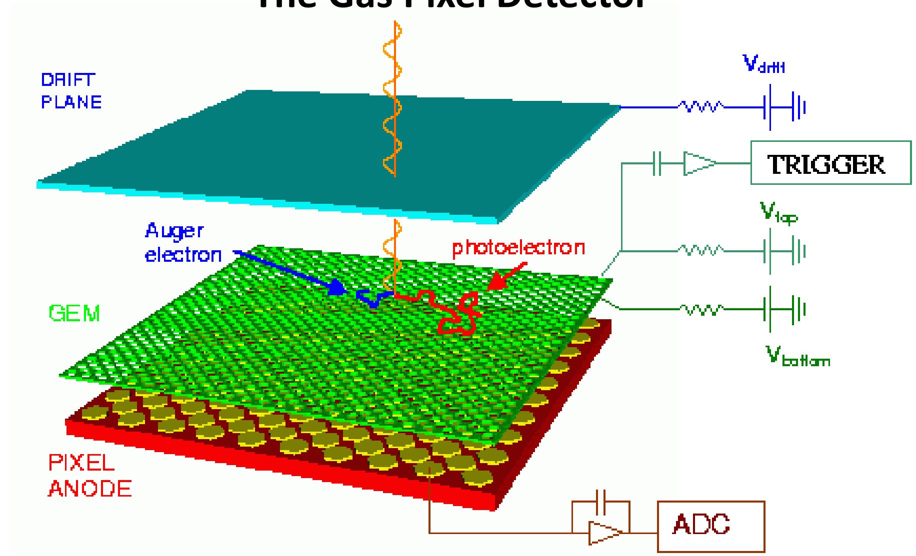
We developed at this aim a polarization-sensitive instrument capable of imaging, timing and spectroscopy

The photoelectric effect

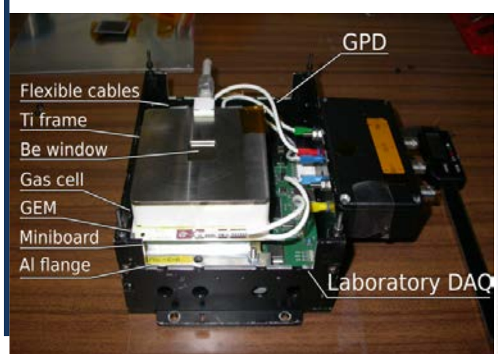
$$\frac{\partial\sigma}{\partial\Omega} = r_0^2 \frac{Z^5}{137^4}\left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$

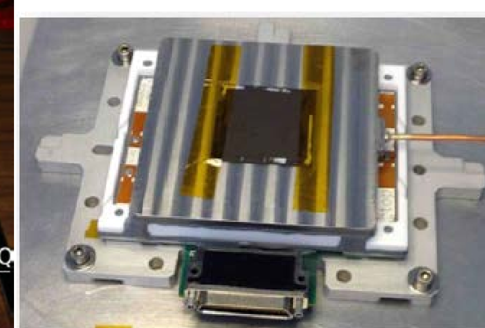


The Gas Pixel Detector



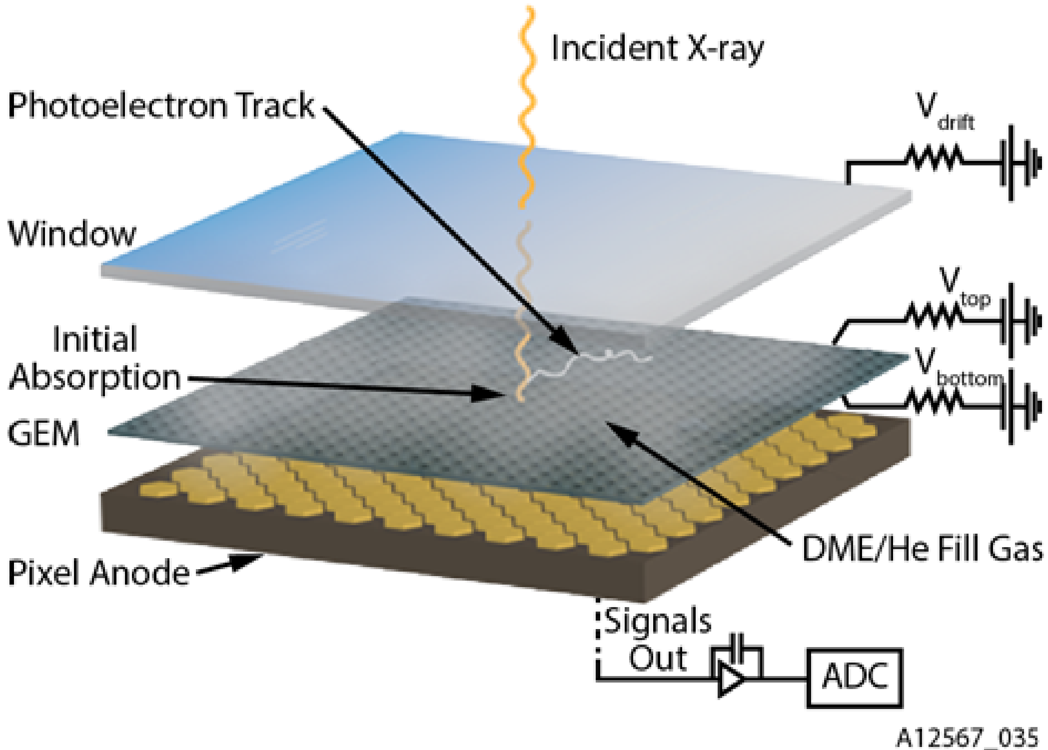
E. Costa et al. 2001, Bellazzini 2006, Bellazzini 2007





The Gas Pixel Detector

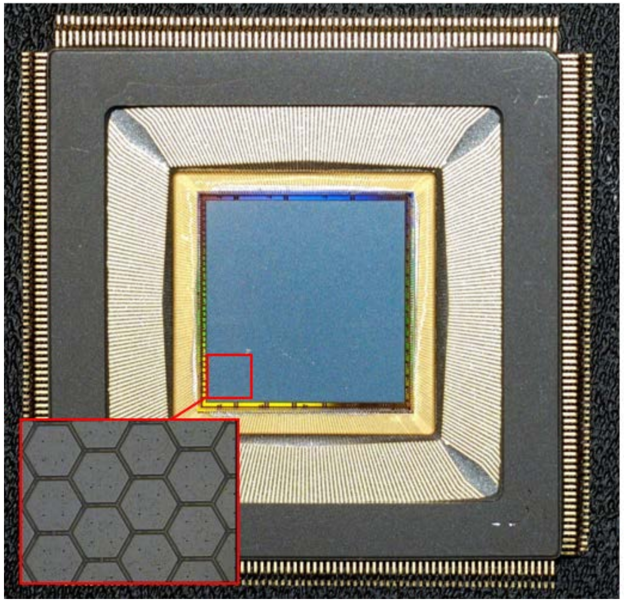
Gas Pixel Detector is the heart of the DU



Performance

1. Dymethyl Ether + Helium fill gas, 1 cm deep at 1 atm, gives CBE 18.6% quantum efficiency at 2.6 keV

2. Pixel anode with 50 micron readout pitch gives CBE 120 micron spatial resolution at 2.3 keV and 29% modulation factor at 2.6 keV



The GPD output

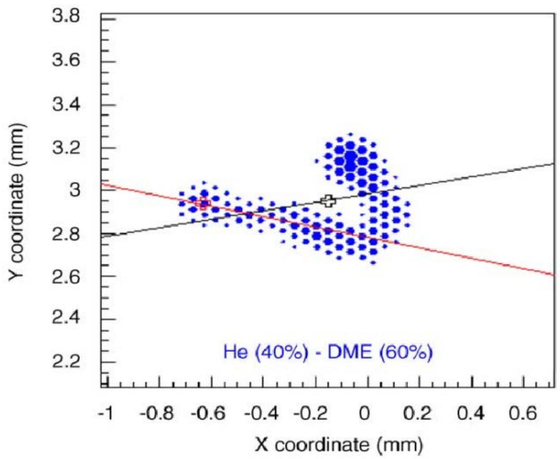
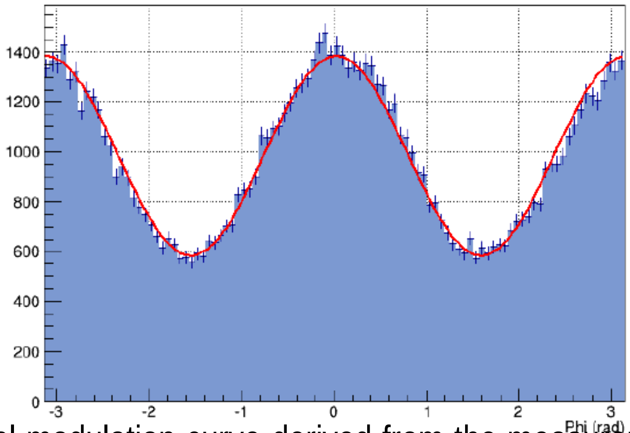
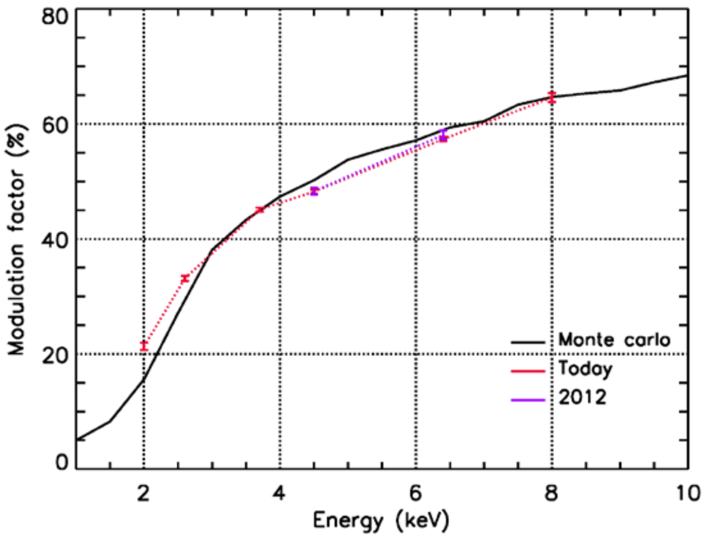


Image of a real photoelectron track. The use of the gas allows to resolve tracks in the X-ray energy band.

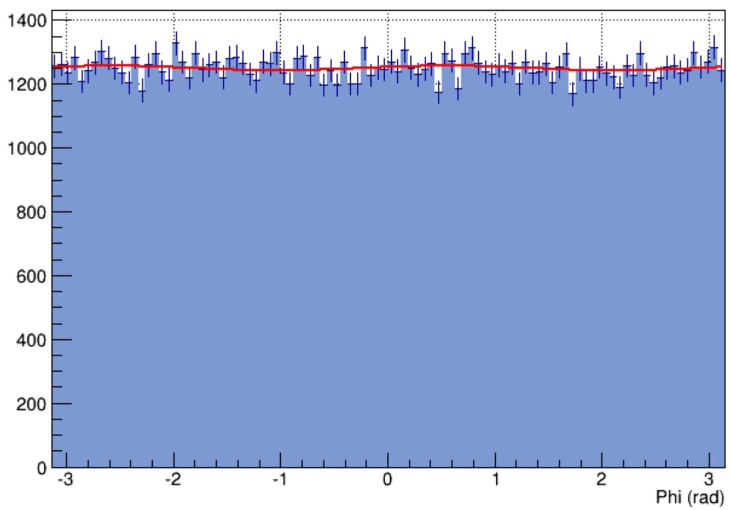


Real modulation curve derived from the measurement of the emission direction of the photoelectron.



Modulation factor as a function of energy.

Muleri et al. 2008,2010

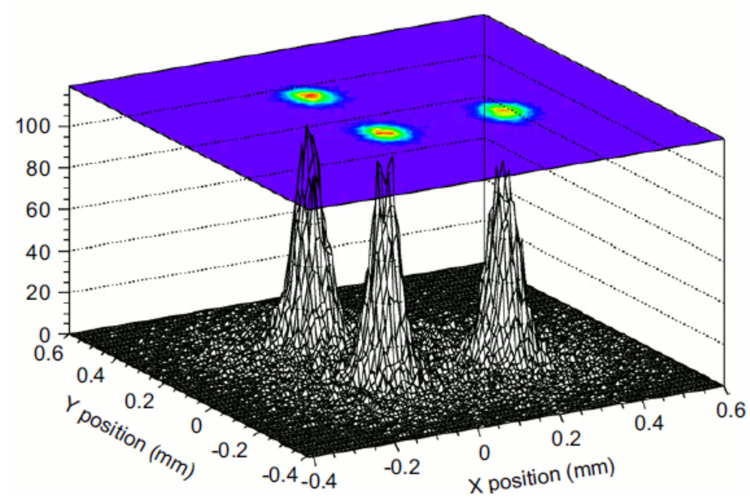


Residual modulation for unpolarised photons.

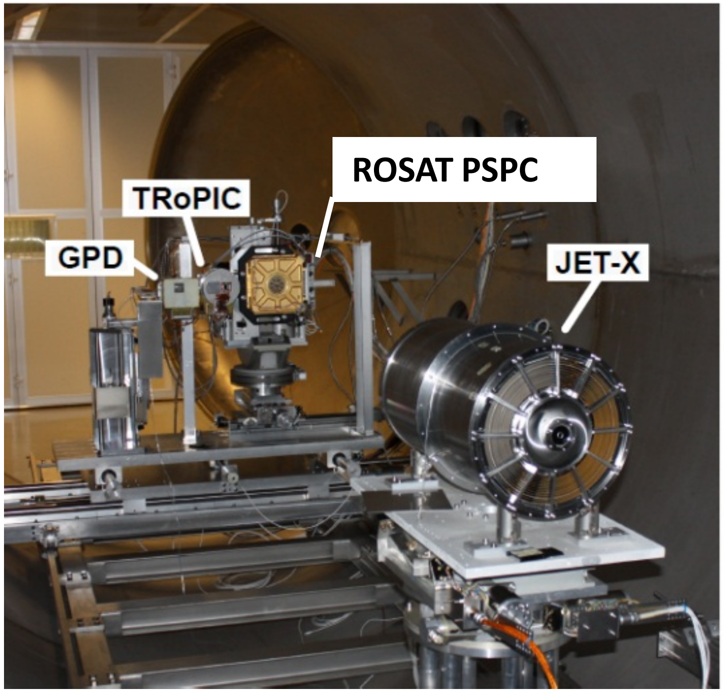
Bellazzini et al. 2012

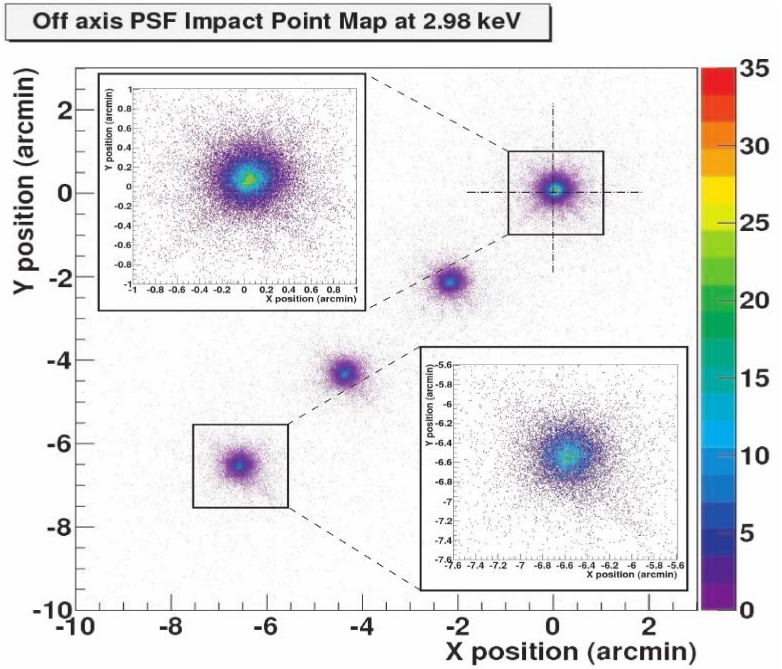
Imaging Capabilities

- Good spatial resolution: 90 µm Half Energy Width
- Imaging capabilities on- and off-axis measured at PANTER with a JET-X telescope (Fabiani et al. 2014)
- Angular resolution for XIPE: <26 arcsec

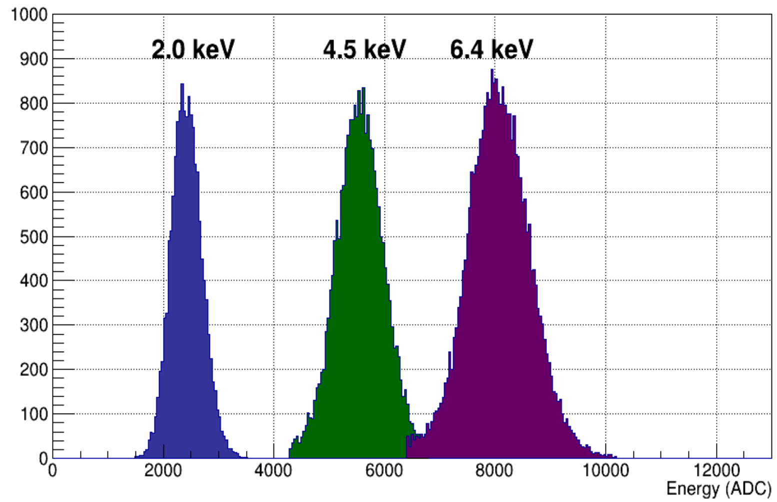


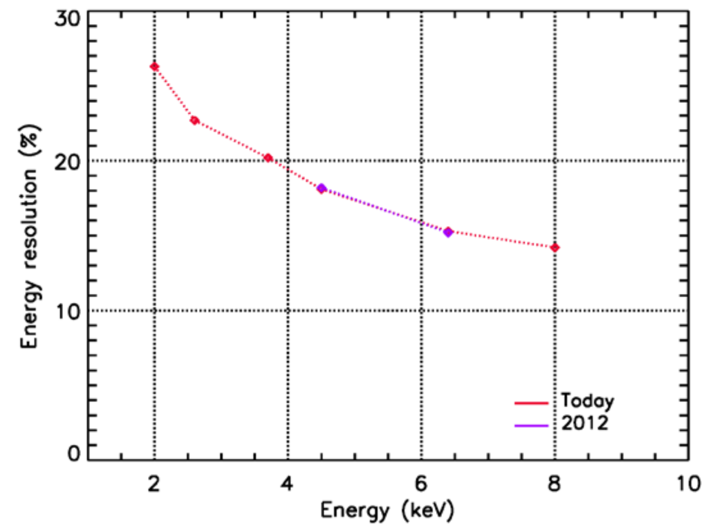
Imaging capabilities of GPD tested at PANTER



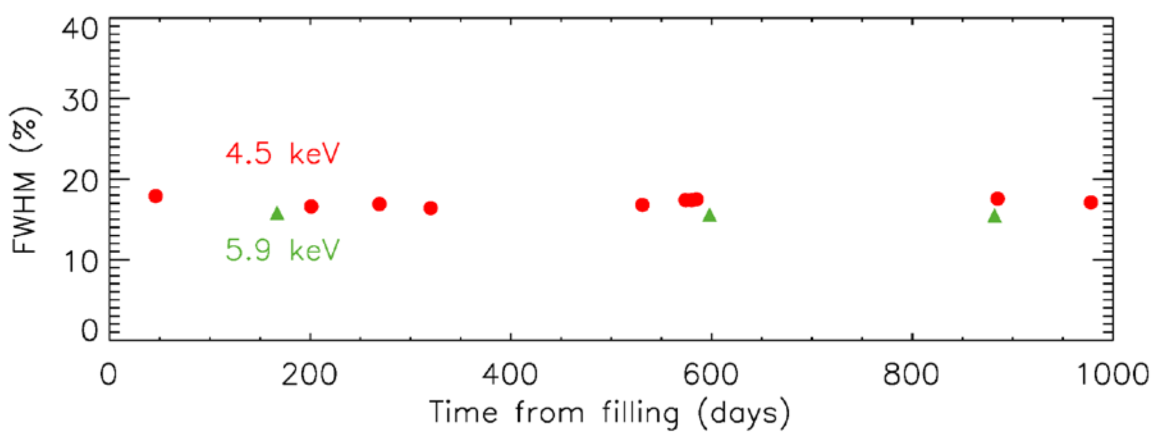


Spectroscopic capabilities

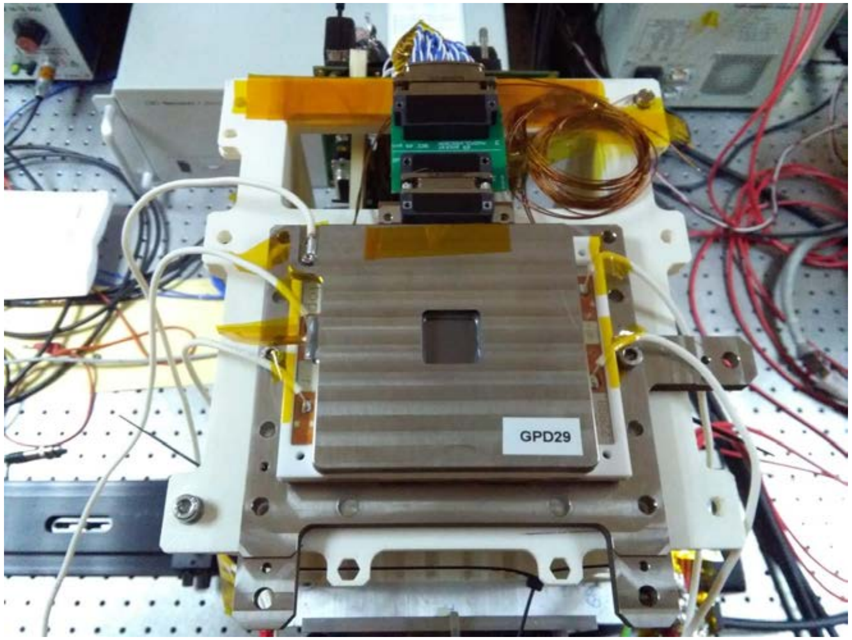


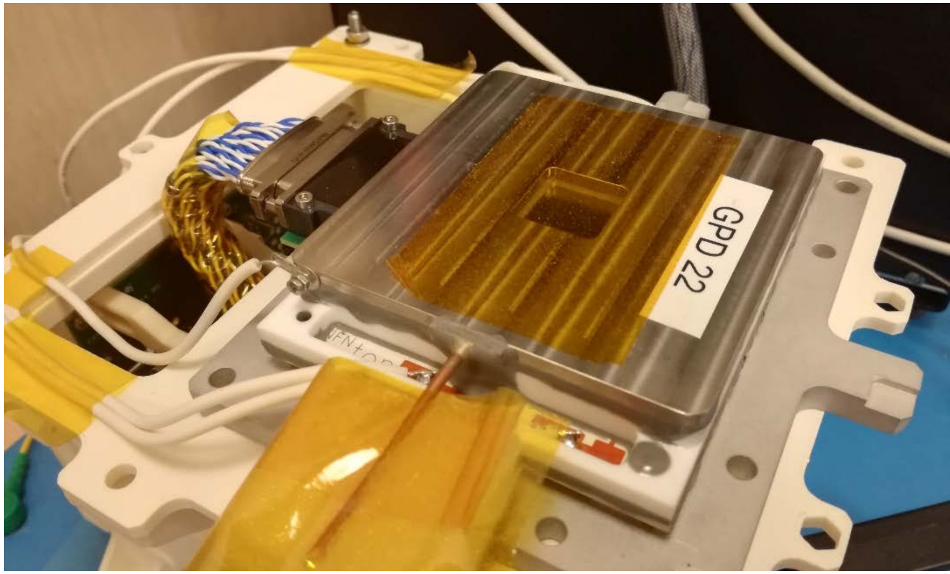


- Adequate spectrometer for continuum emission (16 % at 6 keV, Muleri et al. 2010).
- Stable operation over 3 years



GPD 22 and GPD 29





- Assembled @ INFN in Summer 2017
- Backed-out and filled @ OIA.
- Sealed on September 18, 2017
- 16+ months of operation, so far.

Instrument status

Phase B

Instrument:

I-SRR (30 October 2017)

I-PDR (5-6 March 2018)

I-CDR (14-15 May 2018)

Phase C-D (15 May 2018 – Dic 2019)

GPD Flight Model no. 1 at OXFORD Instruments Technologies OY (OIT Finland) for baking and filling

GPD Flight Model no. 2 at OIT waiting for baking.

HV Board (OHB-I), Bread Board (BB), Engineering Model (EM) ready

Filter Calibration Wheel (OHB-I) BB tested, Qualification Model tested.

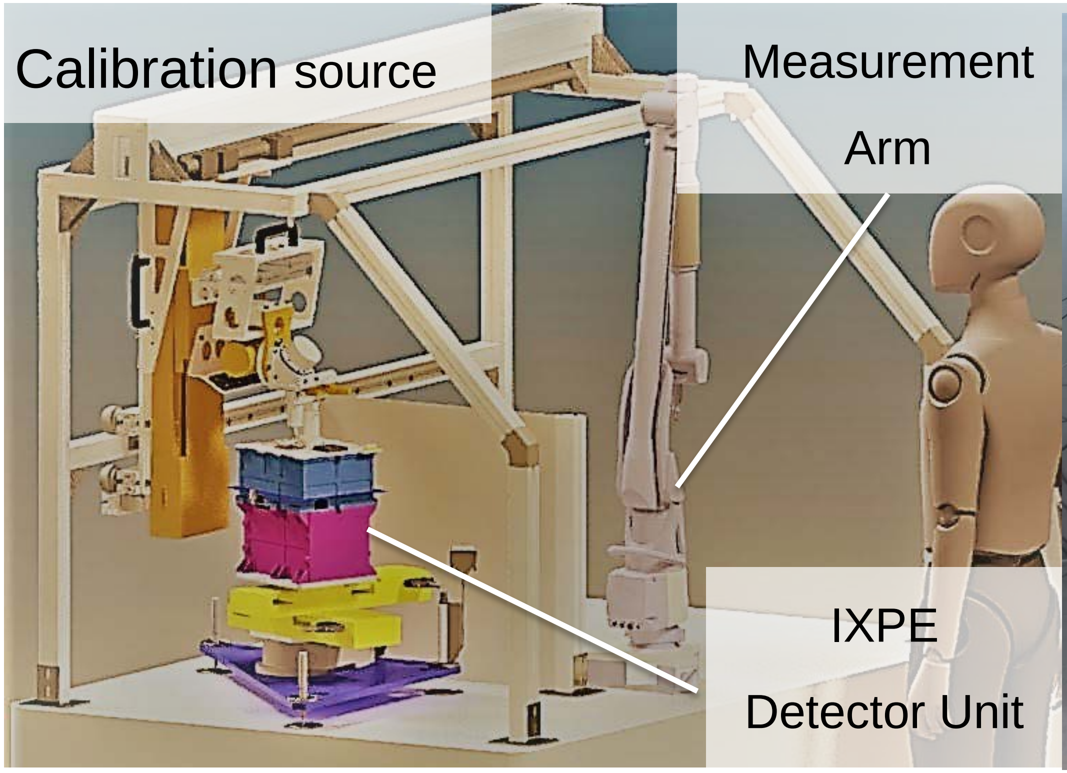
Back End Electronics (OHB-I) BB running 2 EM running. A third EM is being produced.

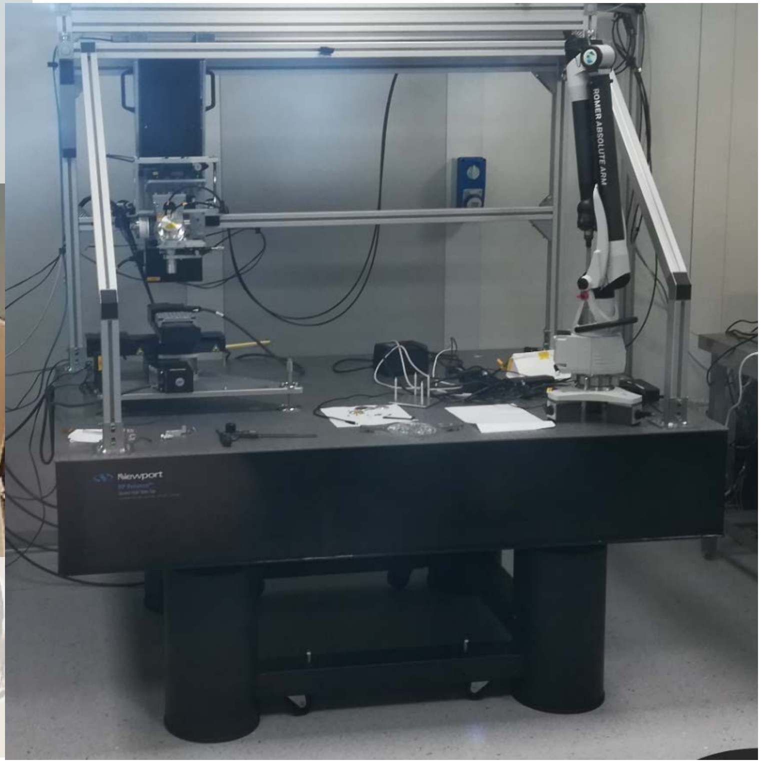
Detector Service Unit (OHB-I) EM test foreseen in spring.

Electrical Ground Support Equipment (OHB-I) no. 1 running, no. 2 ready in February

IXPE Instrument Calibration Equipment at IAPS

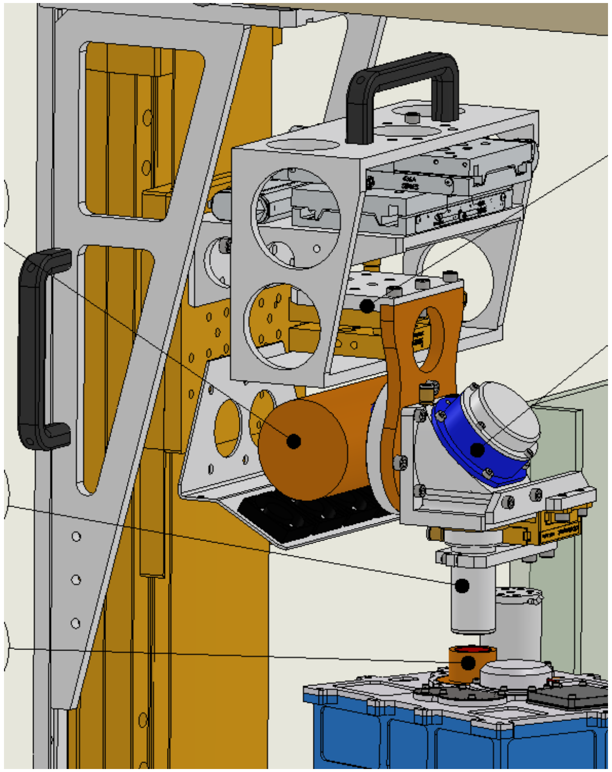
- Same concept as the test facility used since 10 years, with a few improvements:
  - More versatile alignment and measurement of X-ray incident direction (arcmin level)
  - Set of test ancillary detectors (Si-PIN, Si-SDD, CCD)
  - Helium flowing for the large part of the photon path for reducing air absorption
  - Hosted in a clean room (class 10000) refurbished at IAPS primarily with IXPE funding.





IXPE Imaging X-Ray Polarimetry Explorer

Available energies with known polarization



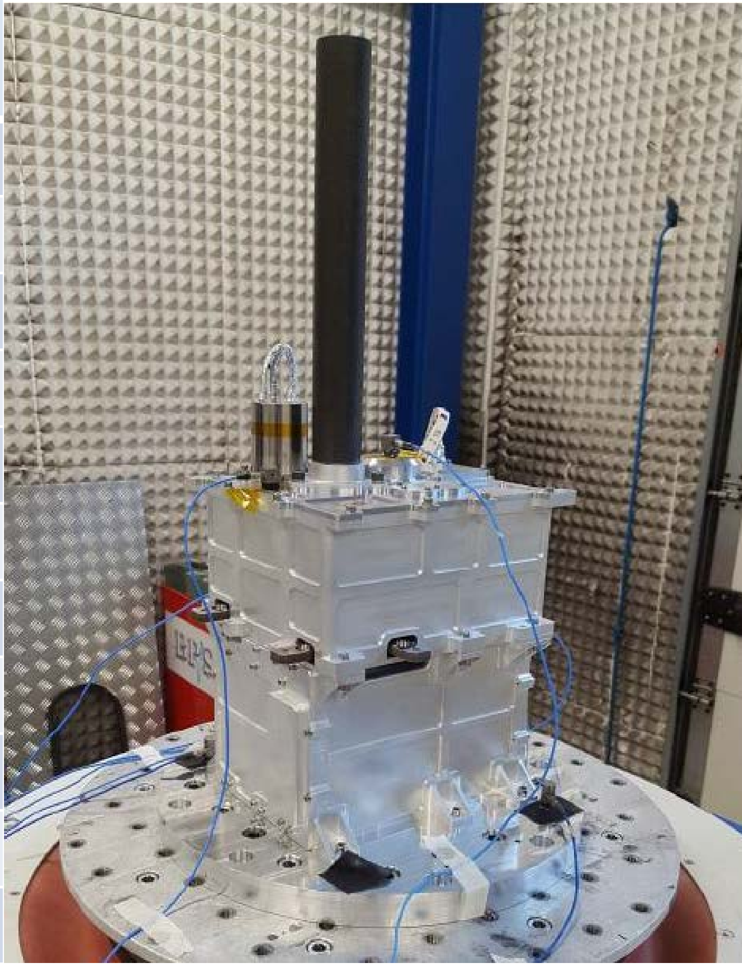
Energy (keV)	Crystal	X-ray tube
1.7	ADP	Oxford 5000 Series, Titanium, 50 W
2.0	PET	Oxford 5000 Series, Titanium, 50 W
2.3	Rhodium (TBC)	Oxford 5000 Series, Molybdenum, 50 W
2.6	Graphite	Oxford 5000 Series, Titanium, 50 W
2.7	Germanium (111)	Oxford 5000 Series, Rhodium, 50 W
3.0	Silicon (111)	Oxford 5000 Series, Silver, 50 W
3.7	Aluminum	Head-on Hamamatsu, Calcium, 0.2 W
4.5	Calcium fluorite	Oxford 5000 Series, Titanium, 50 W
5.2	Graphite	Oxford 5000 Series, Titanium, 50 W
6.4	Silicon (100)	Oxford 5000 Series, Iron, 50 W
8.0	Germanium (111)	Oxford 5000 Series, Copper, 50 W Head-on Hamamatsu, Copper, 2.0 W
9.7	Lithium fluoride	Oxford 5000 Series, Gold, 25 W
Continuum	Lithium rod	Oxford 5000 Series, Tungsten, 50 W Head-on Hamamatsu, Tungsten, 2.0 W

- High polarization degree, typically >95%, calculated with Henke et al. table
- Crystal surface aligned with crystal lattice better than 0.1 deg (3 arcmin measured)

IXPE

Polarization sensitivity (MDP)	<5.5 % for $1x10^{-11}$ erg/s/cm^2 (10 days observation)
Spurious modulation	< 0.3 %
Energy band	2-8 keV
Number of telescopes	3
Angular resolution	< 30''
Field of view	12.9 x 12.9 $arcmin^2$
Focal length	4 meters
Effective area at 3 keV	700 cm^2
Spectral resolution	< 25 % @ 5.9 keV
Operational phase	2 yr + extension (1 yr)
Sky coverage	40 %
Orbit	LEO 540 km (0^o inclination)

Detector Unit



Scientific Working Groups

1. Wayne Baumgartner: **Science Calibration** WG (Co-Chair Fabio Muleri IAPS/INAF)
2. Allyn Tennant: **Science Data Processing** WG (Co-Chair Matteo Perri INAF c/o SSDC)
3. Luca Baldini: **Science Analysis and Simulation** WG (Co-Chair Herman Marshall MIT)
4. Giorgio Matt (Universita' Roma III) and Roger Romani (Stanford): **Science Advisory Team** chairs

Topical Working Groups

- Niccolò Bucciantini (O. Arcetri): **PWNe and isolated pulsars**
- Patrick Slane (Harvard Univ.) : **SNR**
- Michal Dovčiak (Czech Academy of Sciences): **Accreting stellar-mass BH**
- Juri Poutanen (Tuorla Obs.): **Accreting NS & WD**
- Roberto Turolla (Padua Univ.): **Magnetars**
- Frédéric Marin (Astron. Obs. of Strasbourg): **Radio-quiet AGN & Sgr A***
- Alan Marscher (Boston Univ.): **Blazars & radio galaxies**

First Year of observation plan (notional)

Source Class	
AGN	4 Seyfert 6 Blazars
Galactic Center	Sgr B2
Microquasars	6
Pulsar Wind Nebulae + Pulsar	3
Supernova Remnants	3
Magnetars	2
Classical Accreting X-ray pulsars	8
Accreting Millisecond X-ray pulsars and Low B binaries	7

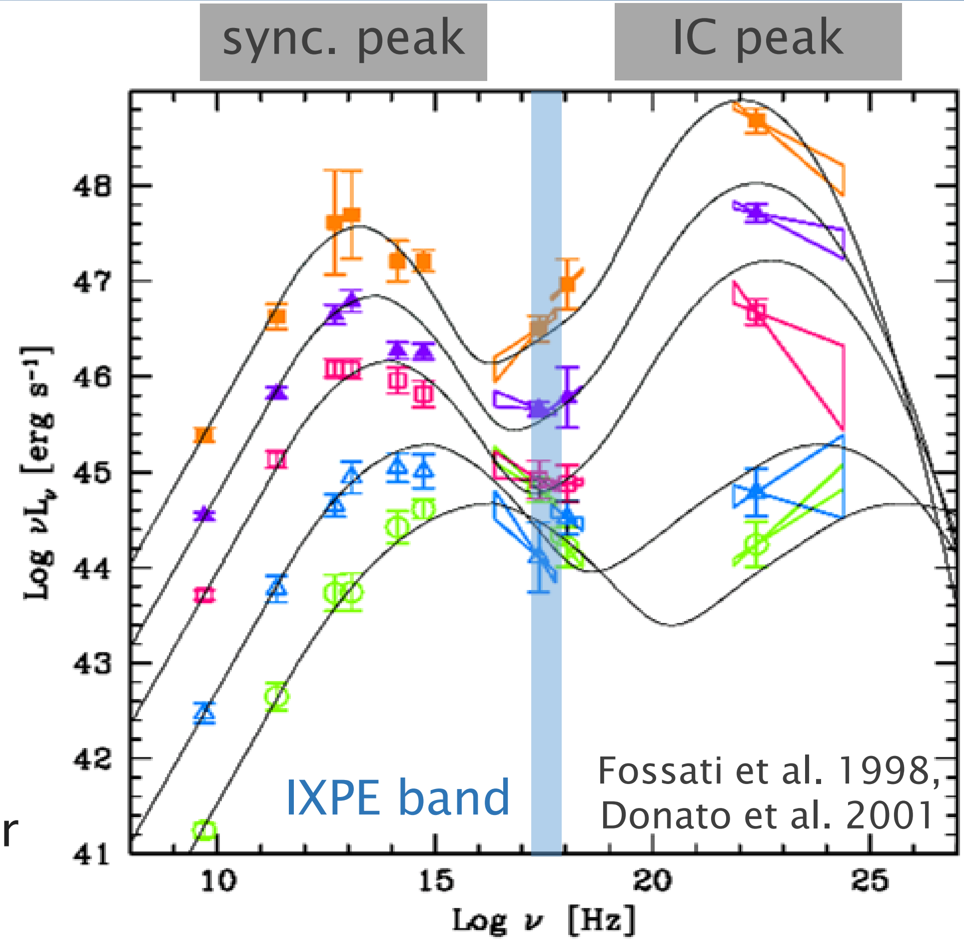
Launch Date April 2021

Blazars

In synchrotron-domnated X-ray Blazars, multi-λ polarimetry probes the **magnetic field.**

In inverse Compton dominated Blazars, multi-λ polarimetry observations can determine:

- **the composition of the jet** (hadronic vs. leptonic)
- **the origin of the seed photons** Synchrotron-Self Compton (SSC) or External Compton (EC)

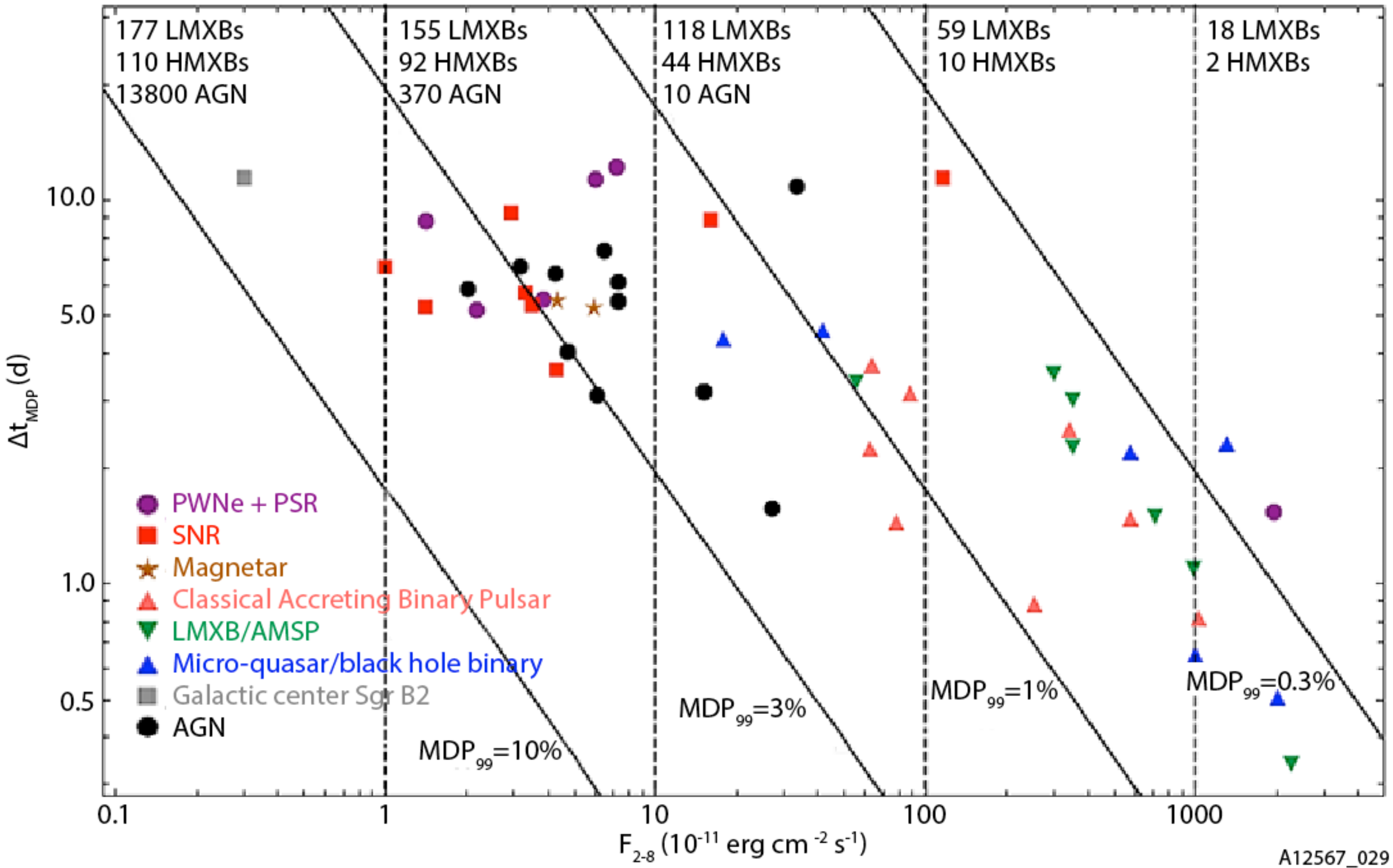


Coordinated multi-λ polarimetric campaigns are **crucial**

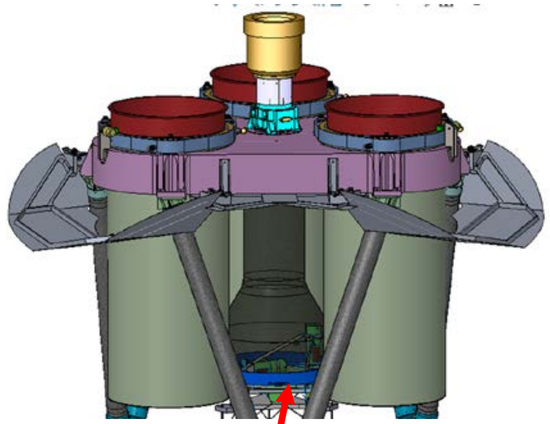
Such campaigns require small telescopes and are routinely organized.

END

IXPE sensitivity

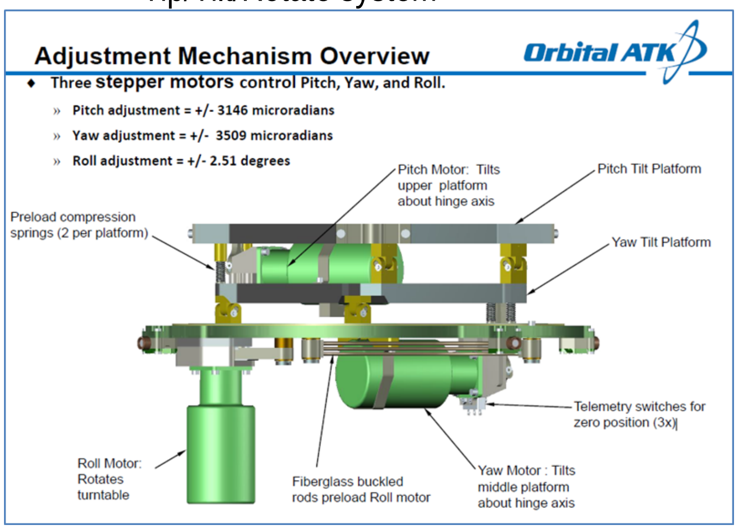


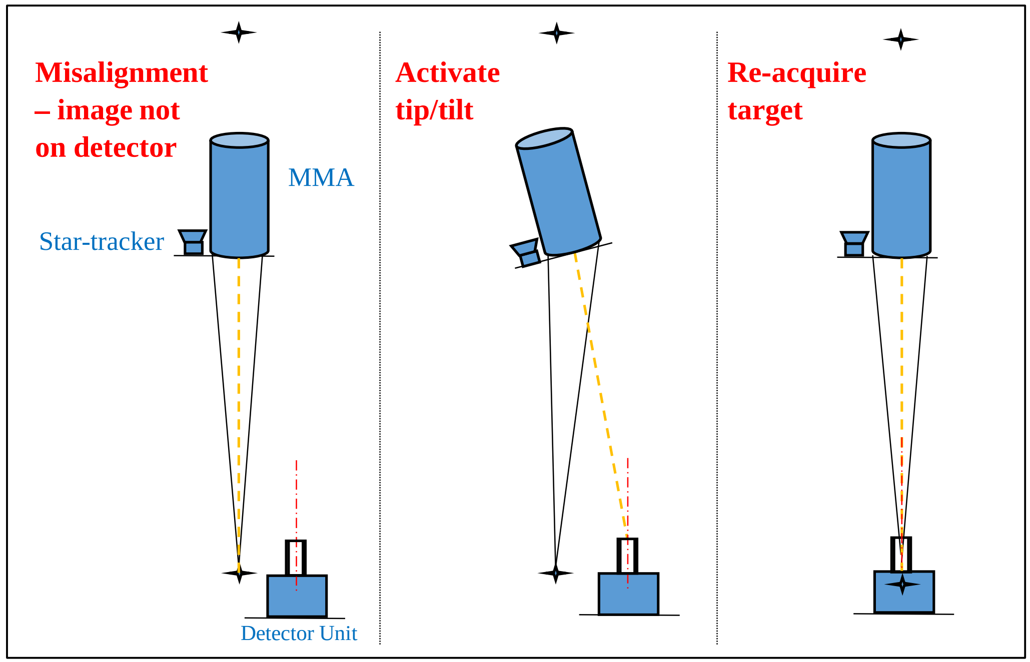
On-Orbit Alignment



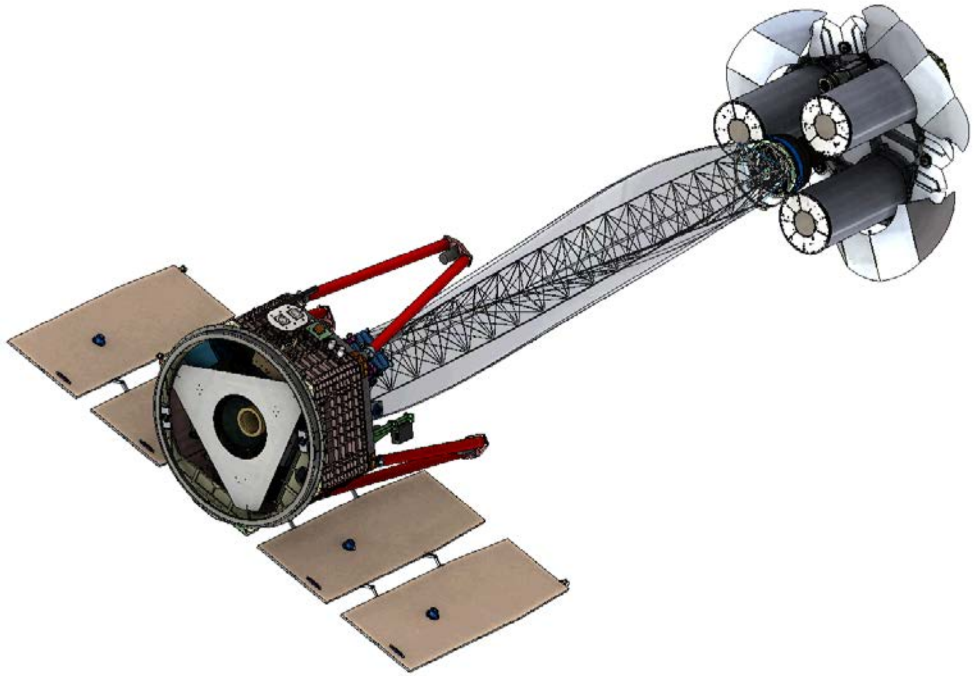
Tip/Tilt/Rotate system

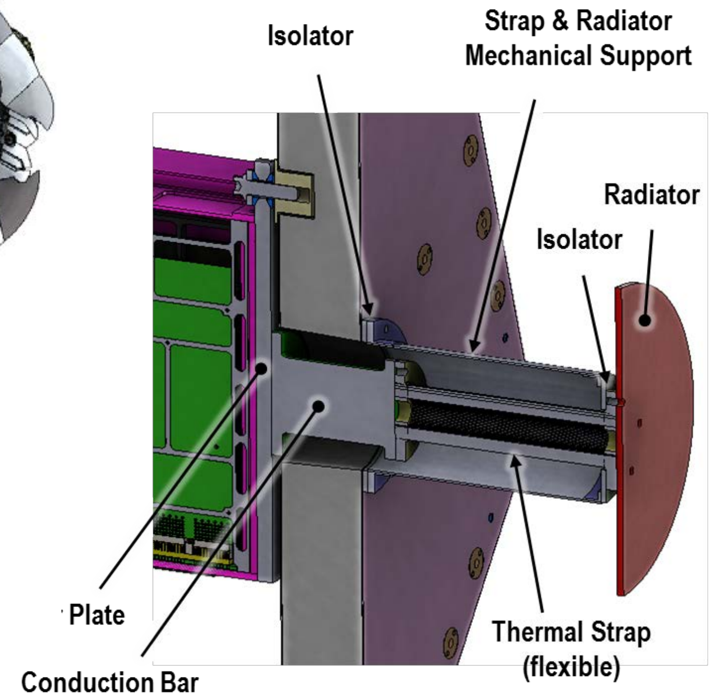
Tip/tilt/rotate stage can take out any misalignment of the MMA system with respect to the detector system after boom deployment





Thermal

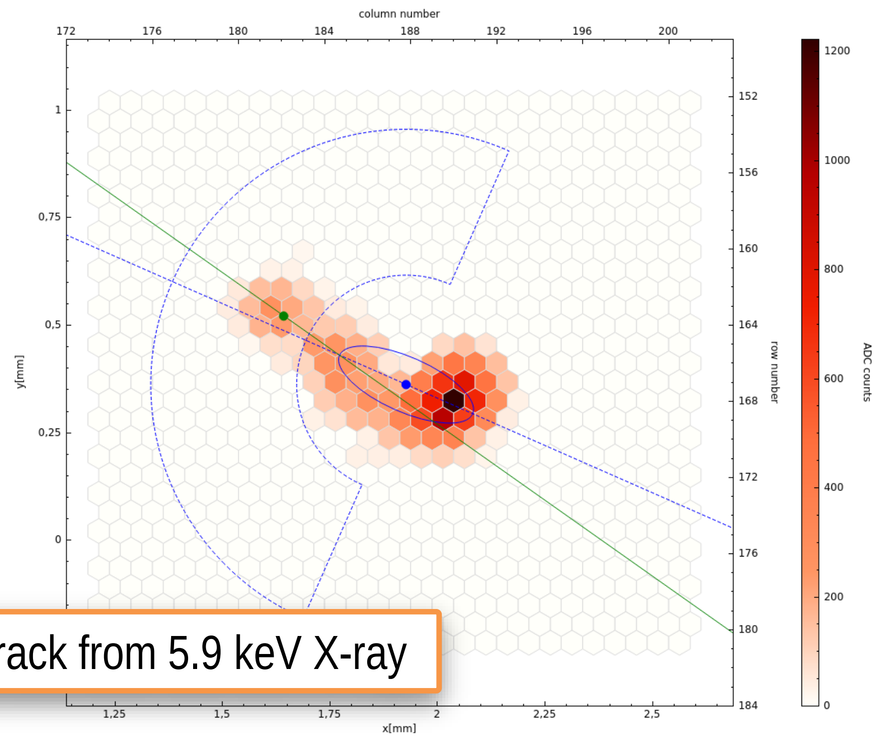




Triangular shape of the radiator.

- 5°- 30°C operating interface temperature range, with a maximum band-width of 15°C
- GPD thermal stability relaxed (15 ^{o}C – 30 ^{o}C)
- Power of the instrument was reduced by about 9 Watts

The Gas Pixel Detector



Real photoelectron track from 5.9 keV X-ray

- Exploit photoelectric effect for high efficiency below 10 keV
  — Polarization information derived from the emission direction of the photoelectron
- Small photoelectron range (less than 1 mm) requires gas as active medium
  — And fine granularity of the multiplication and readout stages

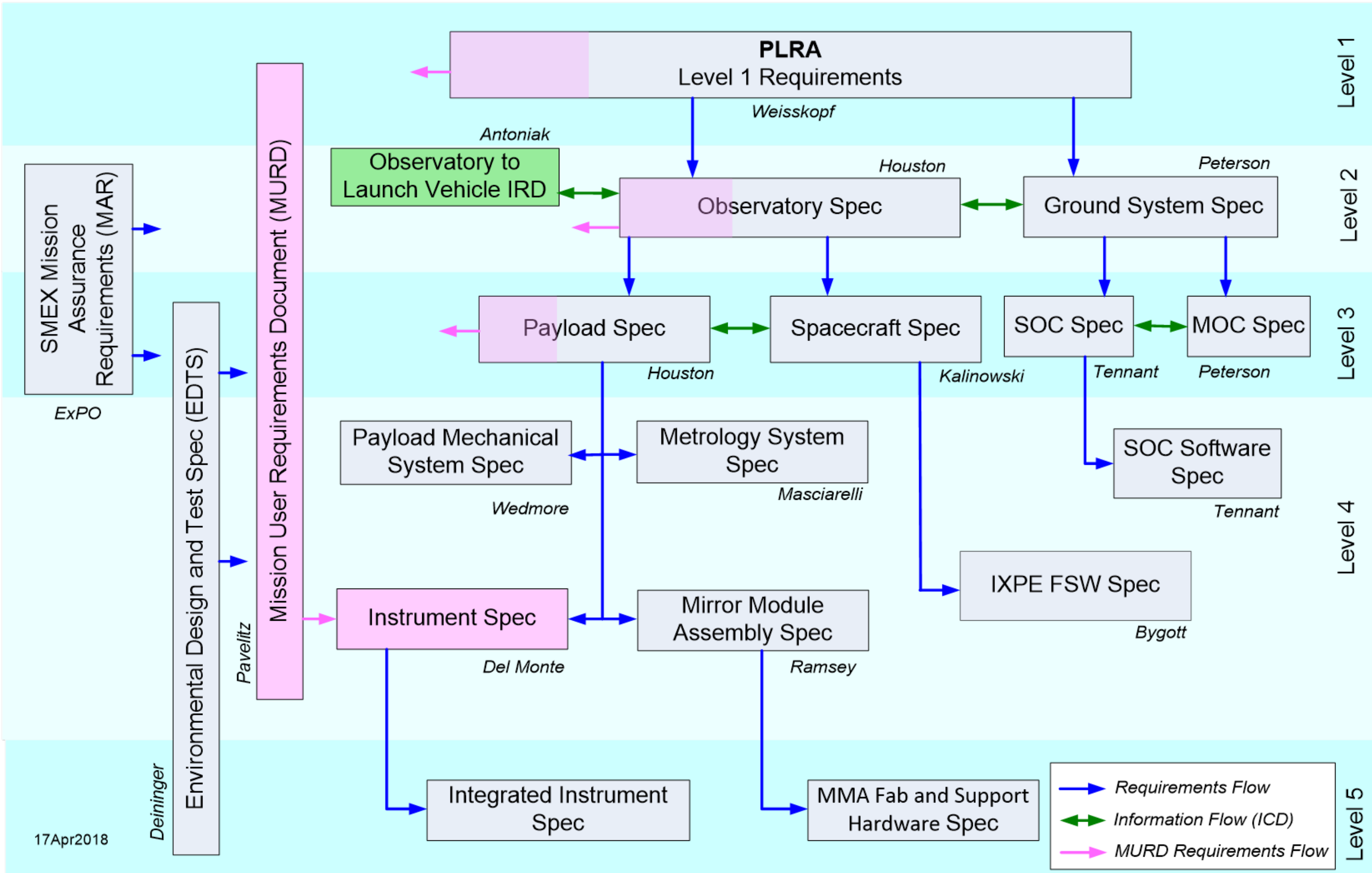
MMA Thermal Requirements

Parent Requirement	ID	MMA Specification	Compliance
IXPE-SPEC-054	No ID	The PI film shall withstand a temperature of 280C The epoxy shall withstand a temperature of 200C	Comply
/IXPE/L3 Payload Spec - 3.4 THERMAL REQUIREMENTS PLD-45	MMA-46	Each MMA shall be designed to withstand a survival temperature range of 0 to 40˚C without permanent loss of performance.	Comply
/IXPE/L3 Payload Spec - 3.4 THERMAL REQUIREMENTS PLD-46	MMA-47	Each MMA shall be designed to operate with a module temperature in the range 15-25 deg C, with radial gradients less than or equal to 5 deg C, and diametric gradients less than or equal to 2 deg C.	Comply
/IXPE/L3 Payload Spec - 3.2 ELECTRICAL REQUIREMENTS PLD-180	MMA-63	The Orbital Average Power (OAP) for each MMA, including line losses and battery efficiency, shall be less than 13.3 W.	Comply

IXPE Specification Tree

Updates since SRR

- Instrument Spec tree matured
- Added MURD
- Deleted PEB spec
- Science Calibration Spec content moved into Payload Spec



IXPE Specifications Are Mature

LVL1-61: Angular Resolution Requirement

L-1

LVL1-61	The IXPE shall have a system-level angular resolution not to exceed 30 arcsec half power diameter (HPD)

L-2

OBS-36	The IXPE observatory shall provide the capability to place the reconstructed image on the celestial sphere to an accuracy of 7 arcseconds (3-sigma, per axis) relative to reference star locations and using data sampled at time intervals longer than 1 second
OBS-176	Each IXPE Telescope shall have a system angular resolution, including aspect solution, less than or equal to 30 arc seconds half-power diameter.

L-3

PLD-44	Each IXPE Telescope (MMA/instrument combination) shall have a system angular resolution of less than or equal to 28 arcsecond HPD.

Bench Metrology
Attitude knowledge
Thermal distortions
Jitter

L-4

MMA-8	The HPD of each mirror module assembly shall be no greater than 25 arcseconds at 2.3 keV and at 4.5 keV on axis.
INT-492	The spatial resolution of each detector unit shall be no more than 190 µm (9.8 arcsec) at 2.3 keV.

Defocus blur, calculated to be 6.1 arcsec, from PLD-21 (focal length)

CBE

22 arcseconds at 2.3 keV and at 4.5 keV on axis.

120 µm (6.1 arcsec) at 2.3 keV.

LVL1-23: Field of View Requirement

L-1

LVL1-23	The IXPE shall have a system-level field of view at least 9 arcmin diameter

L-2

PLD-65	The intersection of the fields of view of the 3 telescopes shall provide a useful field-of-view greater than 9 arcminutes diameter.
OBS-301	The IXPE Observatory pointing performance shall maintain extended IXPE x-ray targets up to 9 arcminutes diameter entirely within each of the three Detector Unit's field of view (11 arcminutes diameter) simultaneously.

L-3

OBS-112	Each Telescope (MMA/Instrument combination) shall have a detector-limited field of view of at least 11 arcminutes diameter.
PLD-48	The optical node of each mirror module assembly shall be aligned to the center of its corresponding detector unit to within 30 arcseconds (3-sigma radius) (TBR).
SC-77	The Spacecraft shall point the Observatory line-of-sight (LoS) in any direction, consistent with viewing constraints, relative to an inertial reference frame to an accuracy of less than or equal to 40 arcseconds (radial, 99% Circular Error Probability (CEP)) while operating in Operations Mode (ADCS/FSW Point State).

L-4

MMA-35	Each MMA shall have retroreflectors near each of the three mounting lugs on the front spider that will be used to provide knowledge on the position of the node of the x-ray mirror shells in the XY plane to within 50 micron (3 sigma).
LVL4 and lower	The detailed (35-term) alignment error budget gives > 60% margin for LVL1-23 requirement.

Summary

Metric	Allocation/ Requirement	Current Best Estimate (CBE) Performance	Margin (Value)	Margin (%)
Observatory Mass (kg)	371 kg	292.5 kg	78.5 kg	26.8%
Power Use (W) (Largest load downlink) Battery DOD	286 W 40%	229 W 21.8%	57 W 18.2%	24% 83%
Pointing - LoS Pointing Accuracy (99% CEP) - LoS Co-Align Accuracy (99% CEP) - Angular Resolution (HPD)	 40 arcsec 45 arcsec 30 arcsec	 25 arcsec 29 arcsec 24 arcsec	 15 arcsec 16 arcsec 6 arcsec	 59% 53% 23%
Link Margins - Cmd U/L (2kbps) (Malindi) - Science D/L (2Mbps) (Malindi)	 >3 dB >3 dB	 29.0 dB 3.9 dB	 26 dB 0.9 dB	 >>3 dB >3 dB
Observatory Center of Mass (Stowed) - Axial - Radial	 0.906 m 0.038 m	 0.773 m 0.005 m	 0.133 m 0.033 m	 17% 660%
CPU Utilization Margin	100%	34%	66%	194%
Data Storage – Science	4 GB	6 GB	2 GB	50%

MMA Angular Resolution (MMA-8)

Mandrel Error Budget Allocations

PARAMETER	ALLOWANCE	HPD (ARCSEC)
CIRCULARITY (OUT OF ROUNDNESS)	0.0125 MM (0.0005")	1.2
P-H SLOPE ERROR	10 MICRORAD	5.8
INTERSECTION SHIFT	0.5 MM (0.020")	1.25
RADIUS ERROR	0.012 MM (0.005")	1.8
AXIAL FIGURE PROFILE	10 ARCSEC	10.0
BOW (PARABOLA)	1.5 MICRON	3.0
TOTAL (RSS)		12.2

Mirror Module Allocations

CONTRIBUTION	HPD (ARCSEC)
NATIVE MANDREL HPD	12
SHELL ELECTROFORMING	15
ALIGNMENT AND ASSEMBLY	10
TOTAL (RSS)	22
(REQUIREMENT)	**≤25**

Past Experience:

- ***ART-XC*** **(25 arcsec HPD modules from 15 arcsec HPD mandrels)**
- ***FOXSI*** **(20 arcsec HPD modules from 10 arcsec HPD mandrels)**
- ***HERO*** **(25 arcsec HPD from 8 arcsec HPD mandrels but with no alignment system)**

Alignment and Alignment Monitoring

LVL1-23	The IXPE shall have a system-level field of view at least 9 arcmin diameter

Necessitates precise alignment and pointing

Align telescopes during integration with boom deployed

↓

Deploy boom on orbit

↓

Measure deployed position of MMA system relative to DU system with on-board metrology system

↓

Correct one time as necessary with tip/tilt/rotate mechanism

LVL1-61	The IXPE shall have a system-level angular resolution not to exceed 30 arcsec half power diameter (HPD)

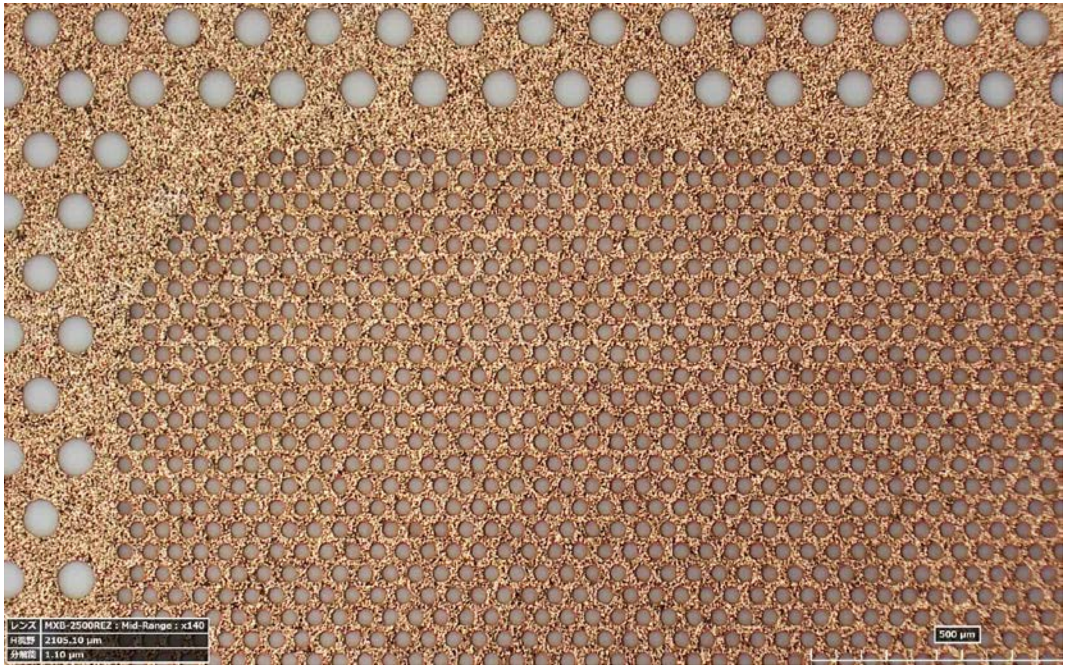
Necessitates real-time monitoring of motion of the MMA system relative to the DU system

Measure displacements with on-board metrology system

↓

Correct as necessary during on-ground data analysis

The Gas Electron Multiplier (GEM)

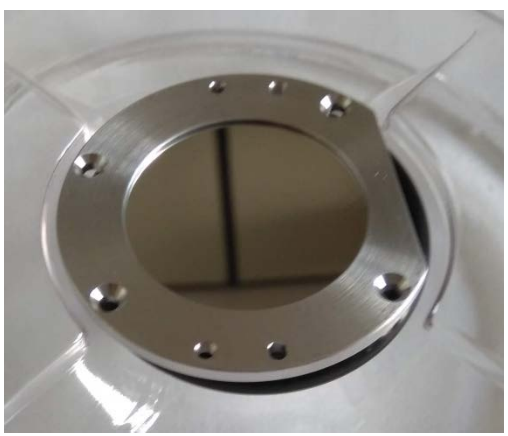


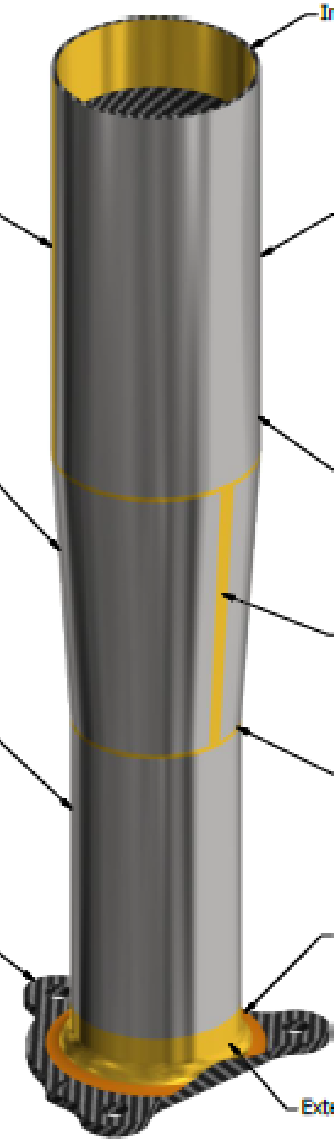
- The GEM provides the multiplication in gas of the primary ionization
  - Fully decoupled from the readout, intrinsically 2-dimensional
- Matching the 50 um pitch of the readout is not trivial
  - Mask alignment, copper etching and substrate drilling need to be under control
- Process developed in collaboration with SciEnergy and RIKEN in Japan

Gas multiplication stage matching the granularity of the readout for optimal track sampling

Design choices of the Detector Unit: housing and collimator

- Reduction of Cosmic Diffuse X-ray Background with a collimator and an X-ray shield
- UV filter to protect the beryllium window and to "contain" the Drift electric field of the High Voltage Board
  - the filter is made by Luxel and has flight heritage

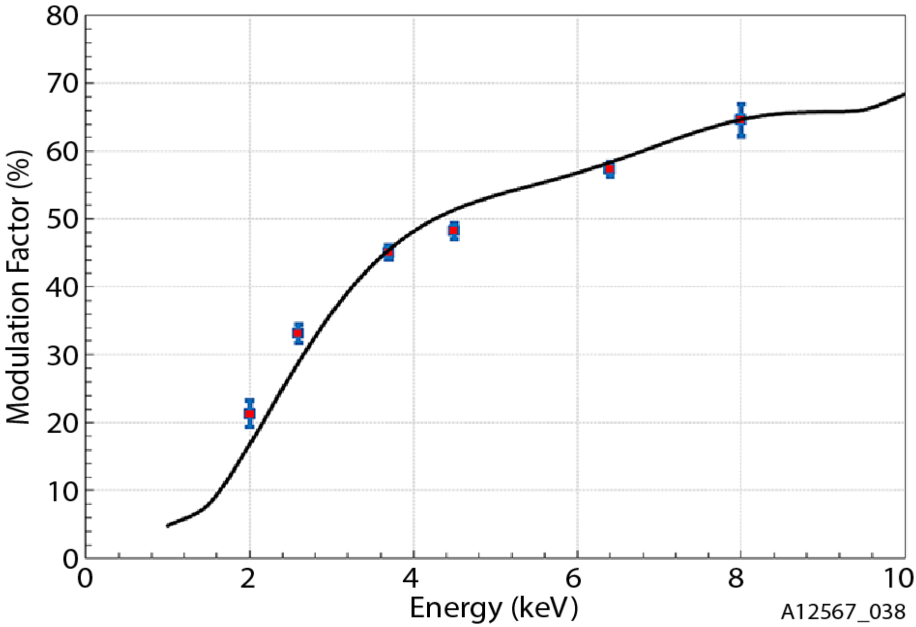




Detector Unit (DU) X-ray Calibration

- **Measured parameters:**

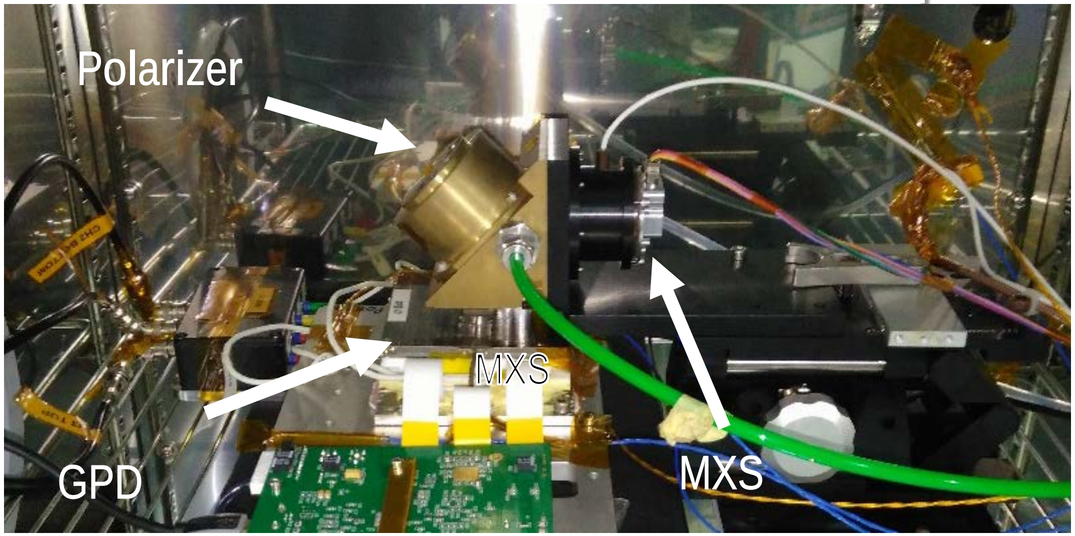
1. Modulation factor, μ, Gain, and Energy Resolution
   - Measurements will be carried out with a beam of collimated, polarized and monochromatic photons at different energies produced by means of Bragg diffraction at ~45 degrees.
2. Measuring the Spatial Resolution as a function of energy.
   - Measurements will be carried out with a collimated, pencil beam of tens μm size, that is much smaller than the GPD spatial resolution, on a grid of 3x3 positions and at three energies (2.3, 4.5 and 9.7 keV).
3. Modulation Amplitude for Unpolarized beam (Spurious Modulation)
   - Measurements will be repeated at three energies in 3x3 positions of the sensitive area. Unpolarized photons will be produced with radioactive sources, e.g. ^{55}Fe at 5.9 keV, and with X-ray tubes (at 2.3 and 3.7).Both kinds of sources have been already used for calibrating the GPD.
4. Angle of Polarization
   - Measurements with polarized radiation at 3.7 keV and 4.5 keV will be repeated in the same point of the detector changing the angle of polarization to verify the relation between the expected and the measured value.
5. Gain Mapping
   - The gain of the Gas Electron Multiplier can change with the position
   - The gain will be mapped by fully illuminating the GPD with two sources, tentatively an X-ray tube with Calcium anode for producing 3.7 keV and a ^{55}Fe radioactive source at 5.9 keV.
6. Efficiency
   - The efficiency of the detector will be measured by means of the comparison of the detected rate with an instrument of known efficiency; the measurements will be carried out in one representative point of the detector and repeated at three different energies (3.7, 4.5 and 6.4 keV).
7. Inclined Measurement (attachment & efficiency)
   - The study of the differential absorption as a function of depth is possible with a beam which is inclined with respect to GPD axis. This makes possible to measure the attachment coefficient and the efficiency of the detector without the need of any other instrument.

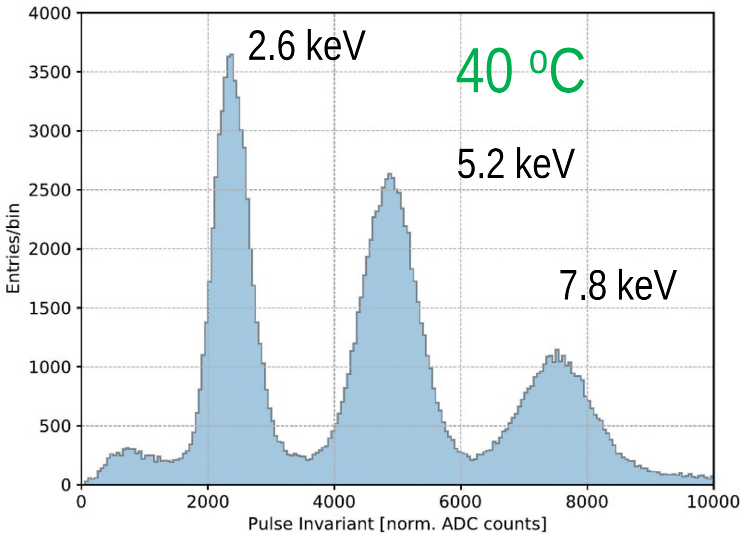


μ(E): Instrument response to 100% polarized photons

Lab measured points plotted on model curve

Scientific performance of the GPD as a function of temperature

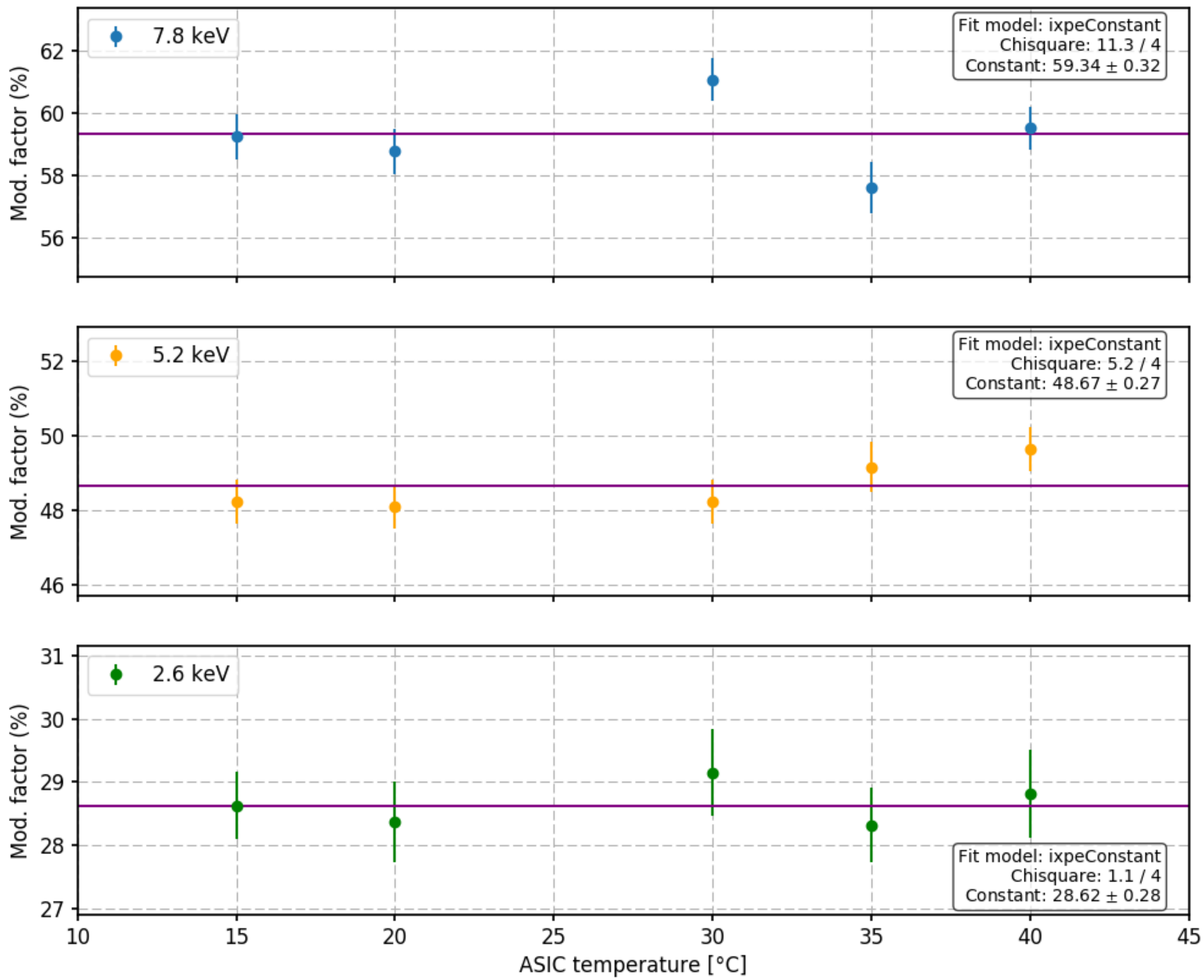




- The performance of the GPD was measured with polarized radiation
  - at temperatures of the ASIC of 15°C, 20°C, 30°C, 35°C and 40°C
  - at three energies: 2.6 keV, 5.2 keV and 7.8 keV
- The gain (measured by means of the ADC peak values of the energy lines) shows variations no larger than 2% and no dependence on the ASIC temperature is highlighted;
- The energy resolution has variations of the order of 3% and no dependence on the ASIC temperature is highlighted;
- The mean values of the distributions of pedestals decrease by ~7% as the temperature of the ASIC increases from 15°C to 40°C.

Poster by Fabiani S. et al [10699-188]

Thermal test @ IAPS Thermal Chamber



LVL1-20: Polarization Sensitivity Requirement

L-1

LVL1-20	The IXPE shall provide a minimum detectable polarization (MDP99) not to exceed 5.5% for a point source with an E-2 photon spectrum and a 2-8 keV flux of 10^{-11} ergs/cm^2/sec and an integration time of 10 days [baseline mission].

L-2

OBS-110	The IXPE Observatory shall provide a minimum detectable polarization (MDP_{99}) not to exceed 5% for a source with an E^{-2} photon spectrum and a 2-8 keV flux of 10^{-11} ergs/cm^2/sec and an integration time of 10 days [baseline mission].

L-3

PLD-49	The three telescopes combined shall provide a minimum detectable polarization (MDP_{99}) not to exceed 5% for a source with an E^{-2} photon spectrum and a 2-8 keV flux of 10^{-11} ergs/cm^2/sec and an integration time of 10 days [baseline mission].

L-4

MMA-7	The combined effective area of all three MMAs with their thermal shields shall be greater than 589 cm^2 at 2.3 keV, and greater than 686 cm^2 at 4.5 keV.
INT-471	The quantum efficiency of each detector unit shall be at least 17.7% at 2.6 keV and at least 1.84% at 6.4 keV
INT-472	The modulation factor of each detector unit shall be at least 27.7% at 2.6 keV and at least 53.7% at 6.4 keV

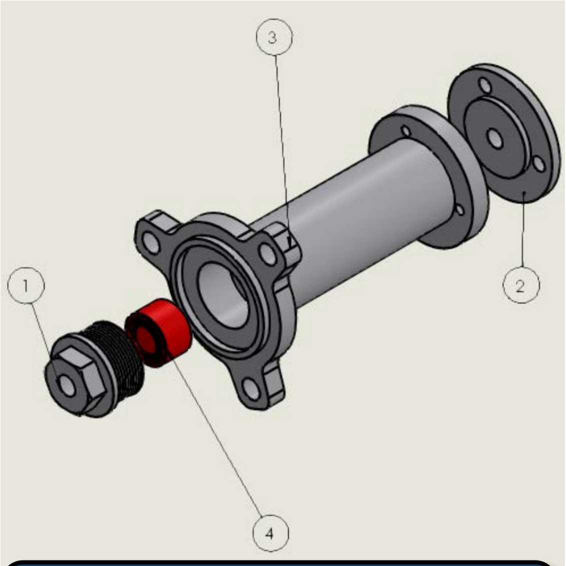
CBE

- MMA-7: 627 cm^2 at 2.3 keV, and greater than 730 cm^2 at 4.5 keV.
- INT-471: 18.6 % at 2.6 keV and at least 1.94 % at 6.4 keV
- INT-472: 29.0 % at 2.6 keV, and at least 56.3 % at 6.4 keV.

Cal B, Cal C and Cal D sources

Cal B

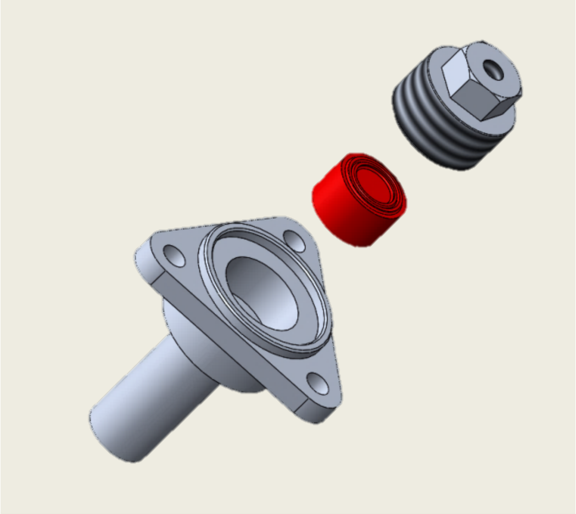
- Unpolarized at 5.9 keV
- Collimated to a 3 mm spot
- Check the absence of spurious signal to a very low level
- Counting rate >60 c/s with 20 mCi (flight source)



Cal B: 5.9 keV collimated non polarized

Cal C

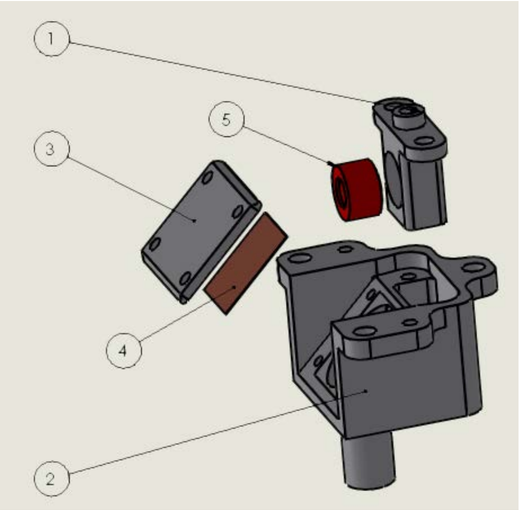
- Unpolarized at 5.9 keV
- Map the GPD gain at 5.9 keV
- Non collimated, full illumination of the GPD
- Counting rate >100 cts/s with 0.4 mCi (flight source)



Cal C: 5.9 keV non collimated non polarized

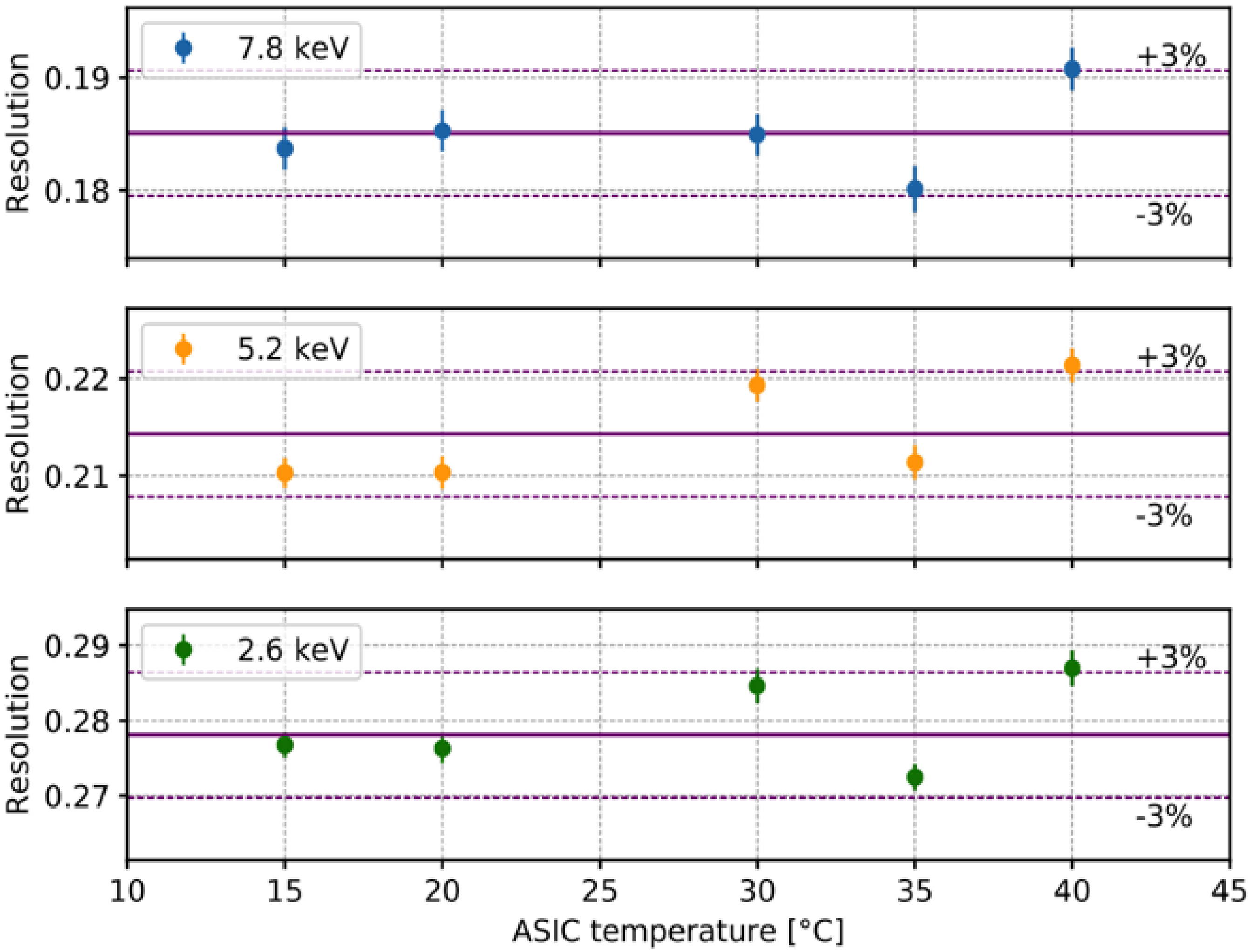
Cal D

- ^{55}Fe source extracting fluorescence from a silicon target
- Map the GPD gain at 1.7 keV
- Full illumination of the GPD
- Counting rate ~40 cts/s with 10 mCi (flight source)



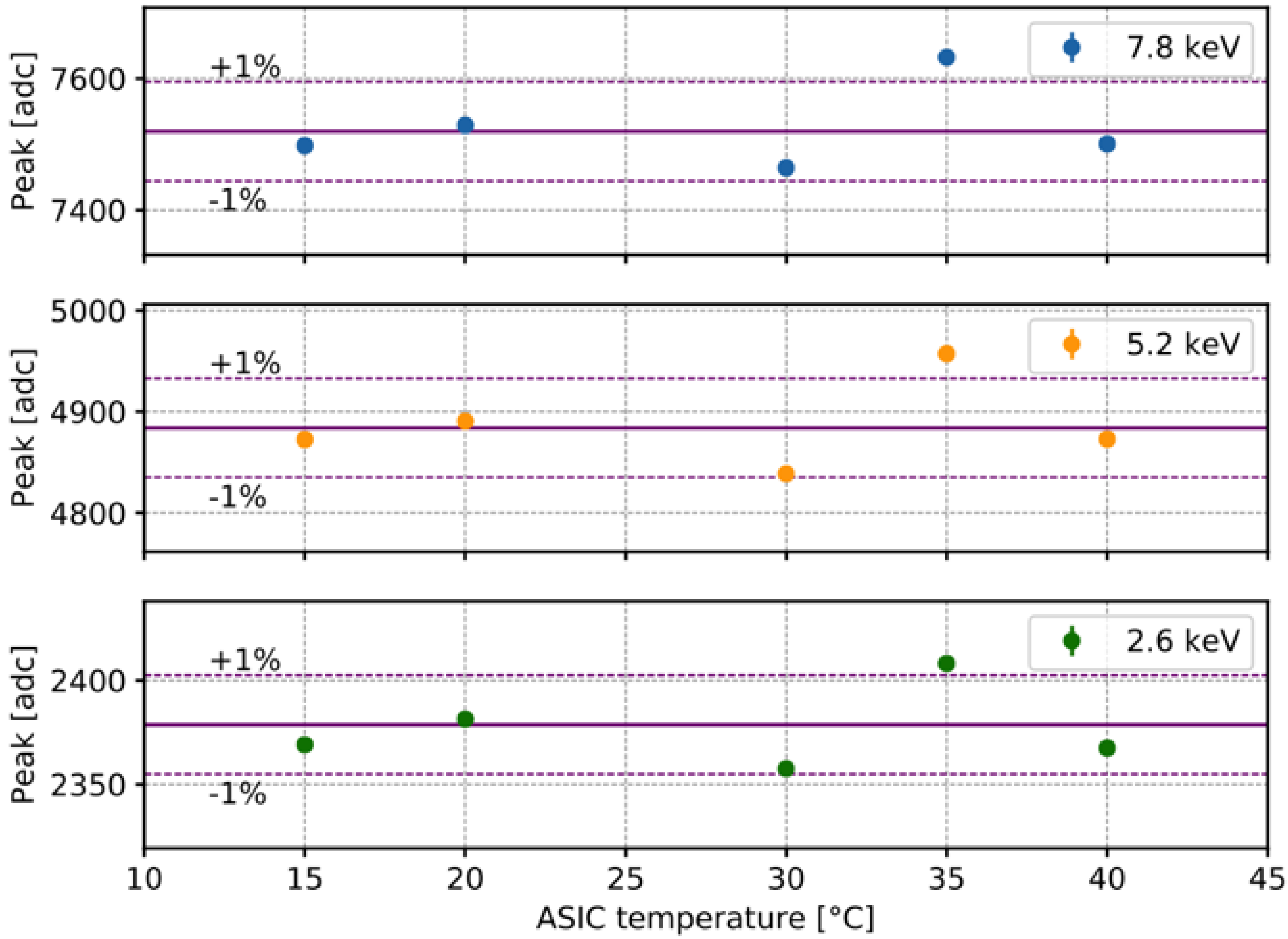
Cal D: 1.7 keV non collimated non polarized

Scientific performance of the GPD as a function of temperature



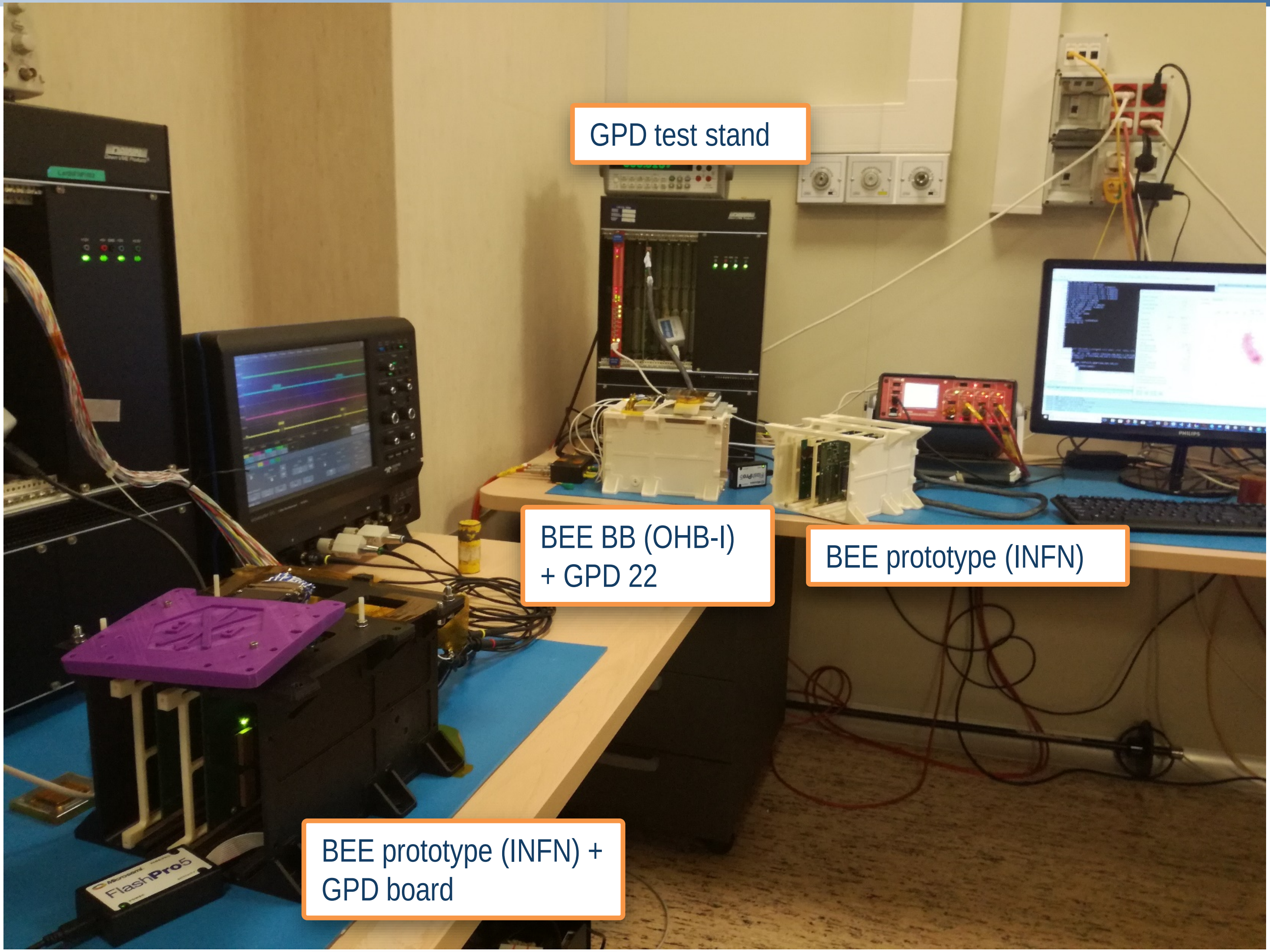
The energy resolution is constant between 15 °C and 40 °C

Scientific performance of the GPD as a function of temperature

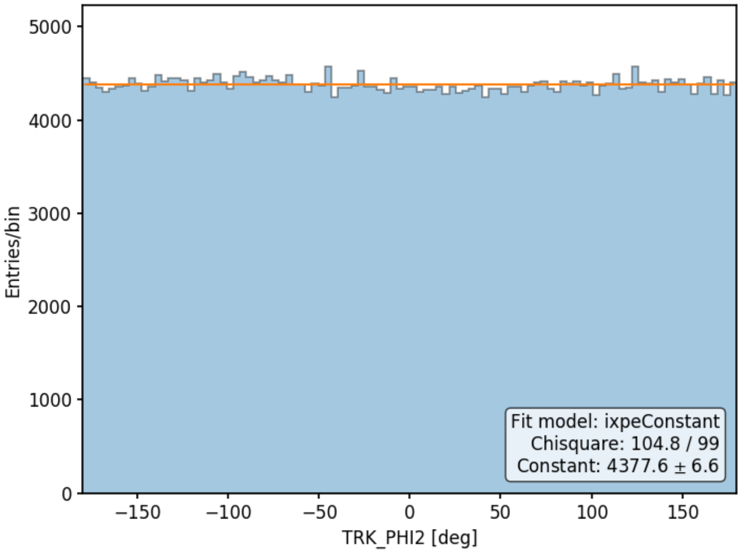


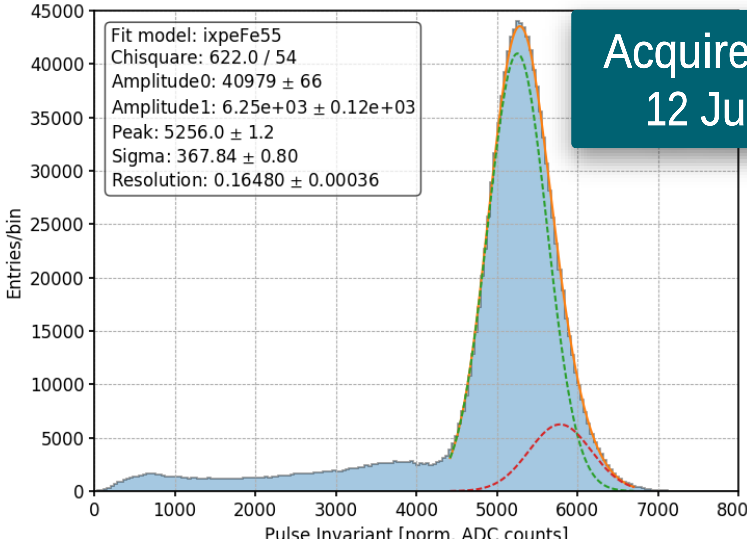
The gain is constant between 15 °C and 40 °C

Detector Unit Breadboard activities: grand summary

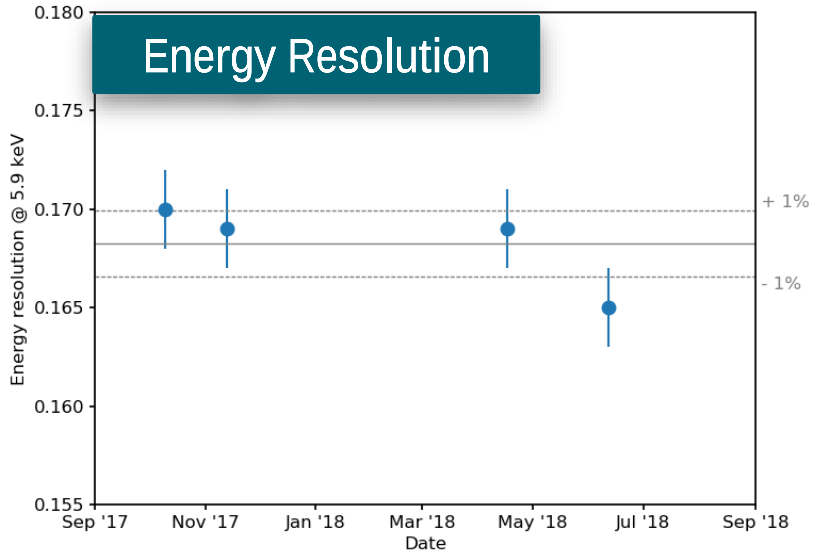


Stability of performance with ^{55}Fe





Acquired on 12 June

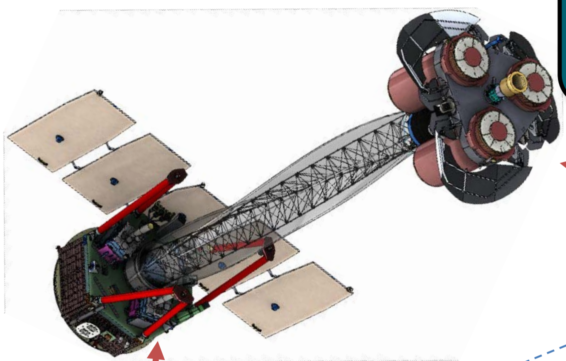


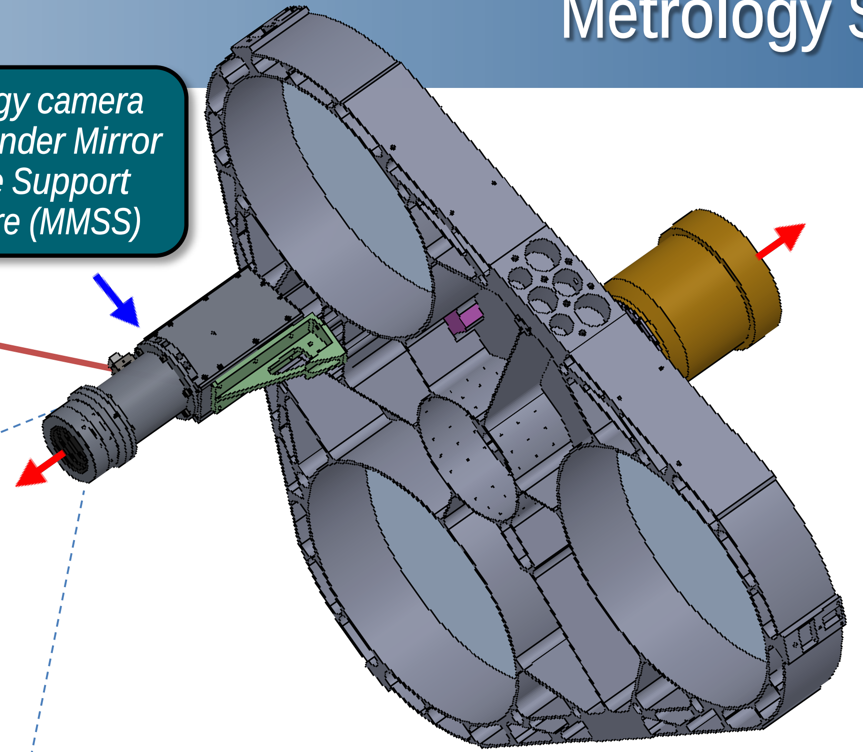
Energy Resolution

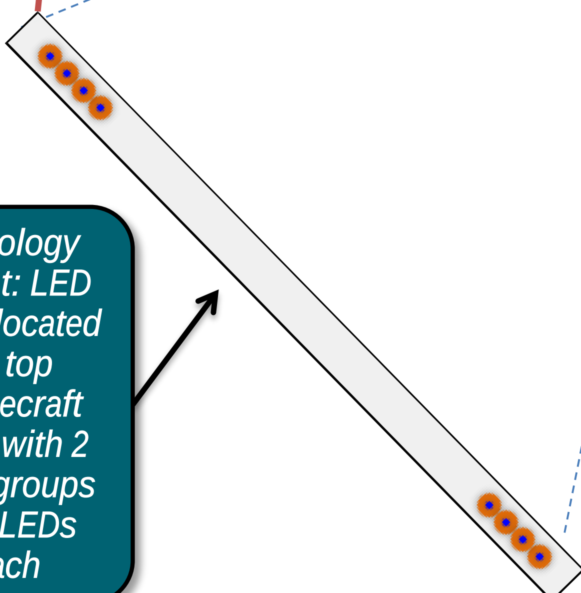
No evidence of performance degradation in nine months of operation

Metrology System

Metrology camera located under Mirror Module Support Structure (MMSS)



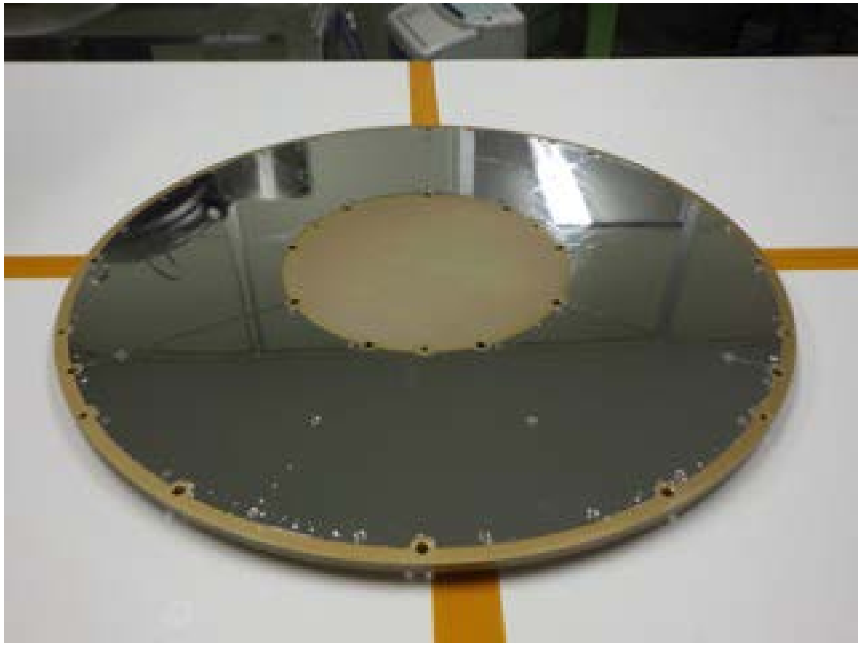


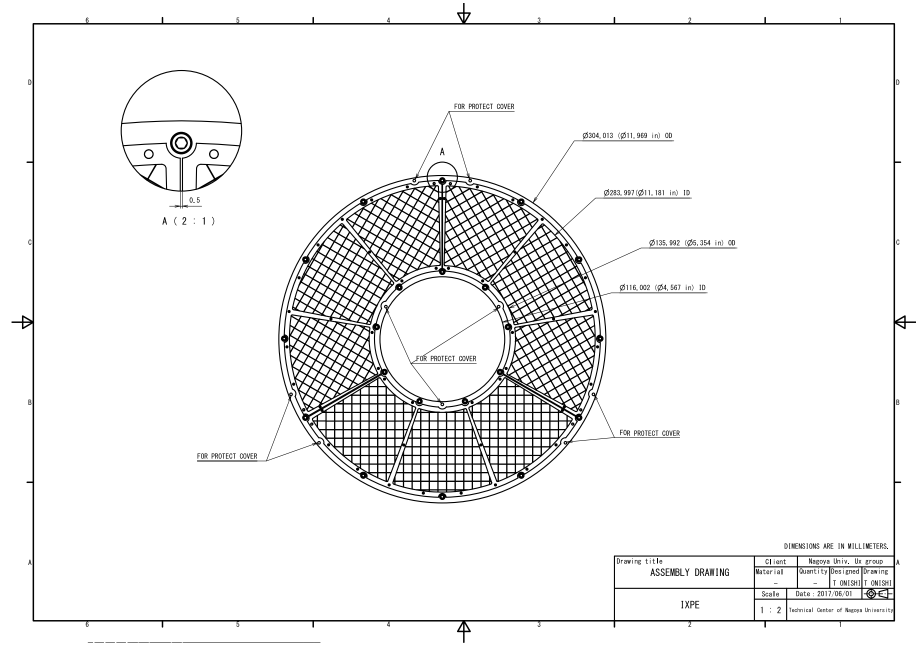


Metrology Target: LED array located on top spacecraft deck with 2 tight groups of 4 LEDs each

The boom metrology subsystem is composed of a camera viewing an array of LED sources on the spacecraft deck at the opposite end of the boom. With the camera aligned to the MMA axes, it watches the spacecraft deck as the DUs move. The LED image centroid data are utilized in ground processing, to aid in alignment of the IXPE during on-orbit commissioning, and in operation to correct the instantaneous line of sight vector for individual x-ray detection events and enable image reconstruction.

MMA Component: Thermal Shield (Nagoya)





- 1.4 micron-thick polyimide film
- Coated with 400 nm of aluminum
- Supported on a 97.5% transparent stainless-steel mesh
- Mesh supported on an aluminum frame
- Set of 4 shields was delivered in May for evaluation

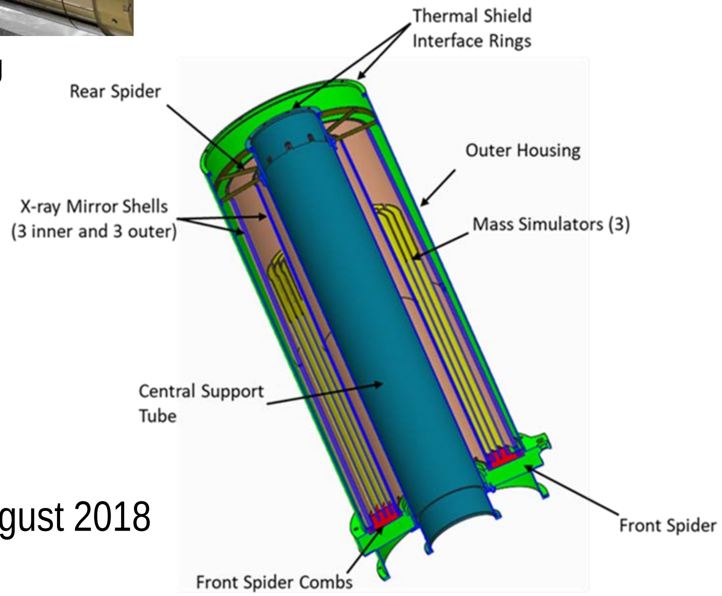
Status of the optics development

(Snapshot as of June 2018)

- Mandrels
  - 7 of 24 flight mandrels completed
  - 3 mandrels currently in polishing
  - 14 awaiting diamond turning

Mandrel Polishing

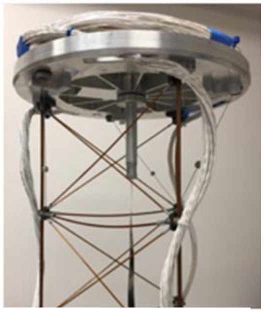
- Engineering Model development
  - EU has 6 flight-like shells (3 inner, 3 outer) plus mass simulators
    - All 6 mandrels completed
    - Front and rear spiders complete
    - Housing and other structure complete
    - Shell attachment combs in fabrication
      - Assembly will start early July 2018
      - Mechanical, thermal and x-ray testing will start in August 2018

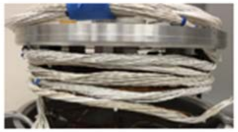


MMA Engineering Unit

Boom Description

- The boom is a 3-sided fiberglass coilable design procured from Orbital ATK
  - Selected over other type booms for favorable mass and volume
  - Similar to 8m design developed for GOES N program
    - Same longeron diameter, batten configuration, triangular size, etc.
  - Coiled longerons provide deployment force
    - Force measured on mockup boom is ~20 lbs
  - Boom twist (~98 degrees) allows tailoring of stowed Vs deployed location of MMAs
  - Elgiloy lanyard is attached to rotary friction damper to control deployment rate
    - Estimated deployment time is 30 seconds
  - Boom is manually resettable
    - Requires manual rotation of top of boom while cranking on the damper to reel in lanyard

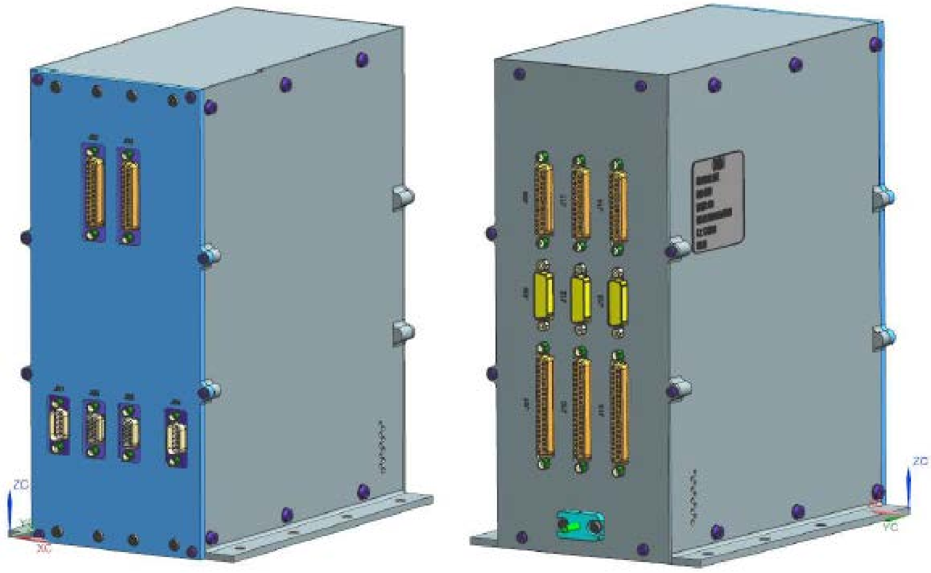




GOES R Boom

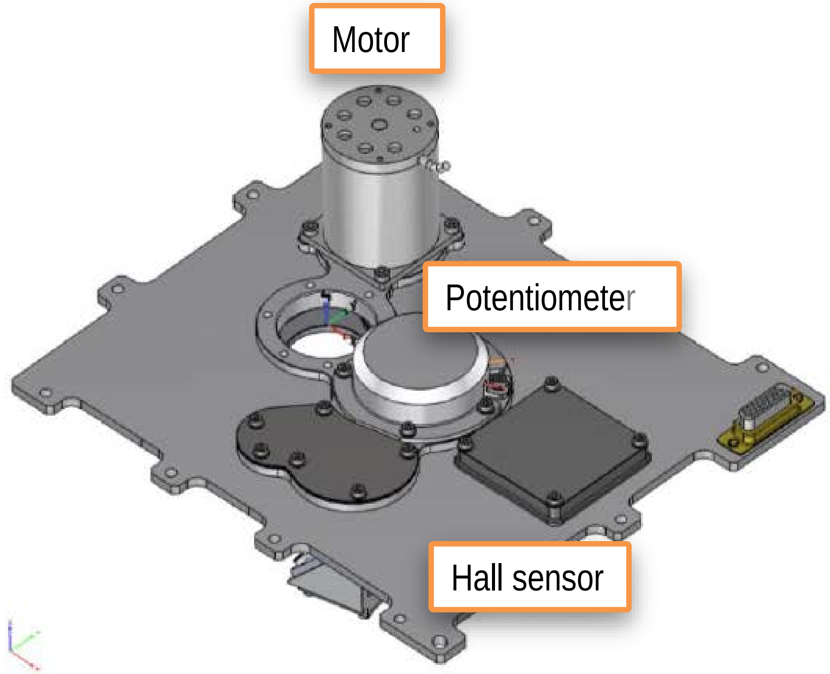
IXPE Boom Similar to Other OATK Designs

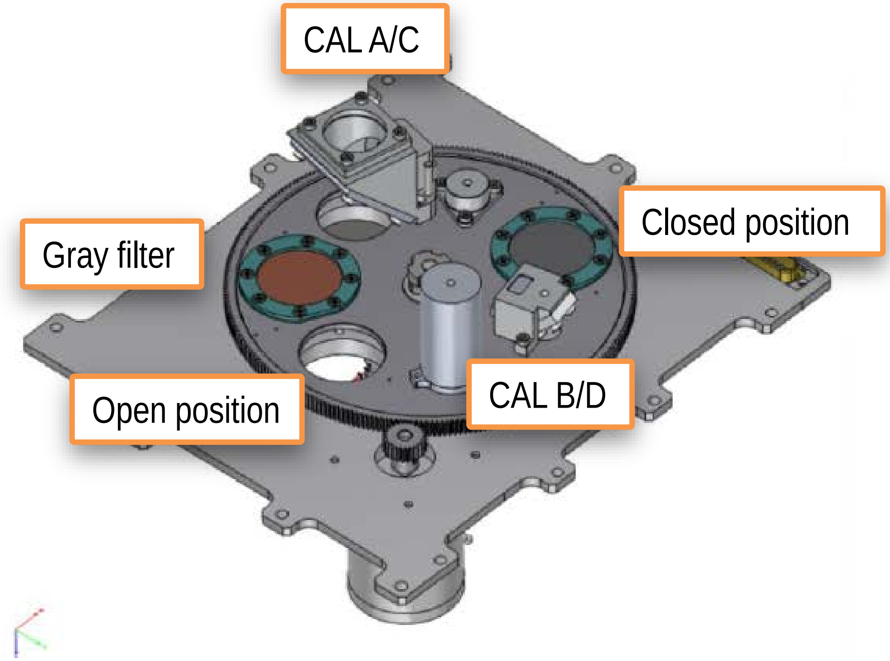
Detectors Service Unit (DSU)



- Cold redundancy:
  - two sets of Single-Board Computer and Power and Service Boards, activated from ground
- The Detector Service Unit controls all the three Detector units
  - Format and compress the data (removal of “orphan pixels”)
  - Time management (Timekeeping)
  - Peltier driver, Filter and Calibratin Wheel driver
  - Housekeepings

Filter and Calibration Wheel

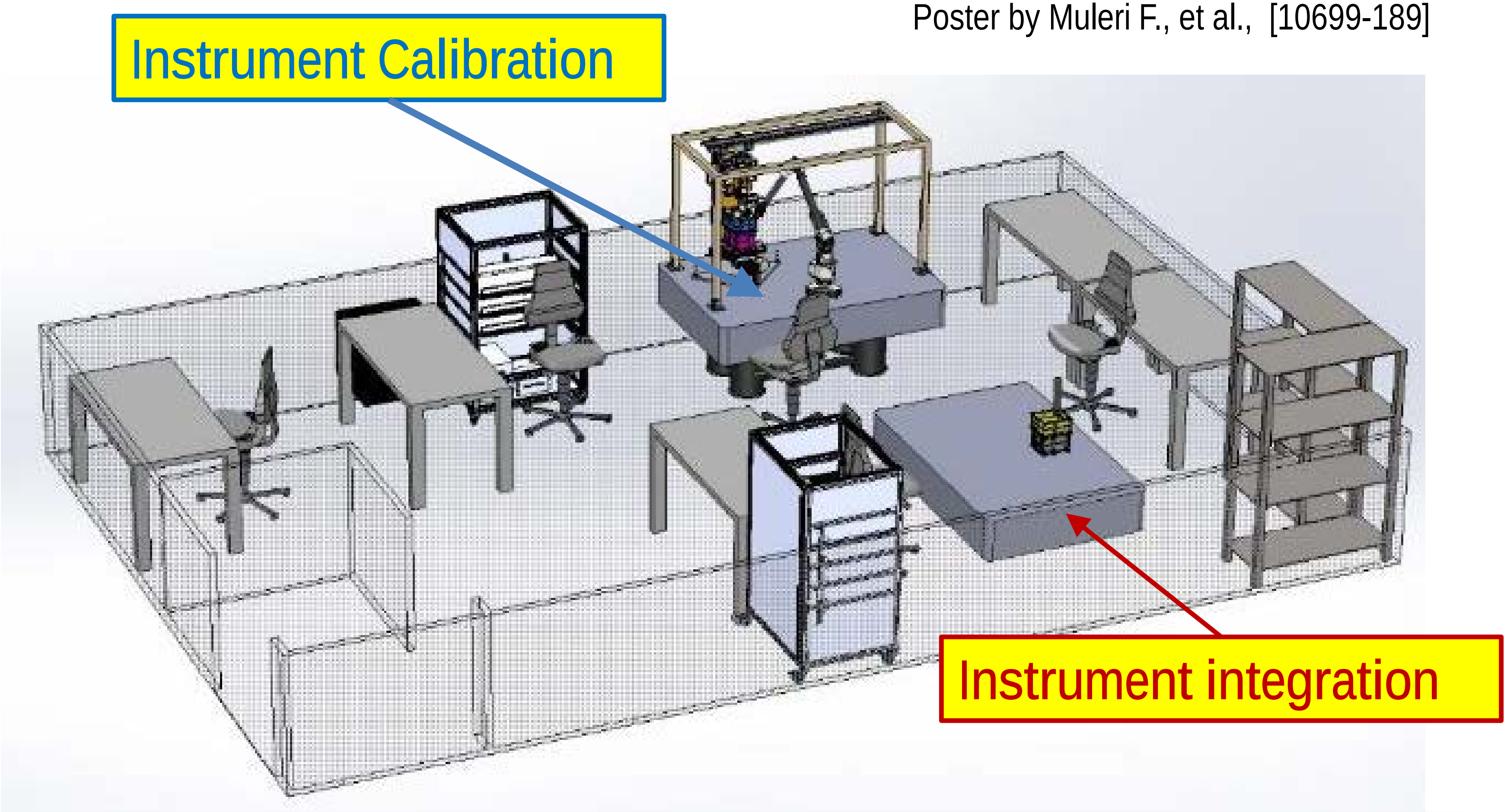




- Design based on that of eROSITA/SRG (launch planned for March/April 2019)
- Stepper motor, two redundant methods to measure the wheel position:
  - potentiometer and Hall sensor
- Four distinct calibration sources (CAL A-D), plus open/closed positions and gray filter

Instrument Integration and Calibration

Poster by Muleri F., et al., [10699-189]



Refurbished class 10000 Clean Room at IAPS is ready, delivered at the end of Feb 2018
Exclusive use for IXPE until instrument delivery at MSFC
Two optical benches: ICE and Instrument integration