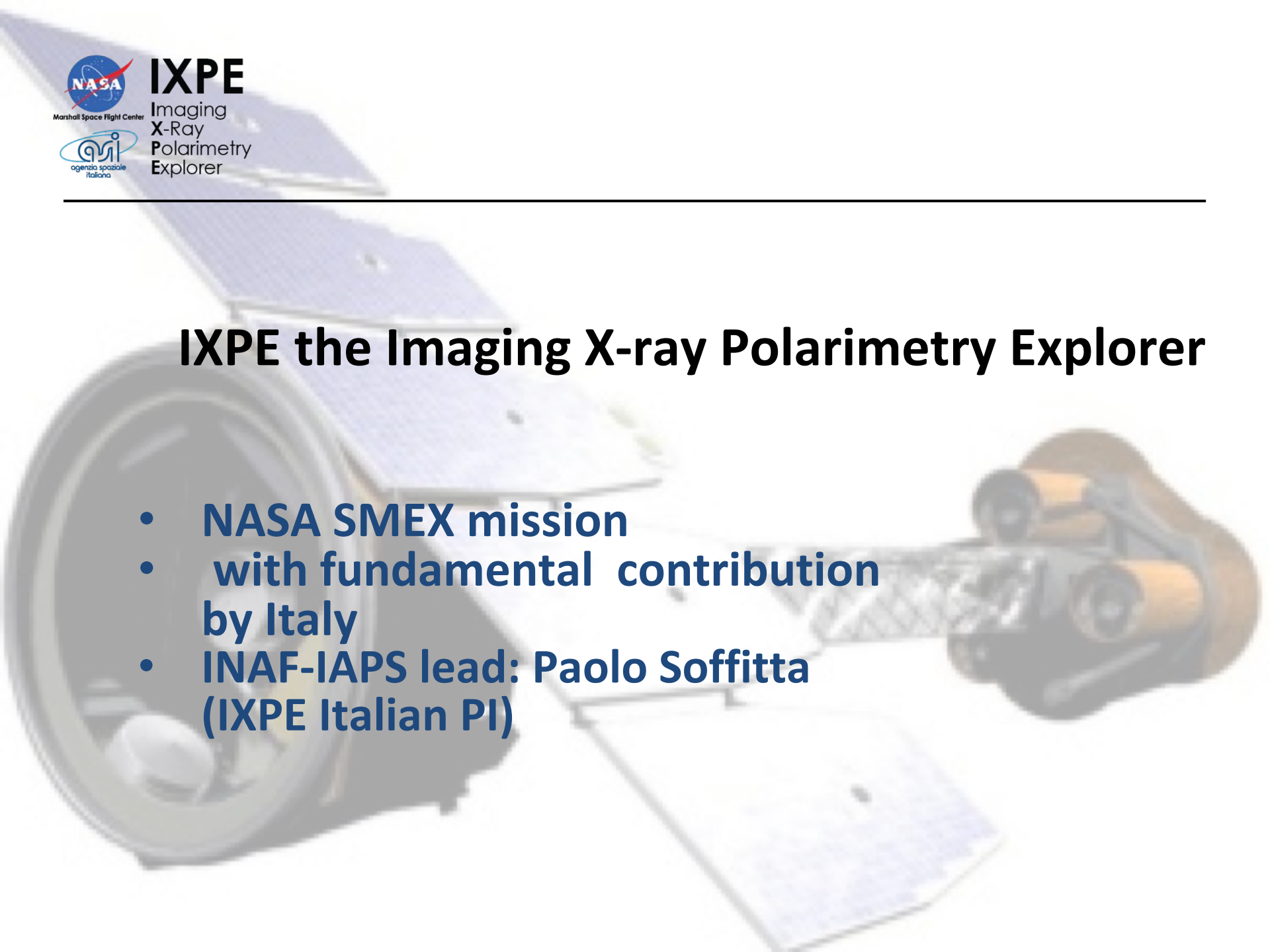
IXPE
Imaging
X-Ray
Polarimetry
Explorer

IXPE the Imaging X-ray Polarimetry Explorer



- NASA SMEX mission
- with fundamental contribution by Italy
- INAF-IAPS lead: Paolo Soffitta (IXPE Italian PI)

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Why X-ray Astrophysical Polarimetry ?

Polarization from celestial sources may derive from:

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

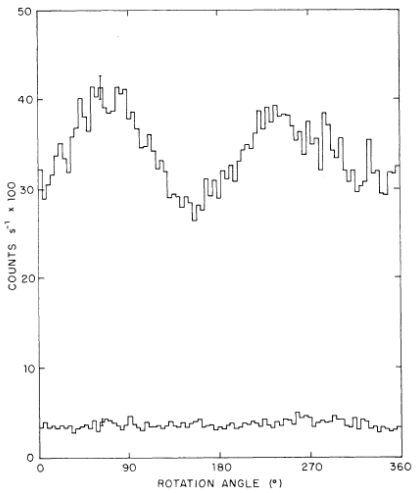
(Westfold, 1959; Gnedin & Sunyaev, 1974; Rees, 1975)

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

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

- **Vacuum polarization and birefringence dure to propagation in extreme magnetic fields**

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



Notwithstanding the theoretical previsions the polarization of only one source was detected so-far by OSO-8 back in the ’70:

Positive measurement: of X-ray polarization of the Crab Nebula without pulsar contamination

(by lunar occultation, Weisskopf et al., 1978).

P = (19.2 ± 1.0) %; ⍰ = 156º.4 ± 1º.4 (2.6 keV)

P = (19.5 ± 2.8) % ; ⍰ = 152º.6 ± 4º.0 (5.2 keV)

The technique was the limit !

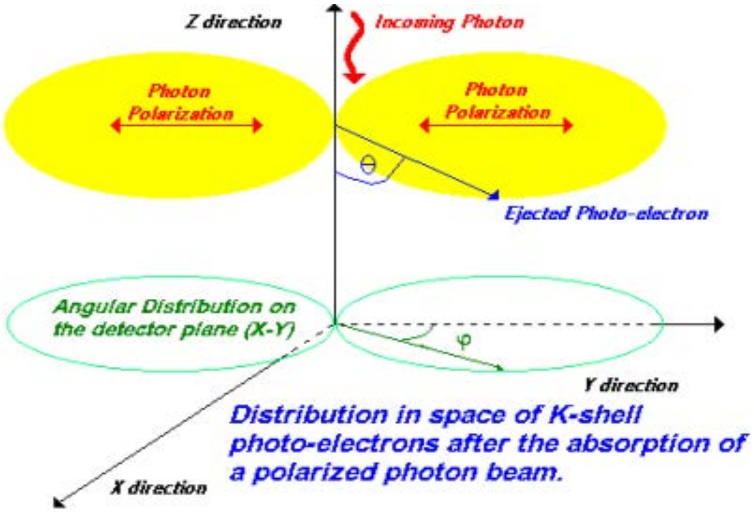


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From proposals to real experiment

In 2001 we developed a tecnique that allows sensitive polarimetry using photoelectric effect

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



Costa et al., 2001

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Minimum Detectable Polarization (MDP)

$$MDP = \frac{4.29}{\mu R_S}\sqrt{\frac{R_S + R_B}{T}}$$

R_S is the Source rate, R_B is the Background rate, T is the observing time
μ is the modulation factor: the response of the polarimeter to a 100% polarized beam (spanning from 0 or no sensitivity, to 1 or maximum sensitivity)

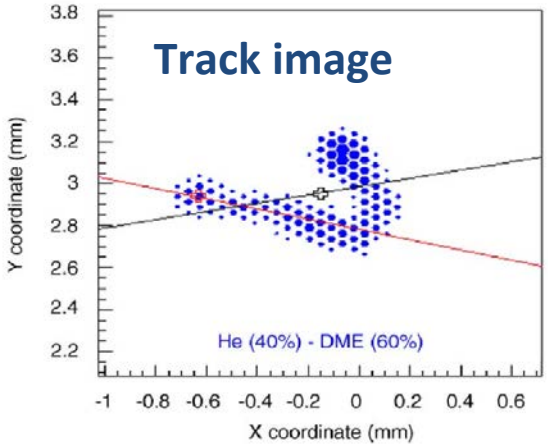
If background is negligible: $\mathrm{MDP} = \frac{4.29}{\mu\sqrt{N_{ph}}}$

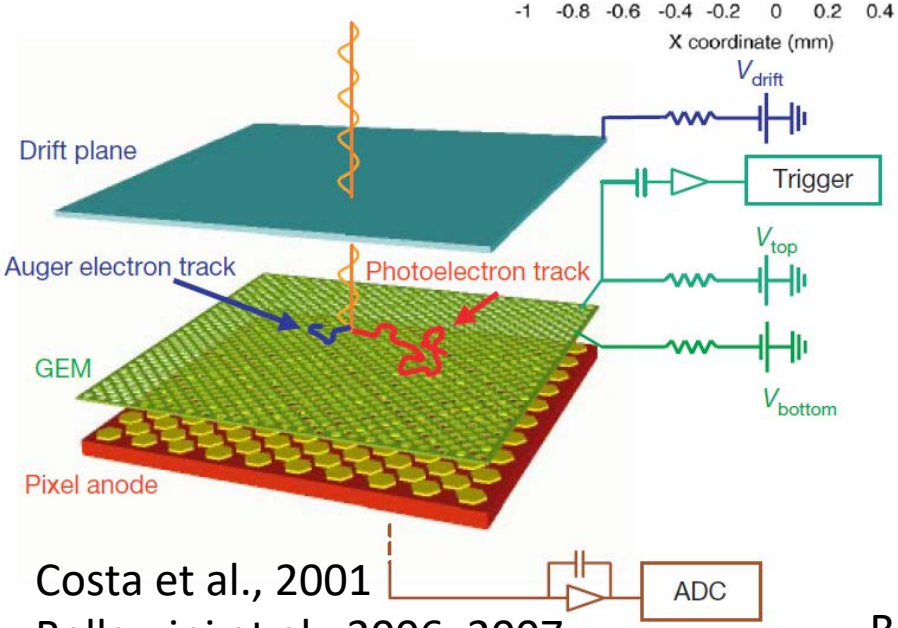
To reach MDP=1% with μ=0.5: $N_{ph} = \left(\frac{4.29}{\mu\ \mathrm{MDP}}\right)^2$ = 736 10^3 ph

Source detection > 10 counts
Source spectral slope > 100 counts
Source polarization > 100.000 counts

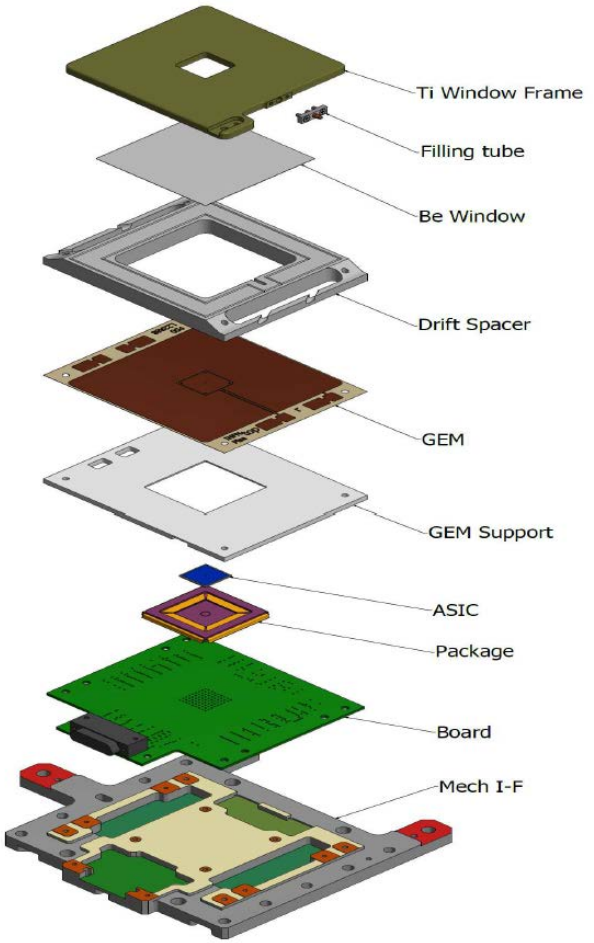
Caution: the MDP describes the capability of rejecting the null hypothesis (no polarization) at 99% confidence. For a 3-sigma meaurement an observing time 2.2 times longer is needed while the 1-sigma error scales like : 28°.5/S/N

The Gas Pixel Detector





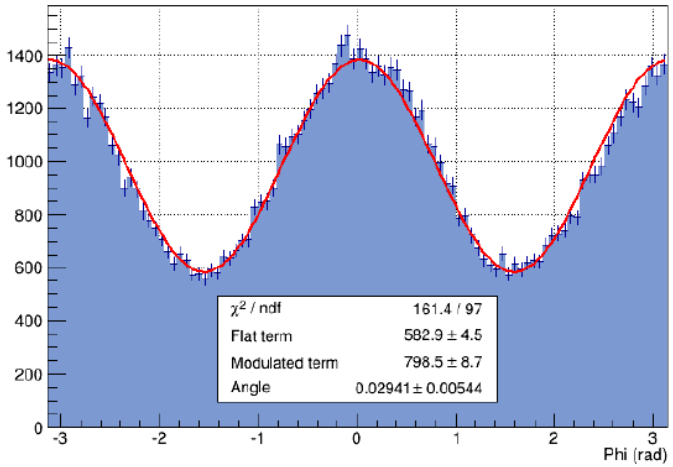
Costa et al., 2001
Bellazzini et al., 2006, 2007



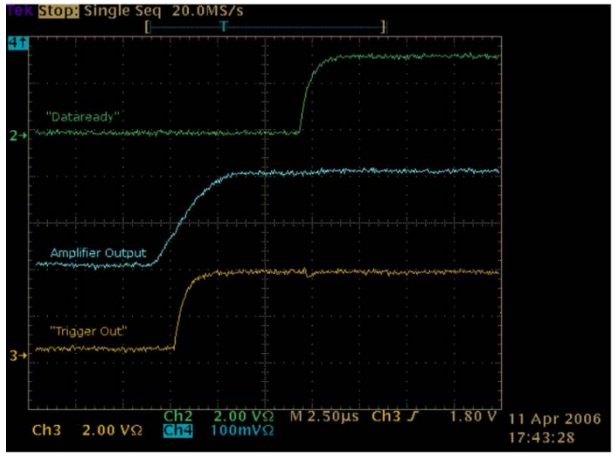
Baldini et al 2021, Soffitta et al., 2021

Linear Polarization, Image, Energy, Time

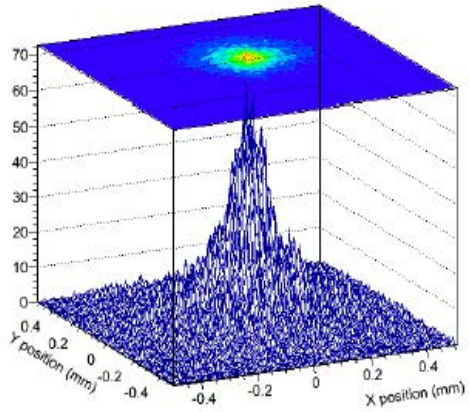
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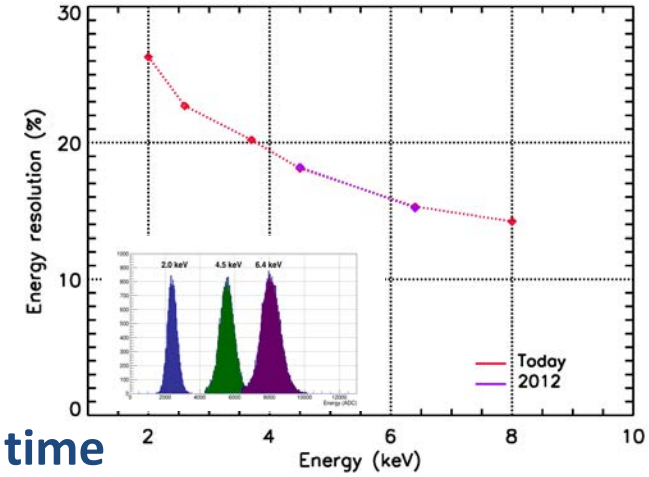
Real modulation curve derived from the measurement of the emission direction of the photoelectron.



Bellazzini et al. 2006



Fabiani et al 2012

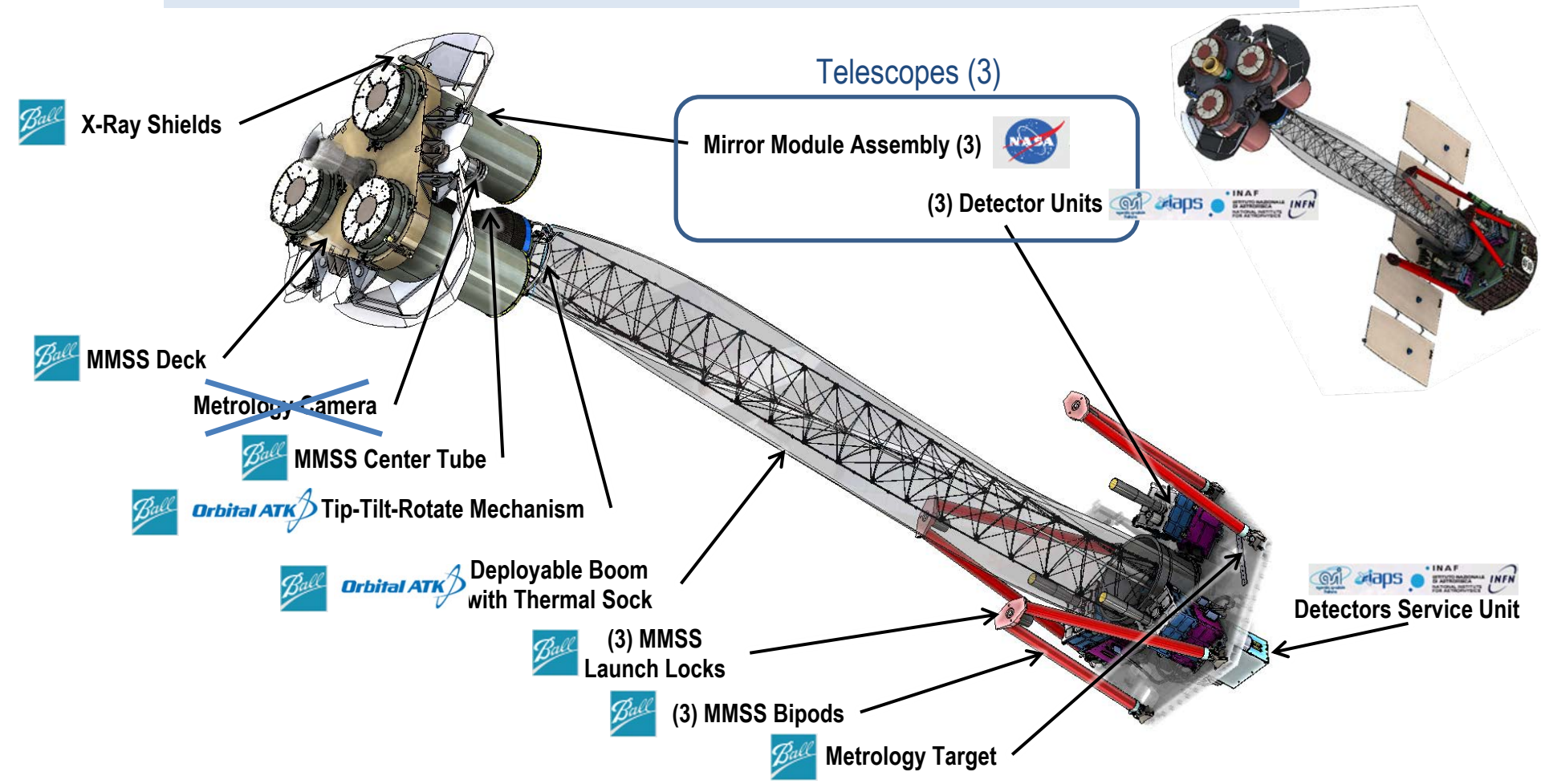


Muleri et al. 2016

Energy, space and time resolved X-ray polarimetry

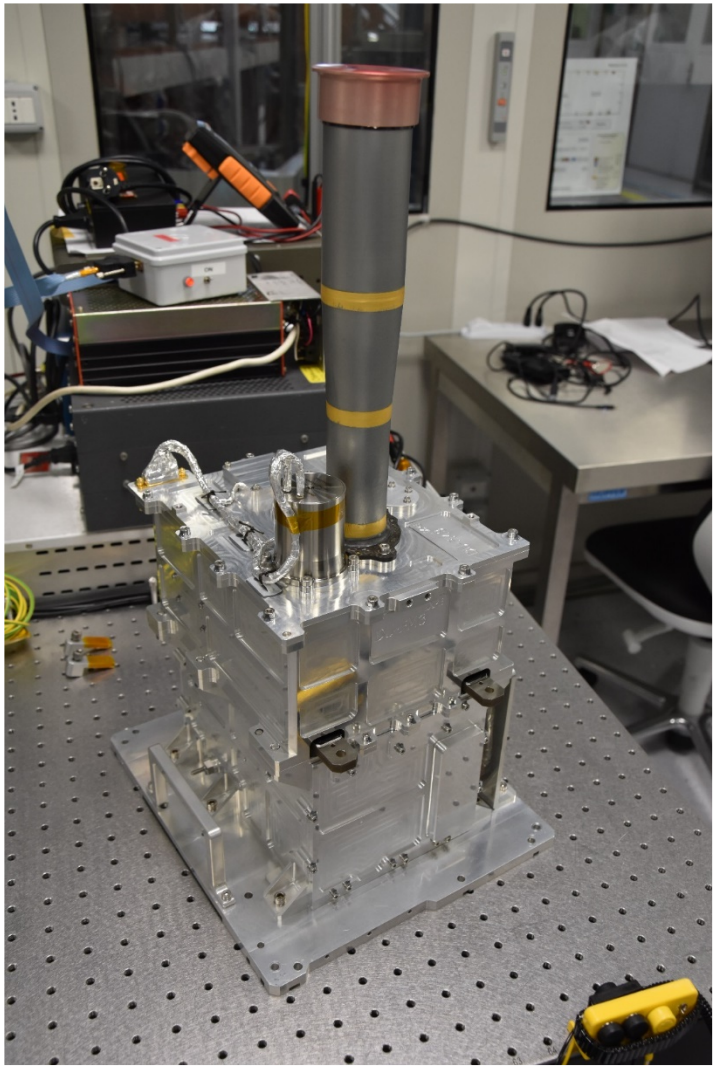
Payload Components

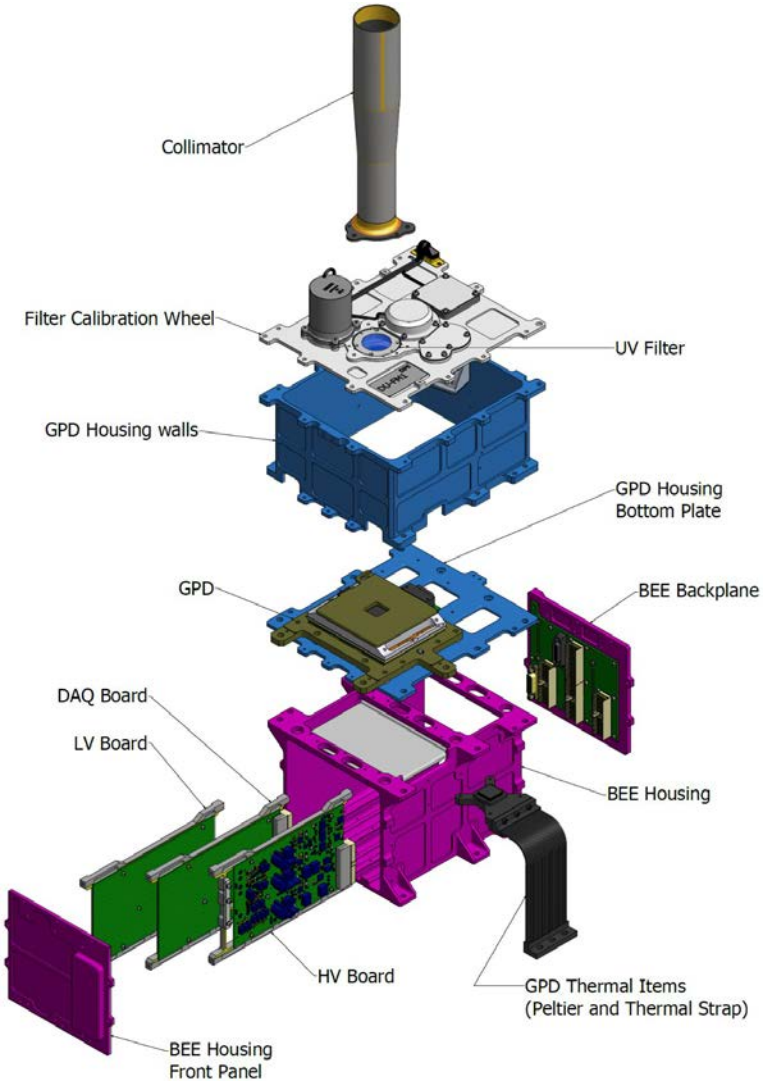
Accomplish the science through integrated system of Telescopes and structure alignment components.



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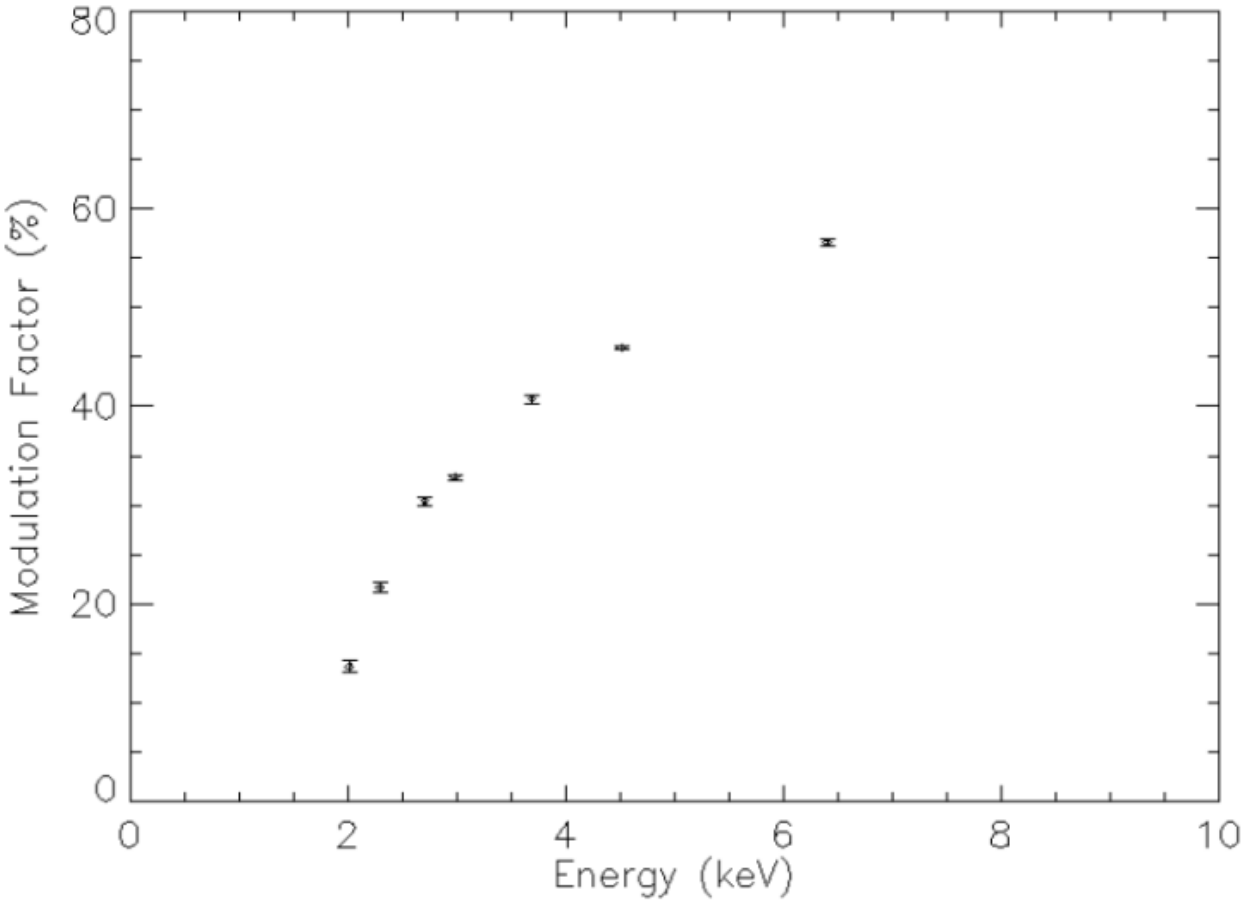
3 FLIGHT DETECTOR UNITS + 1 SPARE



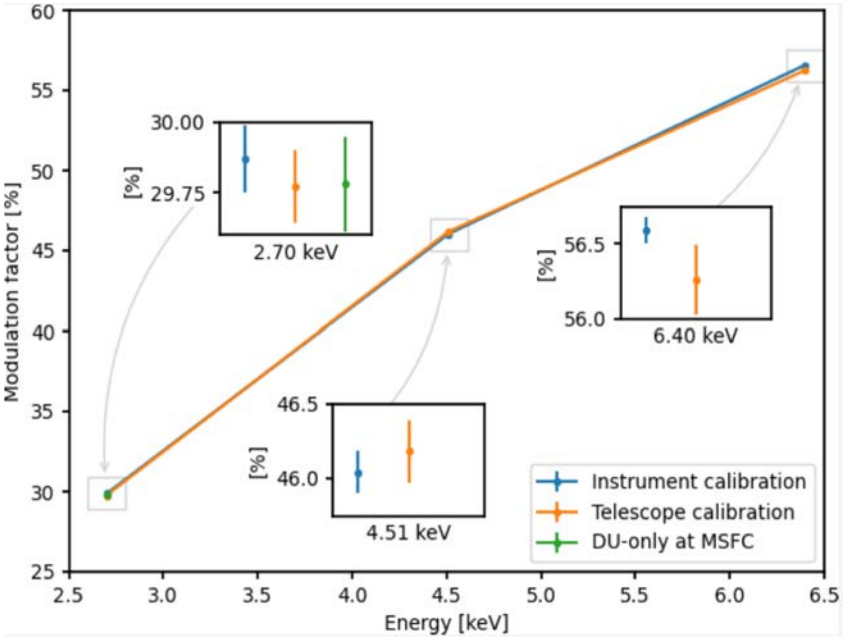


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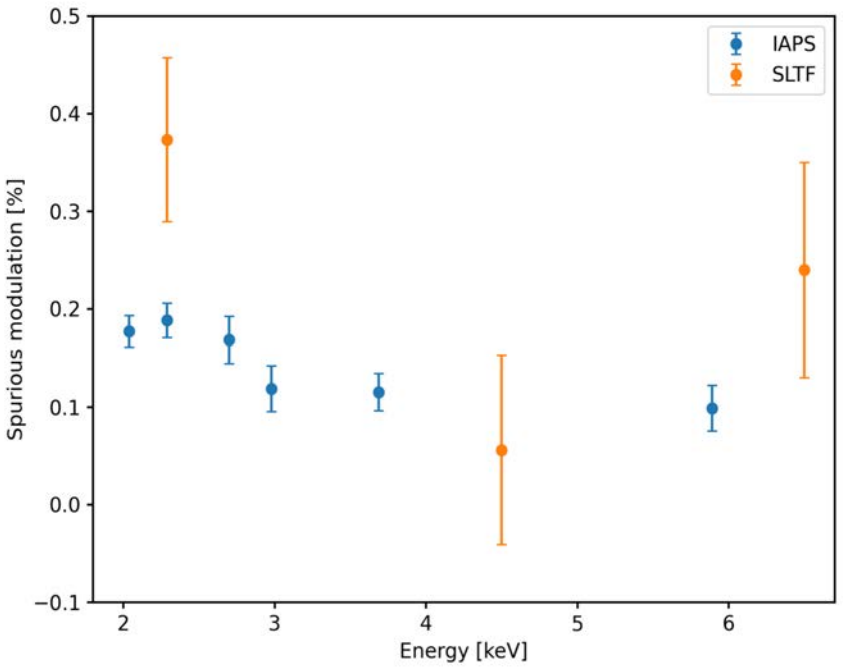
Modulation factor (from calibration)



MAIN RESULTS FROM THE TELESCOPE CALIBRATION



Mirror does not modify the Source polarization



Mirror does not introduce additional spurious modulation

As expected by theory, grazing incidence mirror does not modify the polarization measurement by the detector:

We can fully explot ground calibrations (mirror and DU separately) for determining the flight performances of the three telescopes

IXPE Imaging X-Ray Polarimetry Explorer

MEASURED PERFORMANCES OF THE IXPE INSTRUMENT

Parameter 10-2	Value (Energy 1)	Value (Energy 2)
Modulation factor	28.2 % (2.69 keV)	56.1 % (6.4 keV)
Spurious modulation	0.6 % (2.69 keV)	0.25 % (5.9 keV)
Effective area*	26.1 cm^2 (2.28 keV)	3.1 cm^2 (6.58 keV)
Energy resolution	22 % (2.69 keV)	16 % (6.4 keV)
Angular Resolution*	22'' (2.69 keV)	24'' (6.58 keV)
Dead time	1.1 ms (2.69 keV)	1.2 ms (6.4 keV)
Gray filter Transparency	17.4 % (2.69 keV)	65 % (4.5 keV)

Parameter	Value
Timing accuracy	1-2 μs (with PPS)
Expected Crab nebula rate	150 c/s (2-8 keV)
Expected Crab nebula rate	240 c/s (1-12 keV)
Expected background rate	1.16 10^{-2} c/s/cm^2 (2-8 keV)

*Spare telescope (single telescope)

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Marshall Space Flight Center

agenzia spaziale italiana

THE OBSERVATORY



Credit: Ball Aerospace



IXPE
Imaging X-Ray Polarimetry Explorer

FIRST YEAR OBSERVING PLAN

Targets	no. of sources	Total Time (ksec)
PWNe & PSRs	3	2600
SNRs	3	3000
Persistent XRPs	5	1450
Weakly Magnetized NS	3	300
Persistent BH LMXBs	2	550
Magnetars	2	2000
Radio quiet AGNs	3	1800
Galactic Centre clouds	1	1000
Radio Galaxies	1	200
HSP B Lac objects	5	1550
LSP BL Lac object	2	800
Radio-loud QSOs	3	600

Each year 6 TOOs 500 ks each are foreseen in the long term plan

https://ixpe.msfc.nasa.gov/for_scientists/ltp.html