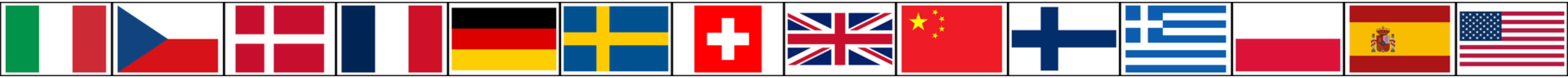
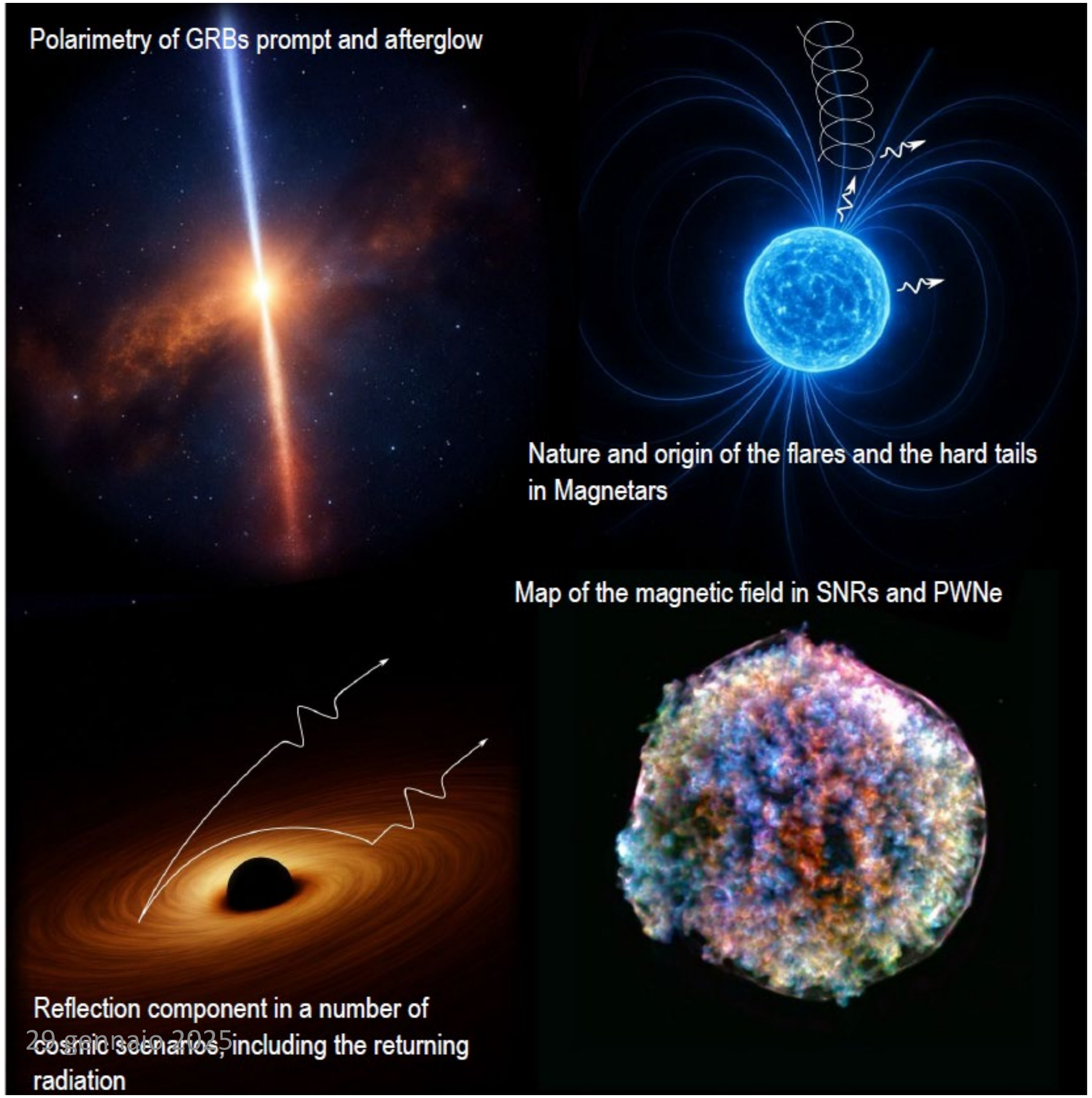




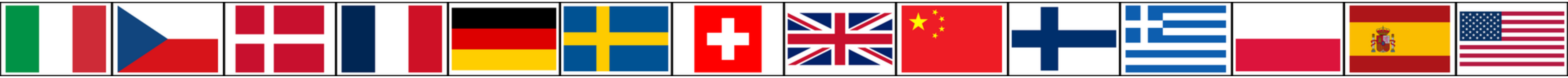
ENHANCED X-RAY POLARIMETRY OBSERVATORY (EXPO)

Paolo Soffitta

(INAF-IAPS)

on behalf of EXPO Team

INAF RSN4 Workshop
Osservatorio Astronomico di Capodimonte
28-30 gennaio 2026



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IXPE Imaging X-Ray Polarimetry Explorer

WHY WE DO THIS: ASTROPHYSICS!
ABOUT 110 DIFFERENT SOURCES SO FAR OBSERVED

Class	Objects
11 PWNe and isolated pulsars	Crab PWN, Vela PWN, MSH 15-52, PSR B0540-69, G21.5, 3C 58, PSR B1259-63, KES-75, PSR J1723-283.7, Lighthouse N, PSR J1023 +0038
6 SNRs (7 pointings)	Cas A, Tycho's, NE SN 1006, RCW 86, RX J1713.7-3946, Vela Jr, SN1006SW
17 Accreting stellar-BH	Cyg X-1, 4U 1630-472, Cyg X-3, LMC X-1, SS433, 4U 1957-115, SS 433 Lobes East, LMC X-3, SWIFT J1727.8-1613, 4U 1957+115, Swift J0243.6+6124, Swift J1727.8-1613, GX 339-4, SWIFT J151857.0-572, MAXI J1744-294, SS 433 Lobe West, GRS 1915+105
38 Accreting NS & WD	Cen X-3, Her X-1, GS1826-67, Vela X-1, Cyg X-2, GX 301-2, Xpersei, GX 9-9, 4U 1820, GRO J1008-57, XTE 1701-46, EXO 2030+375, LS V+44 17, GX 5-1, 4U 1624-49, Sco X-1, Cir X1, GX13+1, SMC X-1, SRGA J144459.2-604207, 4U 1538-52, V395 CAR, PSR J1023+00, GX 340+0, GX 3+1, 4U 1728-34, PSR J1723-2837, 4U 1735-44, GX 9+1, GX 349+2, 4U 1538-52, GX 17+2, 4U 1907+09, EX HYDRAE, 4U 1700-377, IGR J17091-3624,H 1417-624,UW CRB
6 Magnetars	4U 0142+61, 1RXS J170849, SGR 1806-20, 1E 2259+586, 1E 1841-045, 1E 1547.0–5408
10 Radio-quiet AGN & 1 Sgr A*	MCG 5-23-16, Circinus Galaxy, NGC 4151, IC 4329 A, Sgr A* Complex, NGC 1068, NGC 4945, NGC 2119, NGC 3227, 1ES 1927+654
21 Blazars & radio galaxies	Cen A, S5-0716-714, 1ES 19-59-650, Mrk 421, BL Lac, 3C 454, 3C 273, 3C 279, Mrk 501,1ES 1959-650, BL-Lac, 1ES 0229-200, PG 1553 -113, S4 0954+65, 1E 2259+586, RGB J0710+591, H 1426+428, 1ES 1101-232, PICTOR A WEST

Some sources have been revisited:

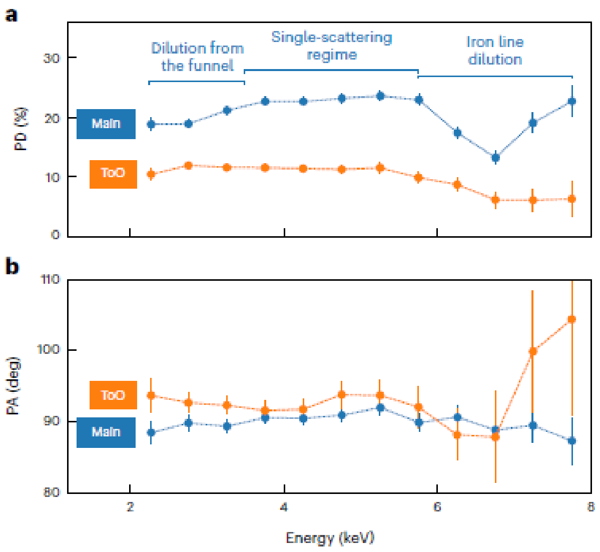
Mrk 421, Mrk 501, BL Lac, Vela X1, Her X-1, MCG 5-23-16, Crab, MSH 15-52, Cyg X-1, Sgr A (complex), NGC 4151 even Crab.

New source classes are being observed such as Galaxy Clusters, recurrent novae, extended black hole jets, and pulsars in binary systems.

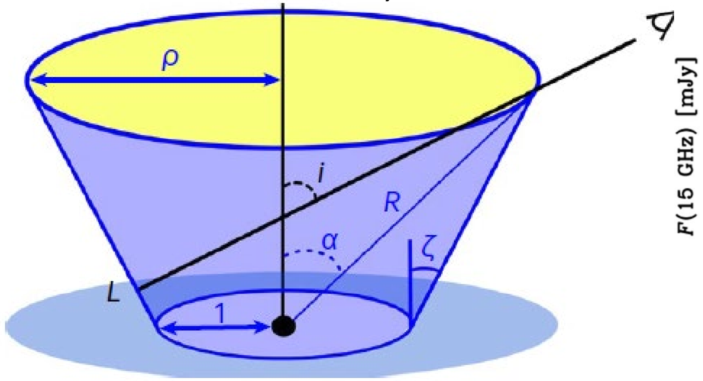
About 50 % of the observed celestial sources displayed a polarization with at least 6 σ significance in the Quick Look Analysis (Integrating in time, energy and position). Resolved analysis showed significant polarization on > 80 % of sources.

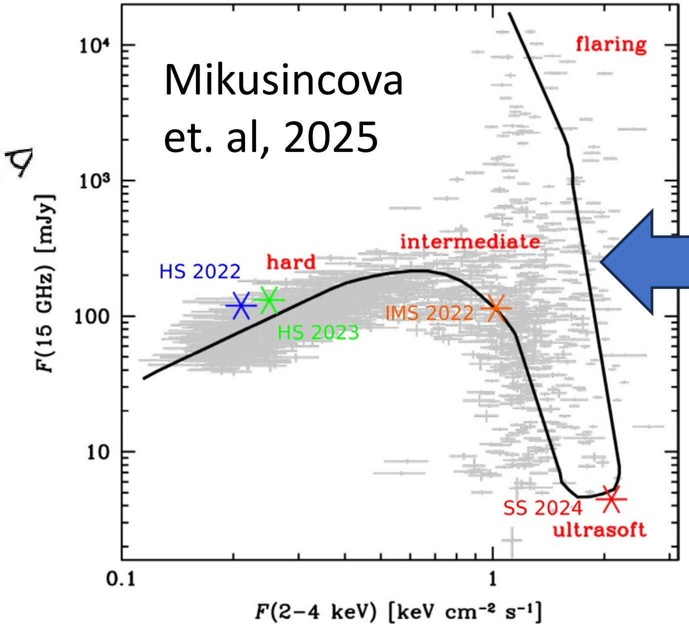
IXPE IS VERY SLOW (> 3 DAYS USUALLY 1-2 WEEKS) IN REPOINTING. NEED OF FAST REPOINTING (SWIFT-LIKE)

Cyg X-3



Veledina et al., 2024



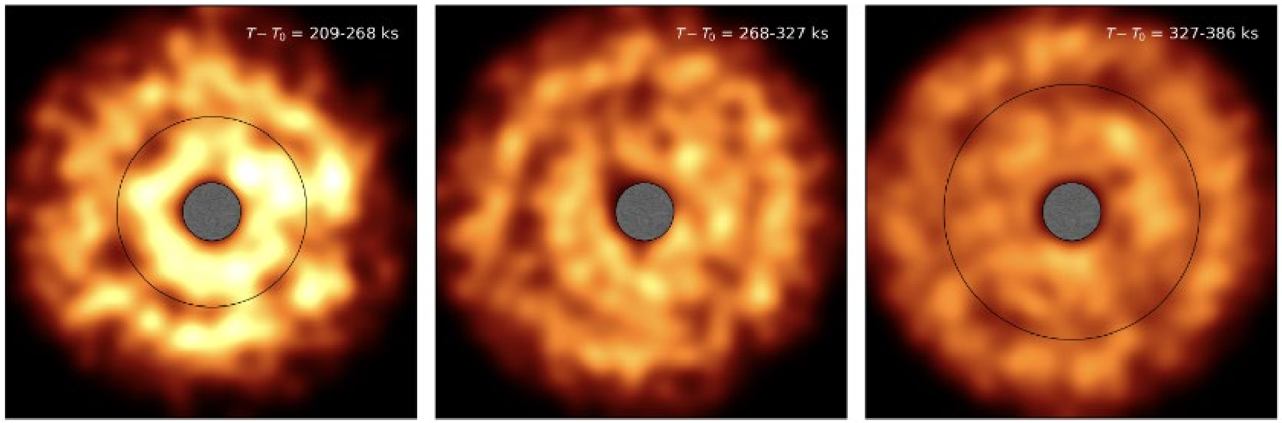


What is the interaction between the jet and the accretion disk ?'

The polarization during the flaring state will be unknown with IXPE.

Need a fast repointing about hours

The BOAT (GRB 221009A)

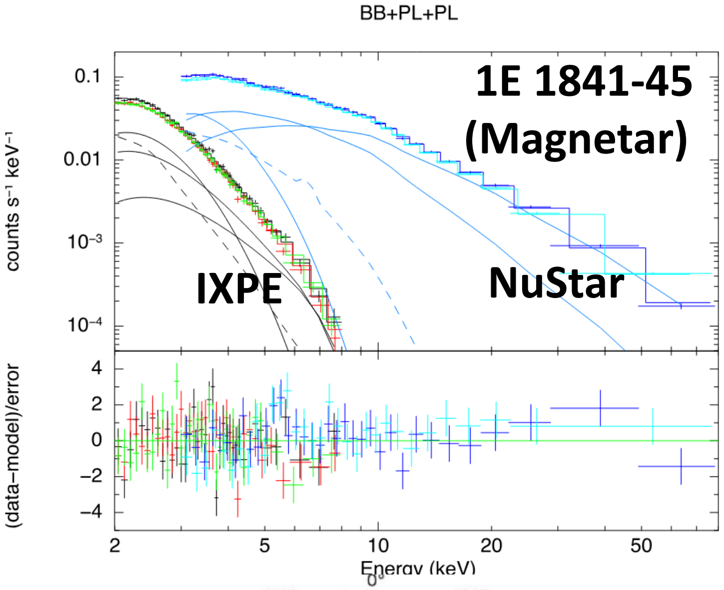


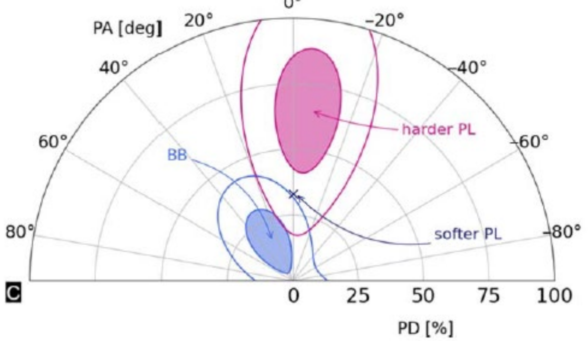
IXPE fastest reaction time ever (3-days)

Coarse upper limit due to the 'slow' repointing time on:
(1) Prompt emission < 53% (99%, using scattering rings)
(2) Afterglow < 13 % (99%)

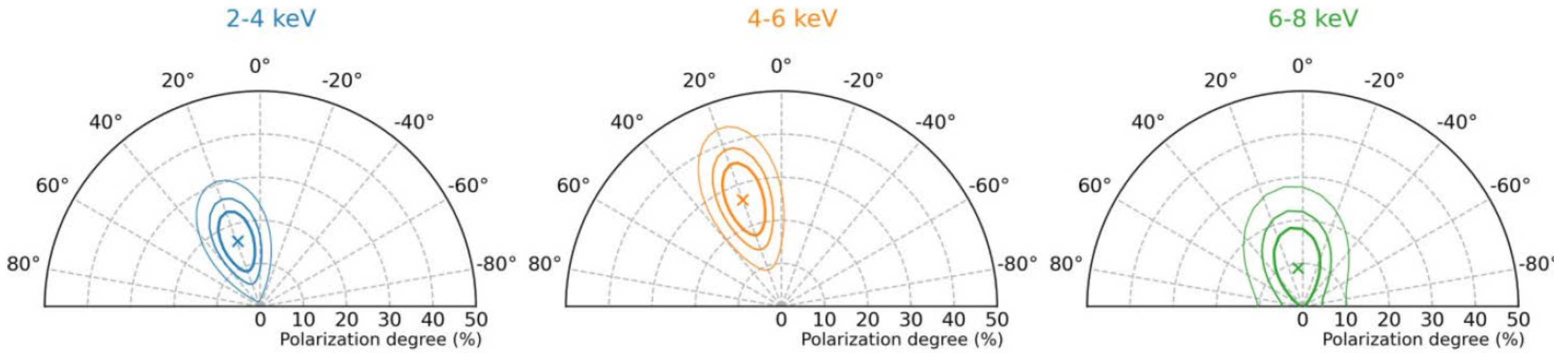
Negro, M. et al., 2023

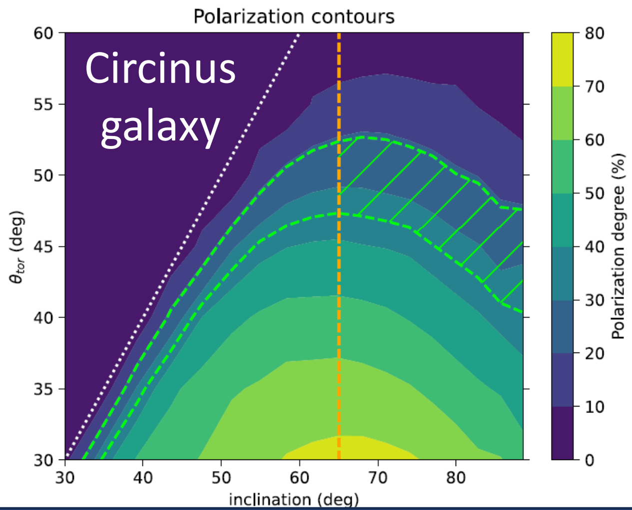
IXPE HAS A NARROW ENERGY BAND (2-8 KEV): NEED OF A WIDE-BAND SENSITIVITY

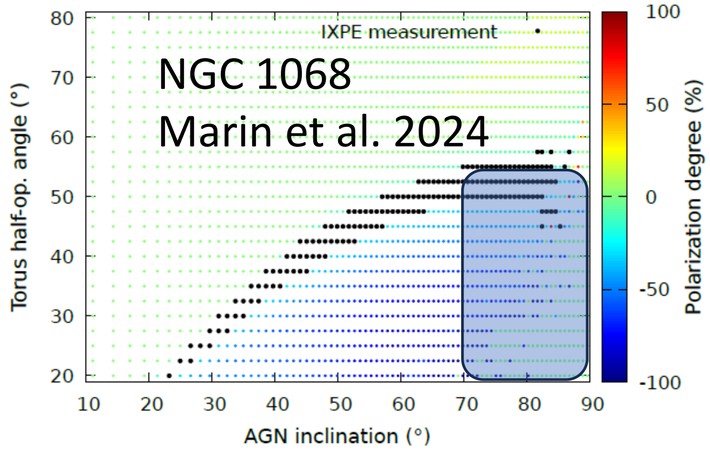




Circinus Galaxy & NGC 1068 the tip of the iceberg (Ursini et al., 2023)



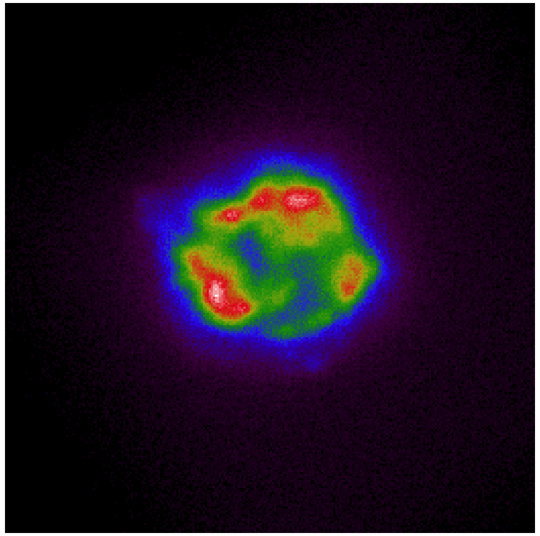




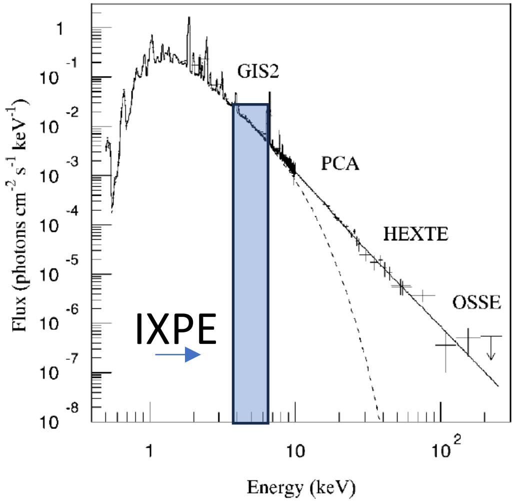
What is the origin of the high energy power-law ? IXPE alone can only suggest (synchrotron ?)

From X-ray polarimetry and Monte Carlo simulation, Cicinus galaxy and NGC 1068 have remarkably the same aperture of the torus: is this ubiquitous for Seyfert 2 galaxies ?

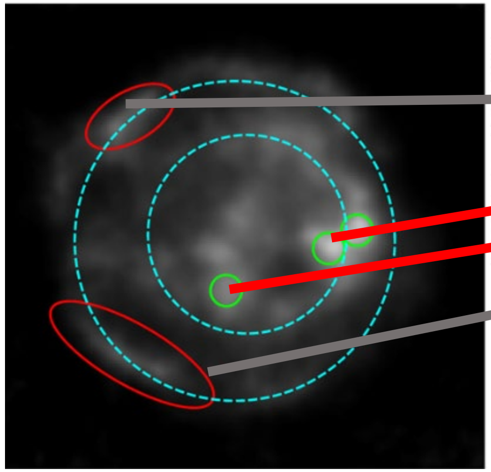
PHOTOELECTRIC IMAGING POLARIMETRY ABOVE 6 KEV:
IN SNRS FEATURES ARE NOT SIMPLE EXTENSIONS OF LOW ENERGY ONES



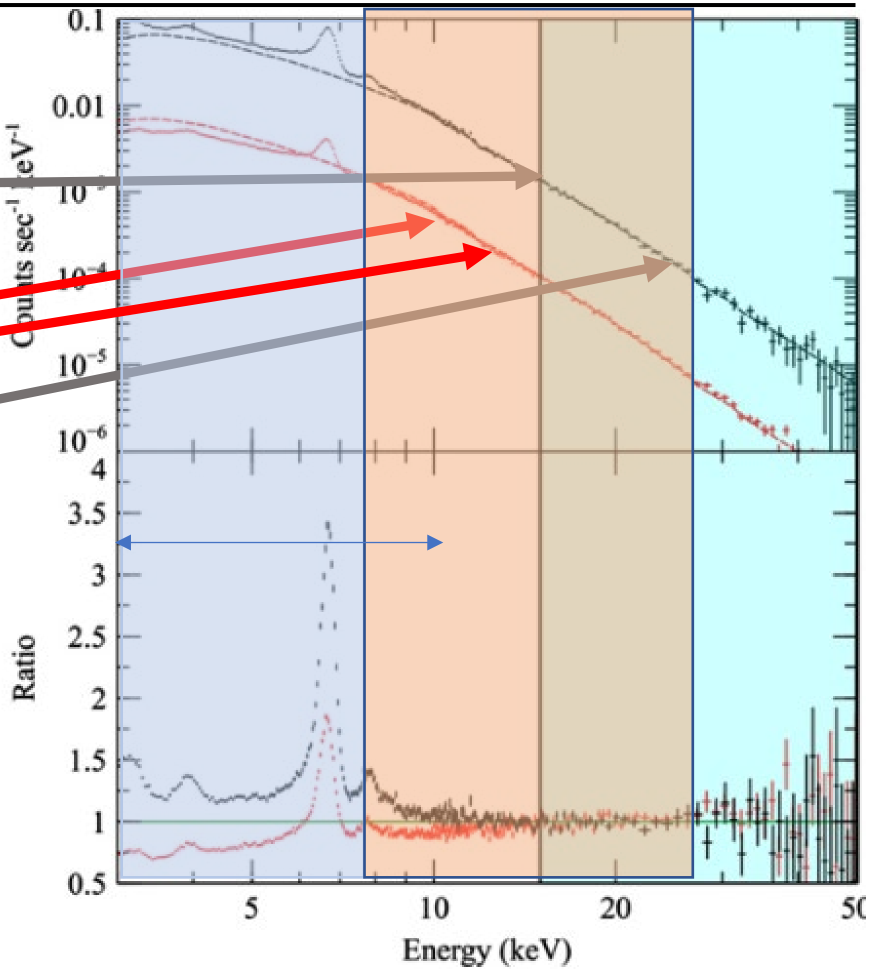
Cas A IXPE Image



IXPE selects data between the Ca-line and the Fe-line.

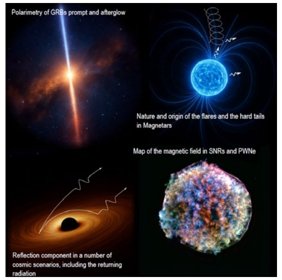


15–20 keV
Cas A NuStar image

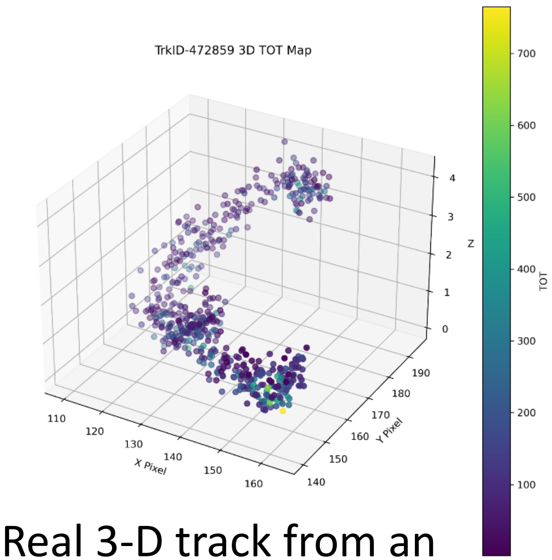


The origin of E >15 keV is a mistery.
It is not dominated by forward or reverse shock but by filaments and knots.
Is the bright knots emission synchrotron (10-100 TeV electrons) or
non-thermal bremsstrahlung (10-100 keV electrons) ?

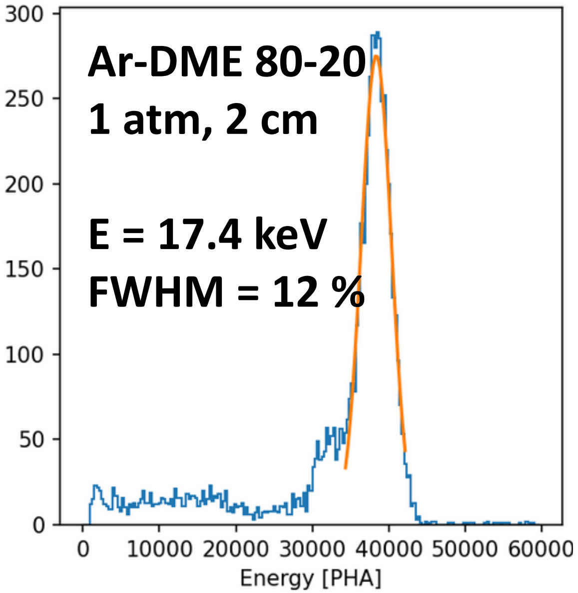
IXPE probes the non thermal emission diluted with thermal bremsstrahlung (blue)
Imaging Hard X-ray polarimetry of genuine non thermal emission (Orange 9-30 keV)

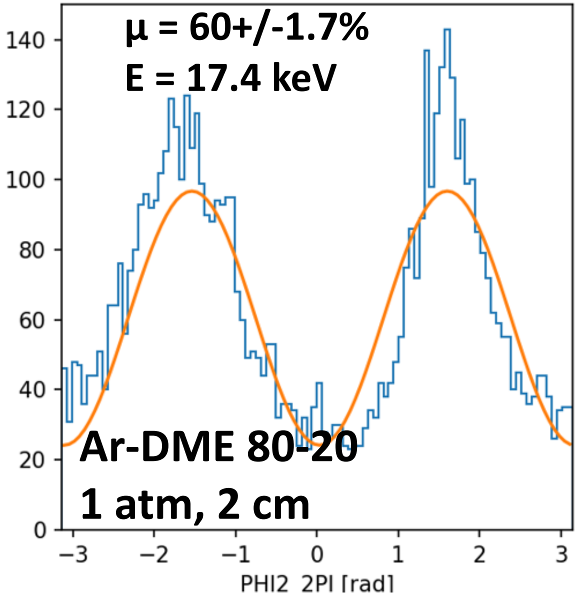


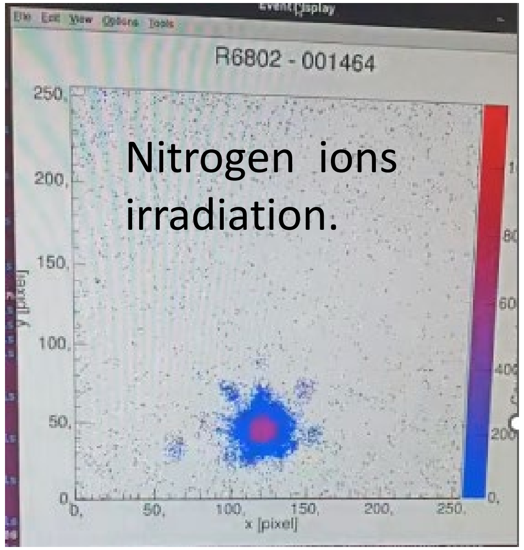
REAL DATA FROM A DETECTOR EARLY PROTOTYPE



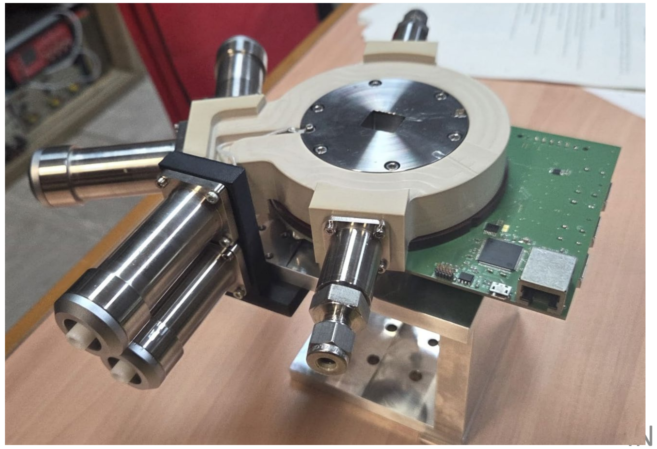
Real 3-D track from an Ar-DME based mixture at 17.4 keV

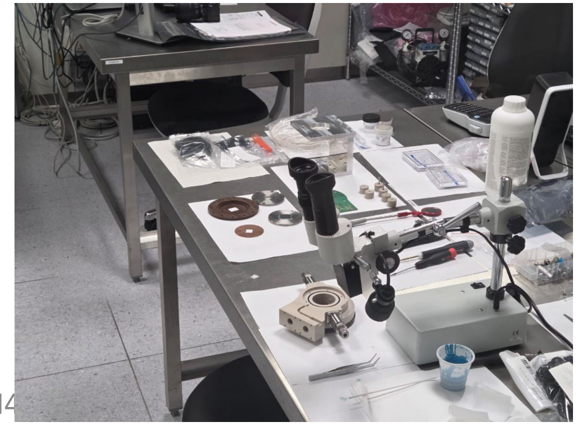


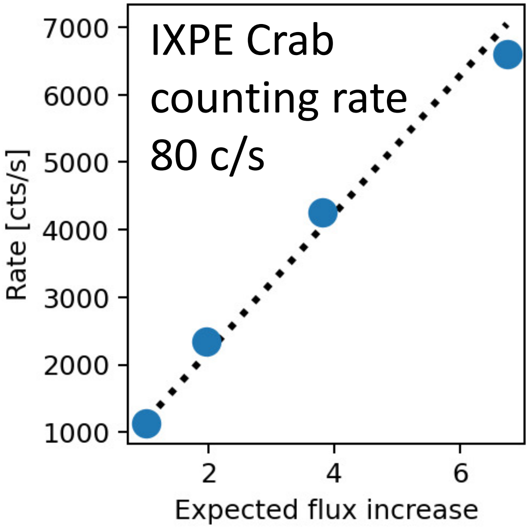


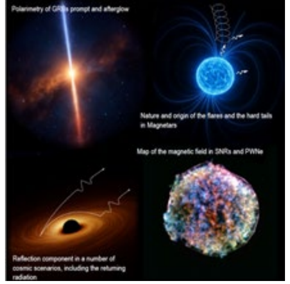


More advanced prototype

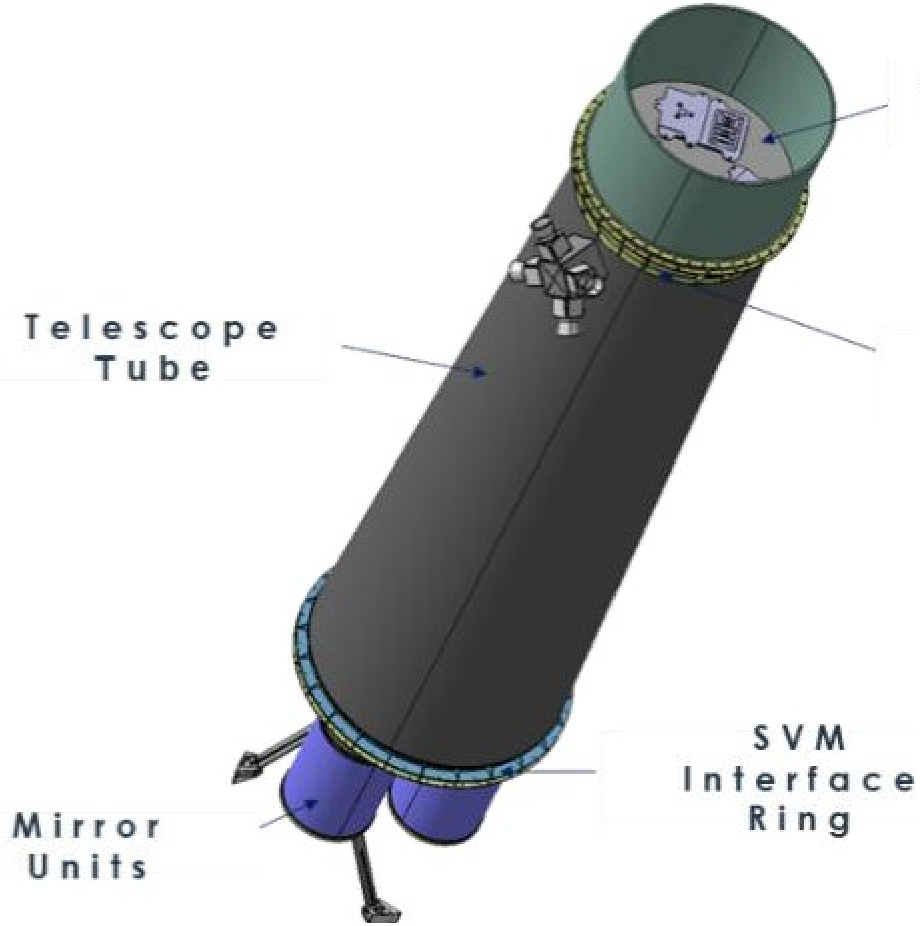








THE EXPO MISSION OVERVIEW



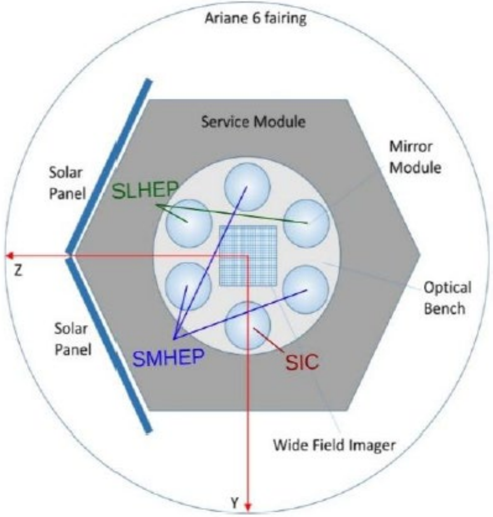
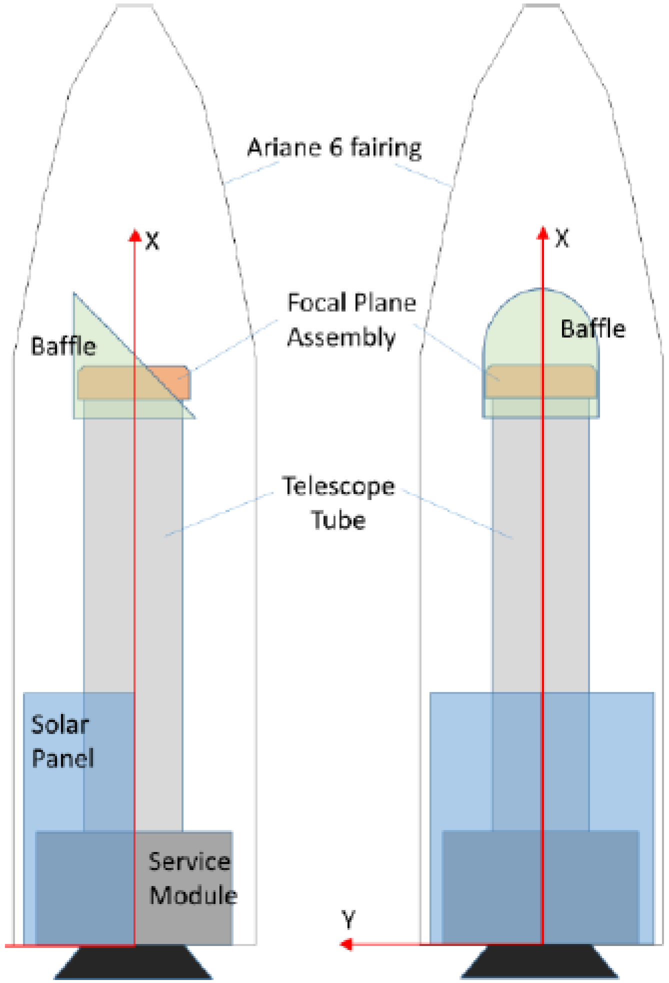
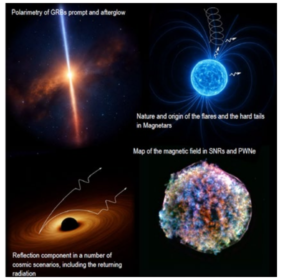


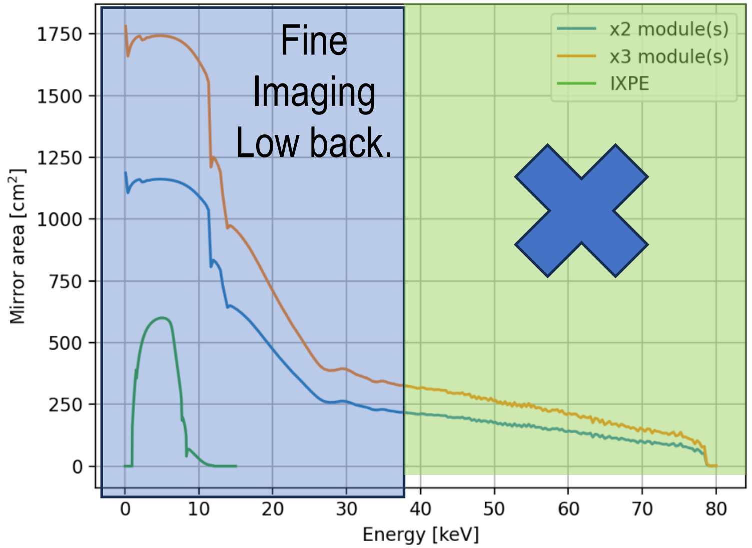
Table 3: Preliminary EXPO mass and power budget

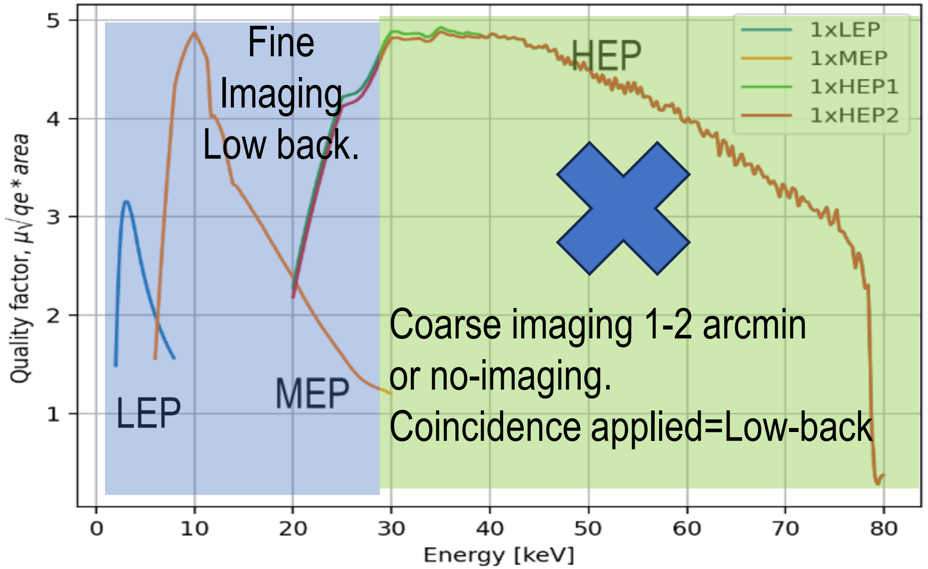
Item	Mass [kg]	Power [W]
Payload (MHEP, LHEP, SIC, WFI, MMs, Detector Service Unit)	845	419
Payload Module Structure (Telescope Tube, OB, FPA structure)	200	-
Service Module Structure	250	-
Thermal Control Hardware (thermal blankets, heaters, sensors)	50	400
Attitude Control Subsystem (star trackers, rate sensors, sun sensors, reaction wheels)	60	150
Propulsion Subsystems (for orbit and attitude control)	40	50
Telecommunication Subsystem (X-band for uplink/downlink)	70	250
Data Handling Subsystem (on-board computer, remote terminal)	30	80
Power Subsystem (solar panels, battery, power distribution unit)	150	70
Harness	70	-
Total (dry mass)	**1765**	**1419**
System margin (20%)	350	284
Propellant (hydrazine) mass	150	-
Grand total	**2265**	**1703**

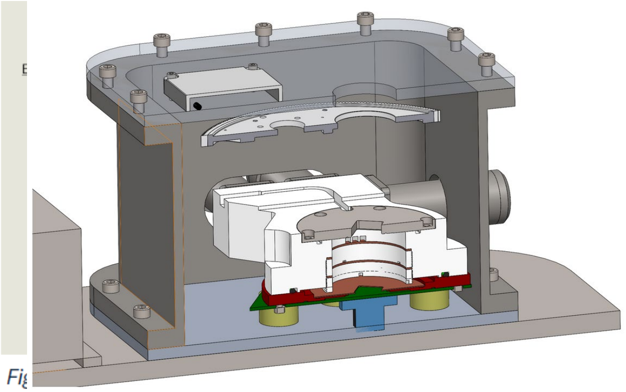




The detector's Quality Factors



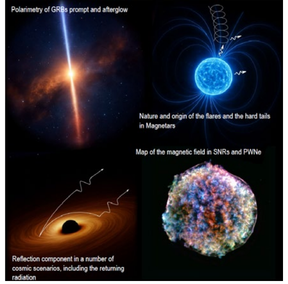




Mirror #	1	2	3	4	5	6
Front Behind	LEP HEP	LEP HEP	MEP HEP	MEP HEP	MEP HEP	SIC

Low Energy Polarimeters, Ne/DME filled	2-8 keV
Medium Energy Polarimeters, Ar/DME filled	6-30 keV
~~High Energy Polarimeters, Compton~~	~~20-80 keV~~
Spectrometer-Imager Camera	< 2 - > 80 keV

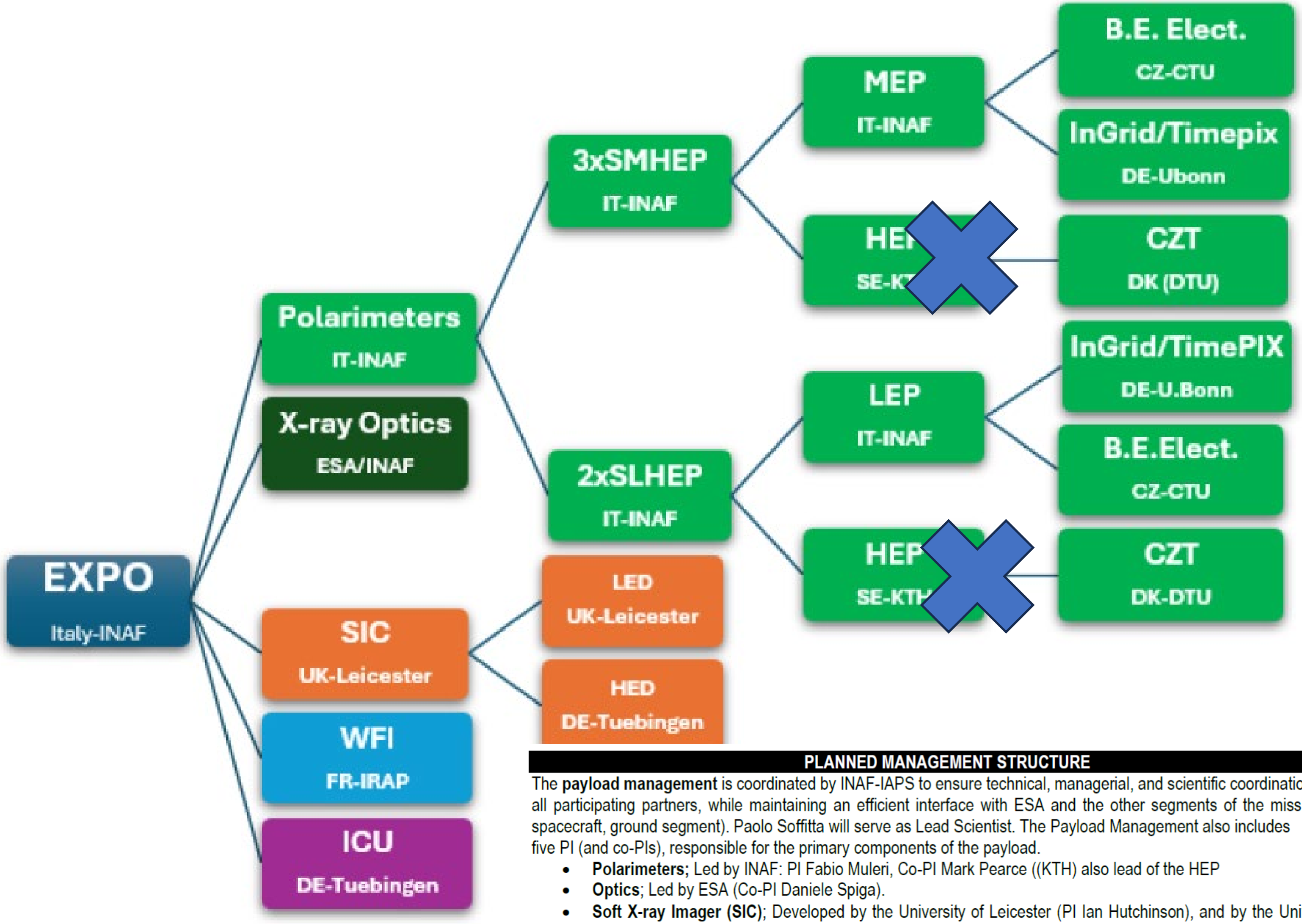
The quality factor of the LEP and MEP provide similar sensitivity at the focus of multi-layer optics.
Focal length is reduced to 7.5 m (from 10 m) and the Compton stage removed



THE PROPOSED EXPO PAYLOAD AND CONSORTIUM INSTITUTION.

Table 1: Summary of volume, mass and power requirements of the EXPO payload

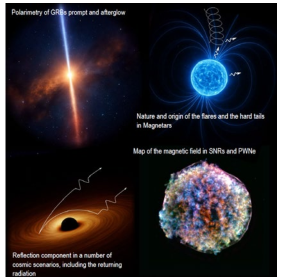
	Unit volume [cm3]	Item	Unit mass [kg]	TOT Mass [kg]	TOT Power [W]
2x	30x18x18	SLHEP	11.5	23.0	30.0
		LEP	3.8		
		~~HEP~~	~~4.7~~		
		Box	2.5		
		Harness	0.5		
3x	30x18x18	SMHEP	11.7	35.1	45.0
		MEP	4.0		
		~~HEP~~	~~4.7~~		
		Box	2.5		
		Harness	0.5		
1x	30x18x18	SIC	13.8	13.8	40.0
		LED	1.8		
		HED	2.0		
		Shielding	5.0		
		Box	4.5		
		Harness	0.5		
1x	54x54x46	WFI	86.5	86.5	84.0
1x	21x15x22	ICU	13.0	13.0	40.0
6x	⌀42x60	MM	112.3	673.8	180.0
		Structure	35.3		
		Shells	73.0		
		Adapter	4.0		
				Mass [kg]	Power [W]
PAYLOAD TOTAL				845.2	419.0



PLANNED MANAGEMENT STRUCTURE

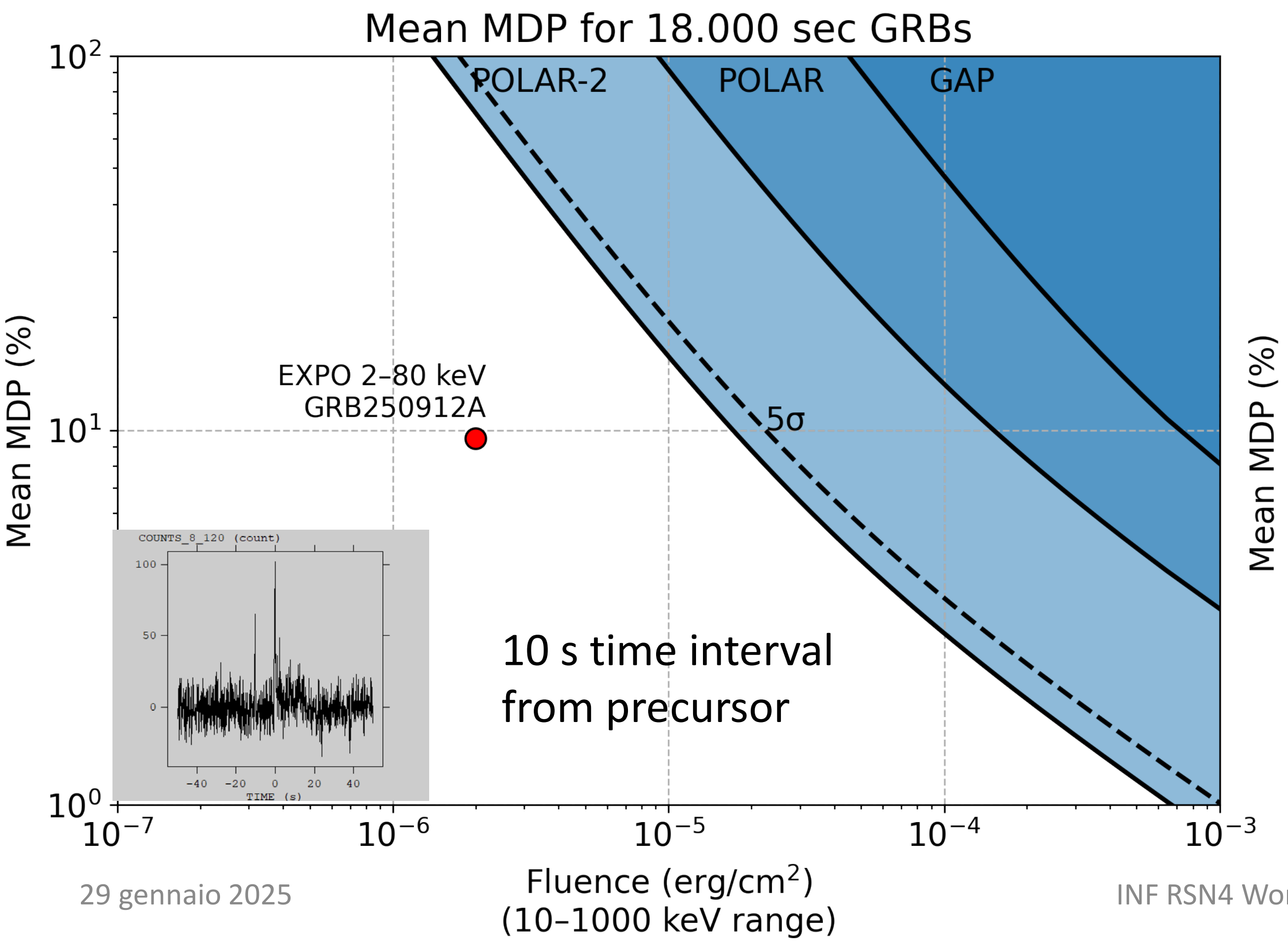
The **payload management** is coordinated by INAF-IAPS to ensure technical, managerial, and scientific coordination among all participating partners, while maintaining an efficient interface with ESA and the other segments of the mission (e.g., spacecraft, ground segment). Paolo Soffitta will serve as Lead Scientist. The Payload Management also includes five PI (and co-PIs), responsible for the primary components of the payload.

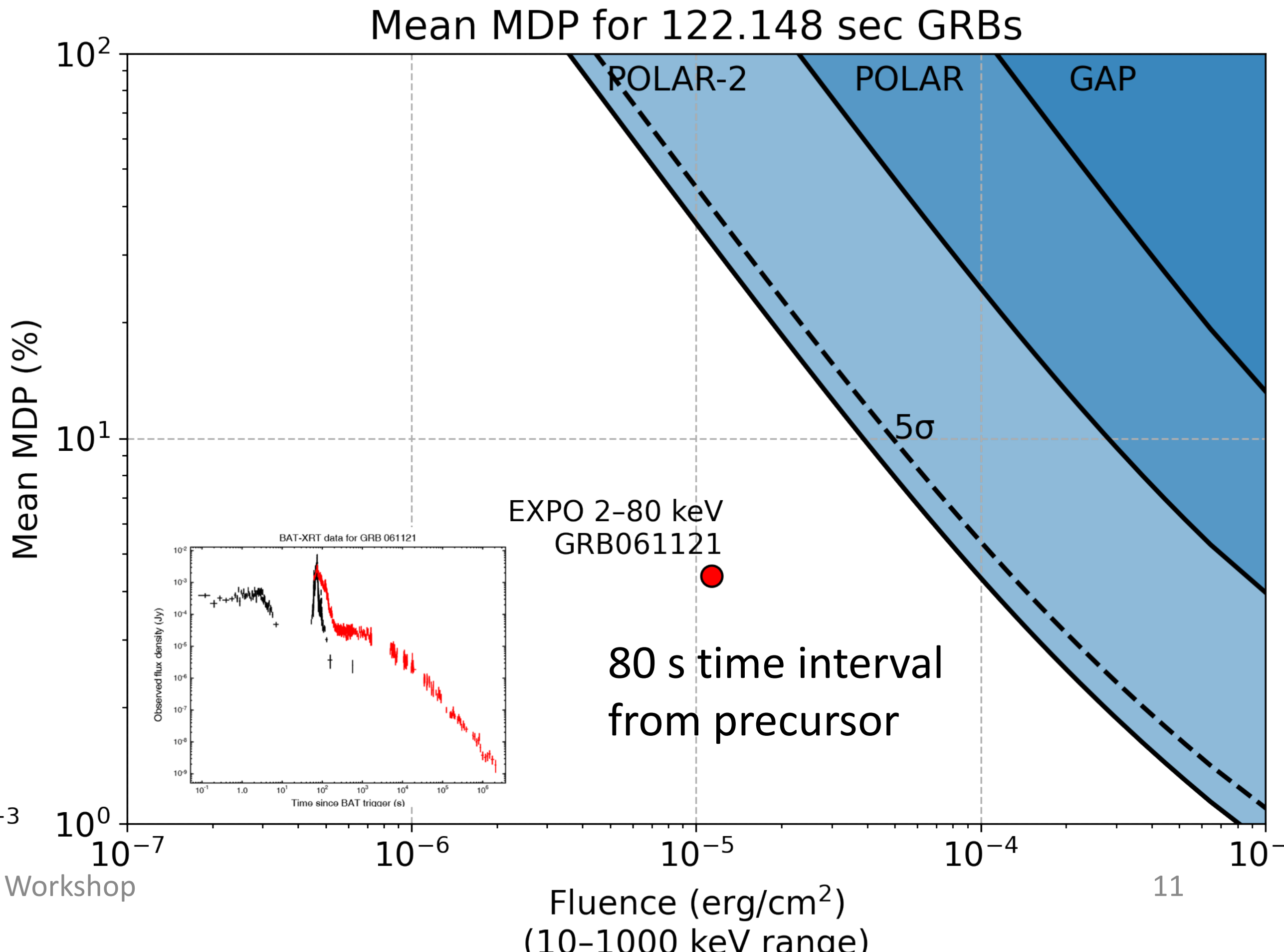
- **Polarimeters**; Led by INAF: PI Fabio Muleri, Co-PI Mark Pearce ((KTH) also lead of the HEP
- **Optics**; Led by ESA (Co-PI Daniele Spiga).
- **Soft X-ray Imager (SIC)**; Developed by the University of Leicester (PI Ian Hutchinson), and by the University of Tübingen (Co-PI Andrea Santangelo).

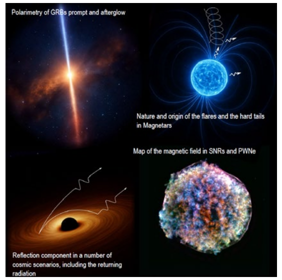


GRB PROMPT EMISSION SENSITIVITY
TRIGGER FROM A PRECURSOR

In these plots EXPO is expected to trigger on a precursor of a GRB for both bursts, then slew (Swift-like), and finally pointing the main event.

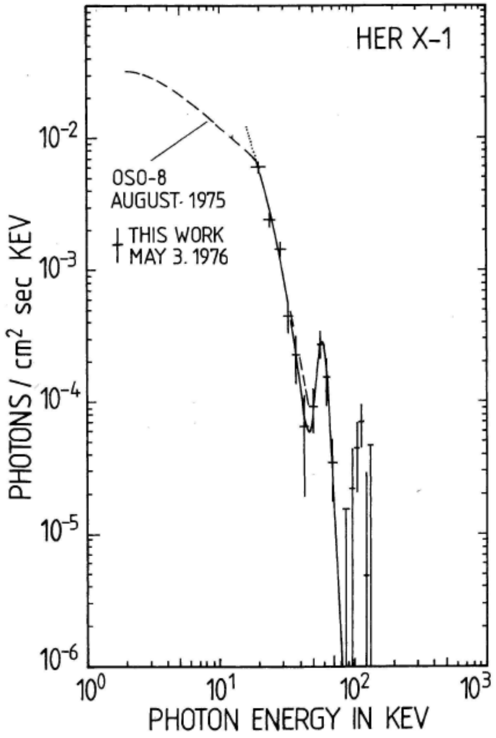


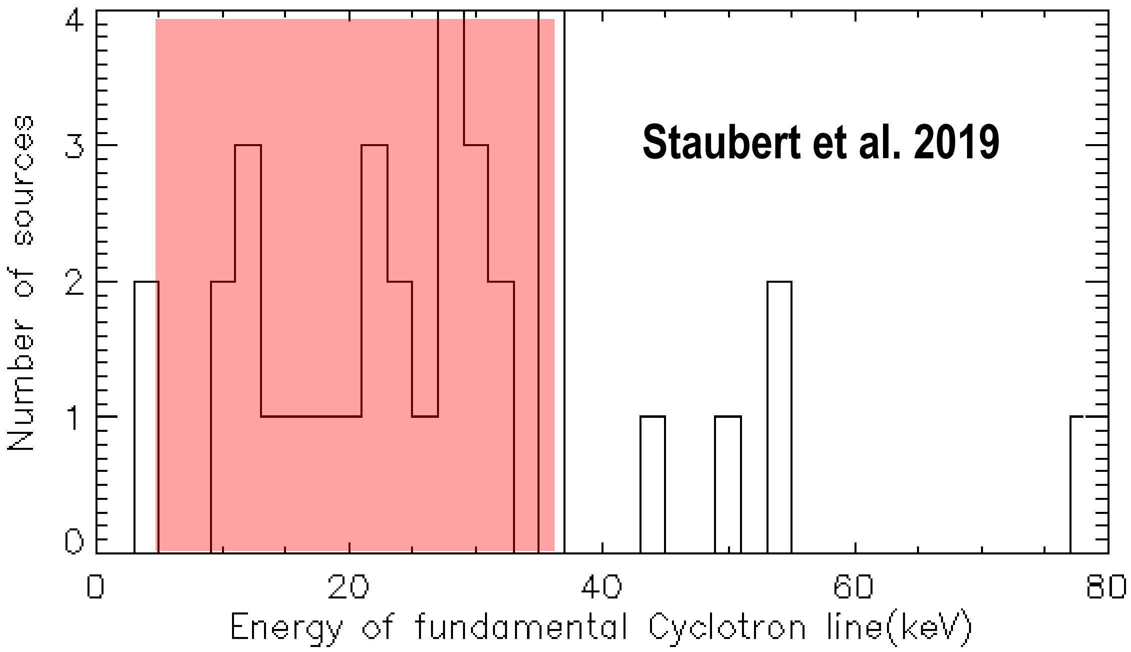




BINARY PULSARS AND CYCLOTRON LINES

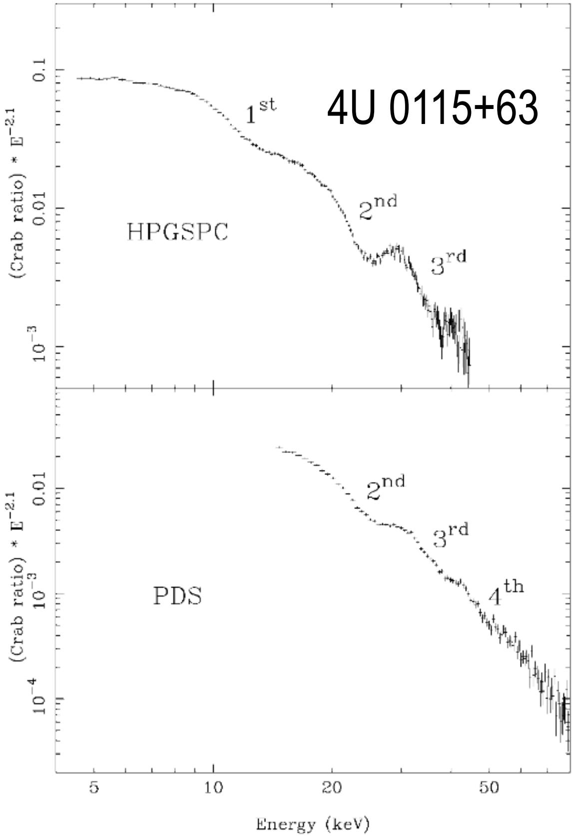
Truemper et al., 1978



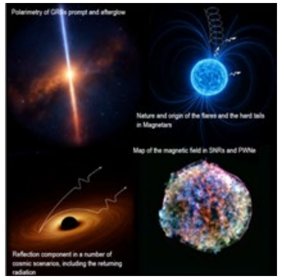


MEP

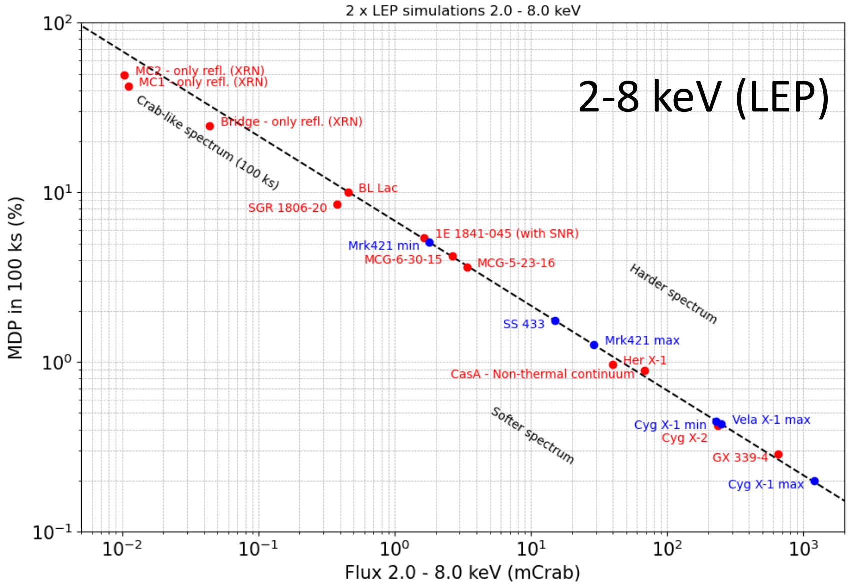
HEP

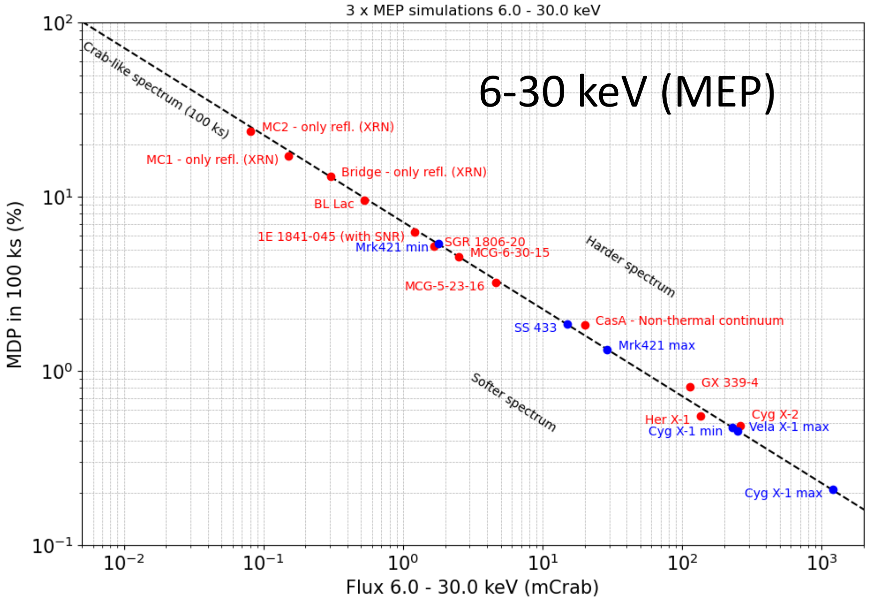


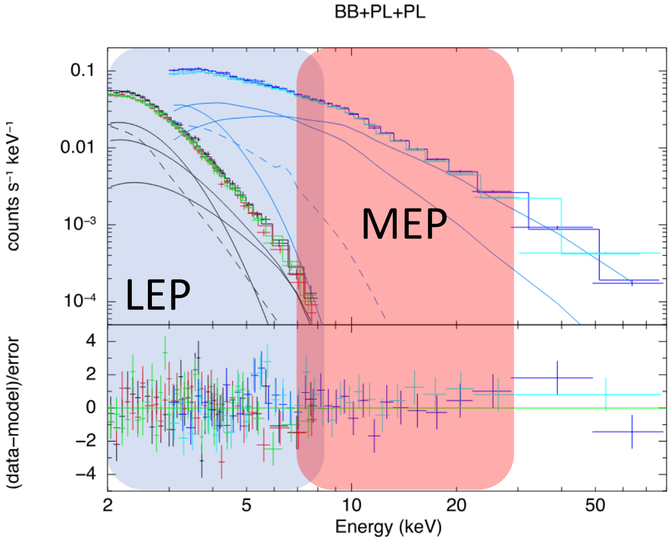
Fundamental cyclotron lines can be probed by photoelectric hard X-ray imaging polarimetry. Covering the higher order armonics and all the fundamental requires Compton polarmeters.



THE EXPO SENSITIVITY







1E 1841-45
(100 ks, Magnetar)

LEP MDP = 5 %

MEP MDP = 6%

Prize dedicated to X-ray polarimetry

High Energy Astrophysics Division

2024 Martin Weisskopf, Paolo Soffitta, and the IXPE team — **Bruno Rossi Prize**

The 2024 Bruno Rossi Prize has been awarded to Dr. Martin Weisskopf, Dr. Paolo Soffitta, and the IXPE team for their development of the Imaging X-ray Polarimetry Explorer whose novel measurements advance our understanding of particle acceleration and emission from astrophysical shocks, black holes and neutron stars. Please see the press release for more information.

The 2026 Prize Winner: Henric Krawczynski — **Bruno Rossi Prize**

The 2026 Bruno Rossi Prize has been awarded to Henric Krawczynski for pioneering contributions to the theory, instrumentation, and scientific interpretation of X-ray polarimetry, including the first hard X-ray polarization measurements with XL-Calibur and enabling landmark IXPE discoveries; both of which have revolutionized our understanding of black hole accretion and relativistic outflows. Please read the associated press release here.

Premio Internazionale Feltrinelli (2025) Accademia Nazionale dei Lincei

Martin Weisskopf, Enrico Costa e Ronaldo Bellazzini – Astronomia. Per il loro straordinario contributo alla realizzazione di IXPE

Ernst Mach medal of the Czech Academy of Science (2025)

Enrico Costa – Astronomy for pioneering X-ray Polarimetry