IXPE
Imaging
X-Ray
Polarimetry
Explorer

The Imaging X-ray Polarimetry Explorer

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On behalf of the IXPE team

Breaking the limits 2018 – Castiadas (CA), Italy, October 1-5, 2018

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IXPE IN A NUTSHELL

- **First mission since ‘70 to be sensitive to (linear) X-ray polarization**
- **Polarization gives a unique insight in fundamental parameters of the sources, especially in X-rays**
- **Sensitivity will allow to observe tens of sources belonging to almost all astrophysical classes of sources:**
  - Galactic black holes, neutron stars, active galactic nuclei, …
  - Access to unique information on source «geometry» and emission mechanism

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IXPE'S TIMELINE

- **(Re)-Proposed to NASA as a SMall EXplorer (SMEX) mission in December 2014**
  - Bilateral collaboration between NASA and ASI
- **Selected for an Assessment study in August 2015, in competition with two other missions (another one dedicated to X-ray polarimetry)**
- **Selected for launch in January 2017**
- **Launch data: April 2021**
- **Baseline duration: 2 years**

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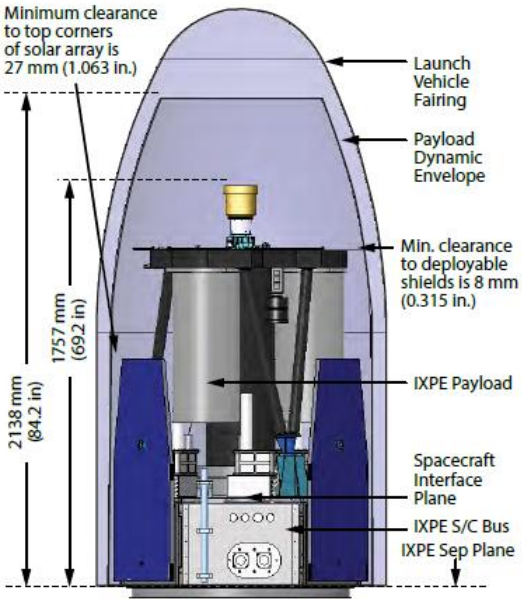
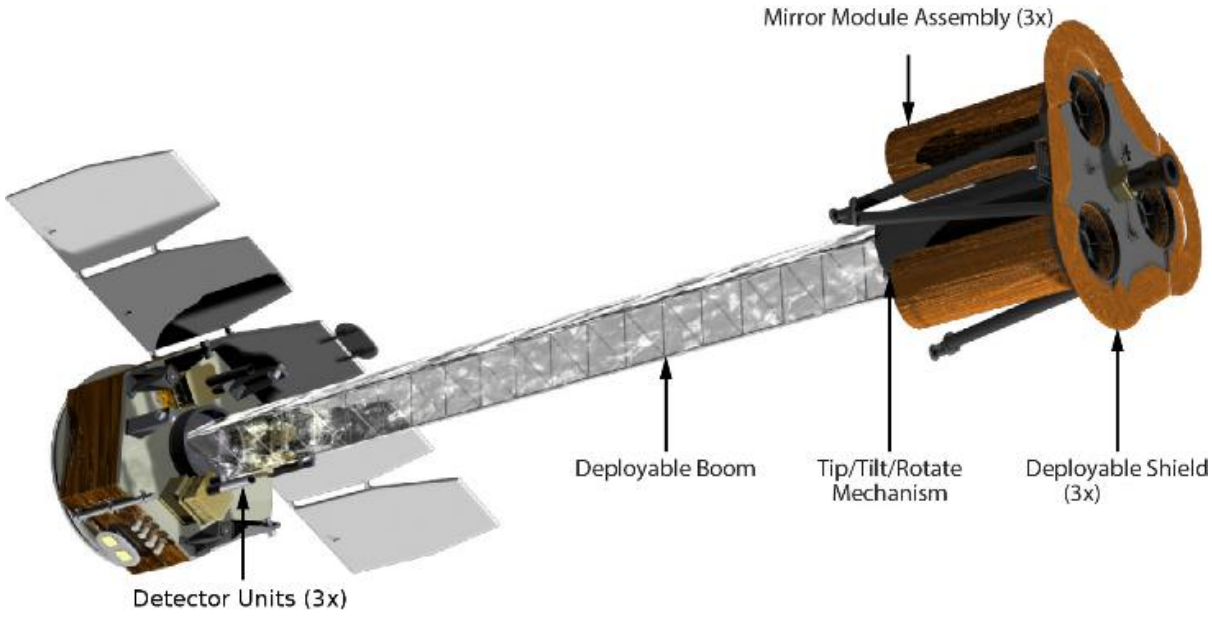
IXPE PAYLOAD

- 3x Mirror Units (MUs) + 3x Detector Units (DUs)
- 4 m focal length, deployable boom and X-ray shield





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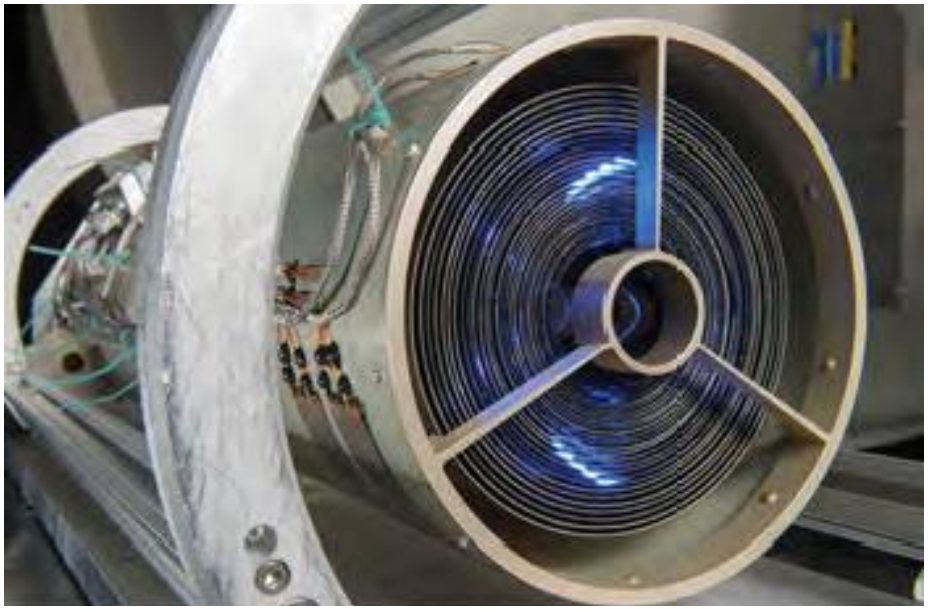
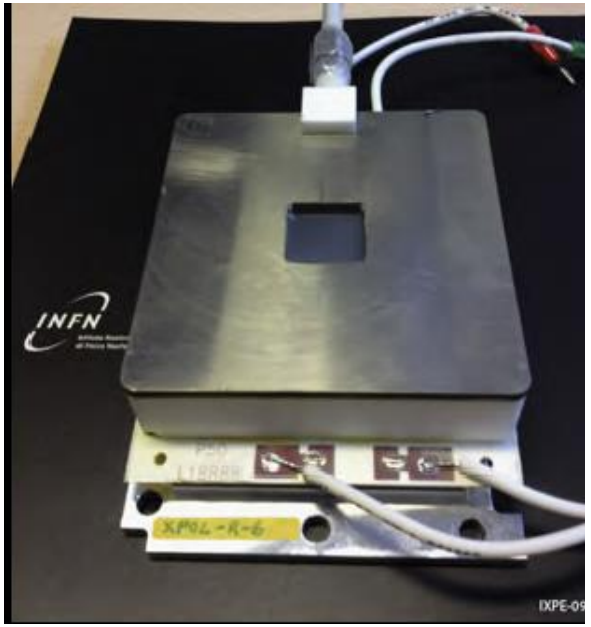
IXPE TECHNOLOGY

- **Mirror based on grazing incidence reflection**
  - Total collecting area: >700 cm^2 at 3 keV
  - Nickel-cobalt alloy shells, 24 shells/module
- **Photoelectric polarimeter based on GPD design**





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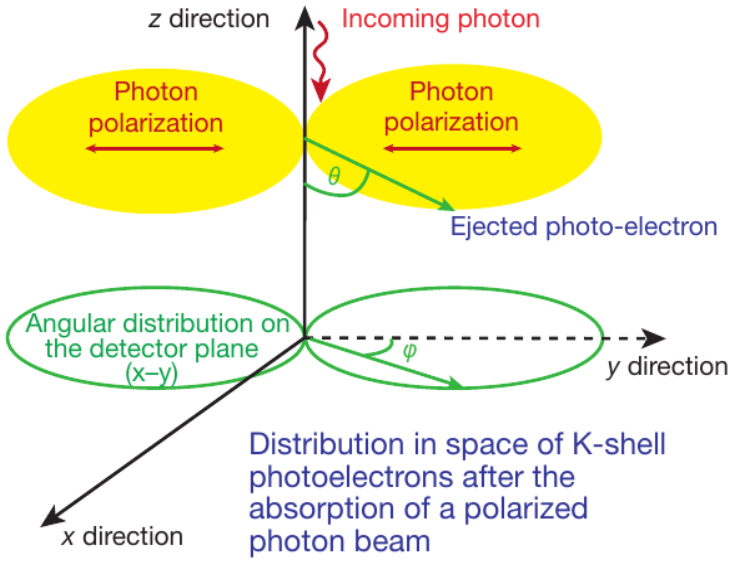
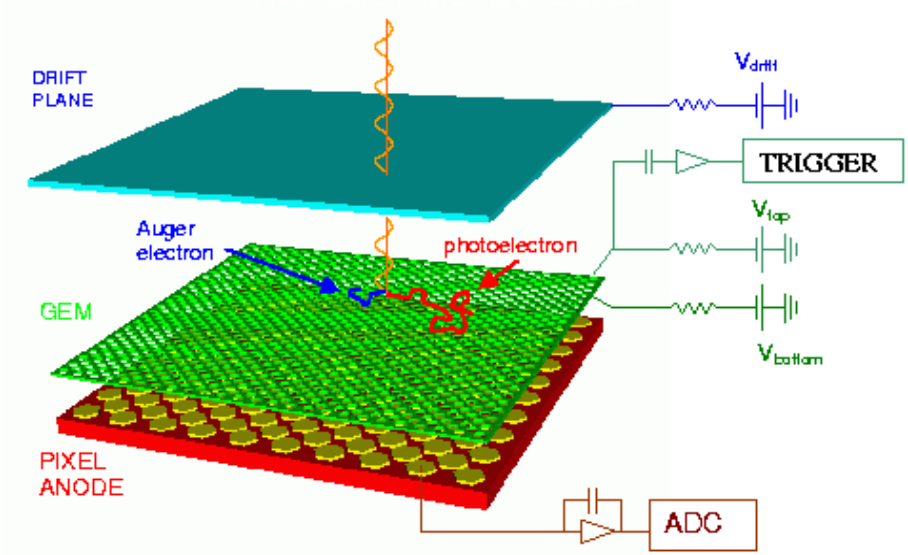
GPD: THE BREAKTHROUGH

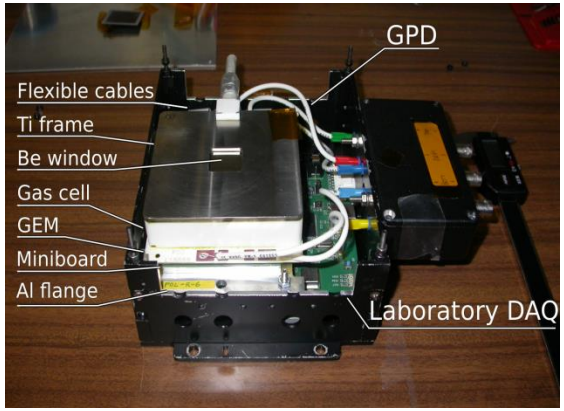
The photoelectric effect

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





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



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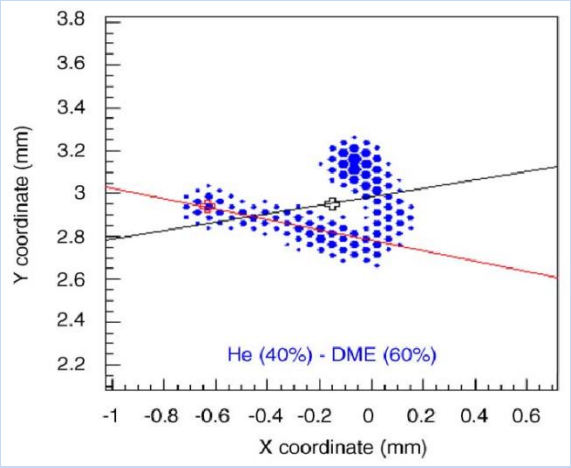
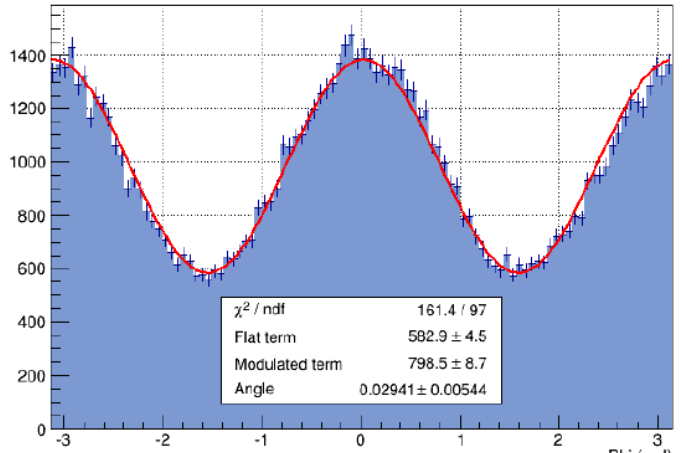
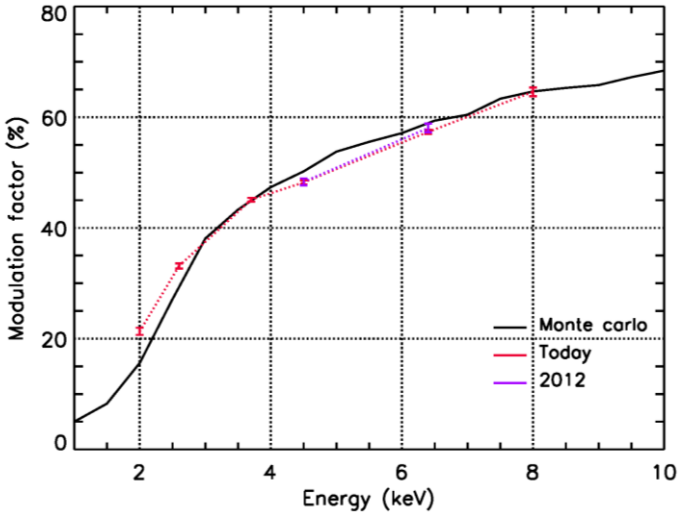
GPD RESPONSE: POLARIZATION

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



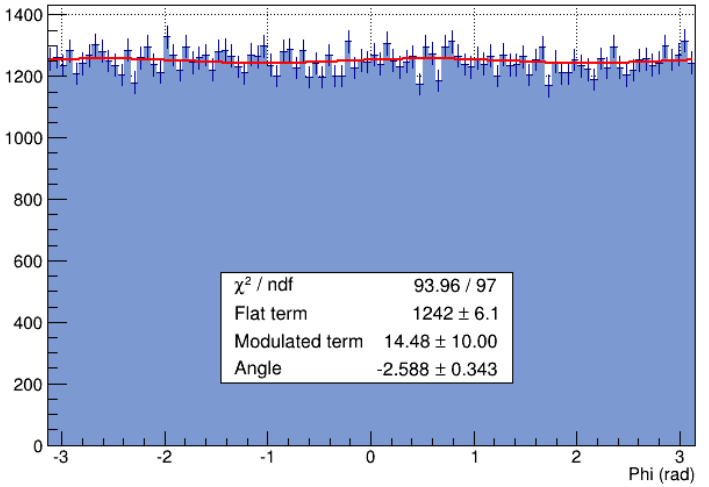


Real modulation curve derived from the measurement of the emission direction of the photoelectron.



Muleri et al. 2008,2010

Modulation factor as a function of energy.



Bellazzini et al. 2012

Residual modulation for unpolarized photons.

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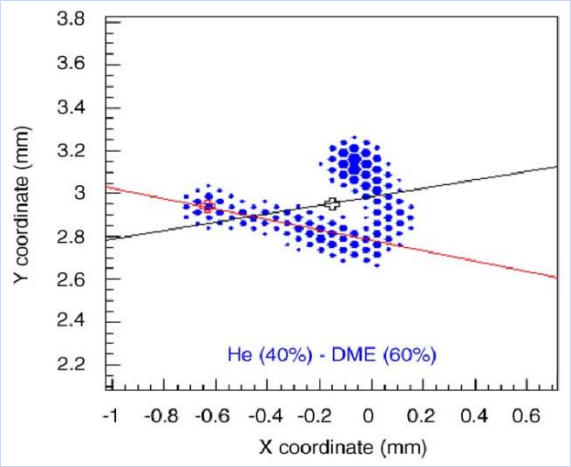
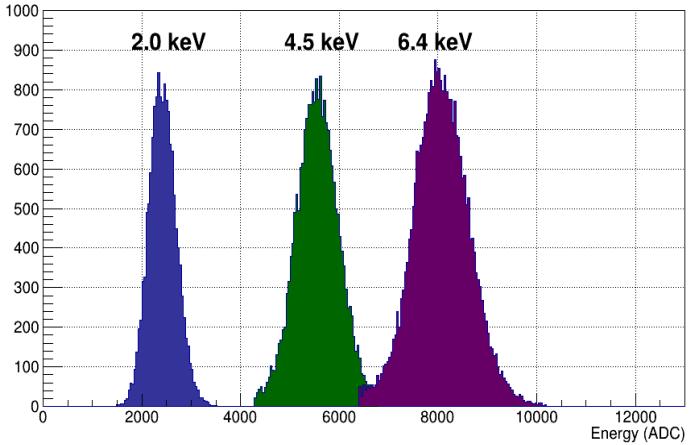
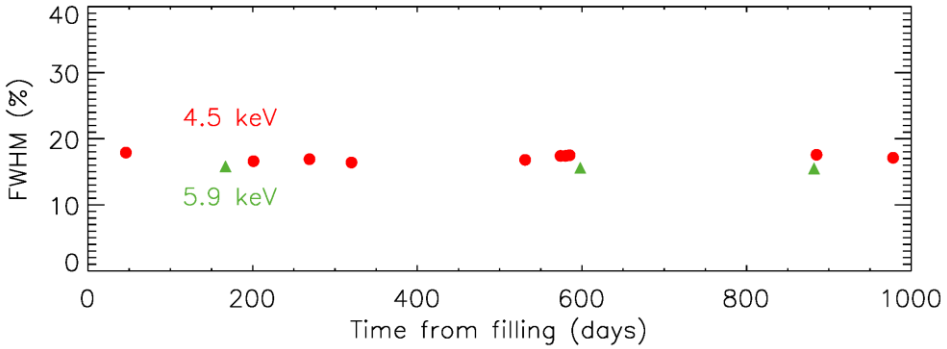
GPD RESPONSE: ENERGY

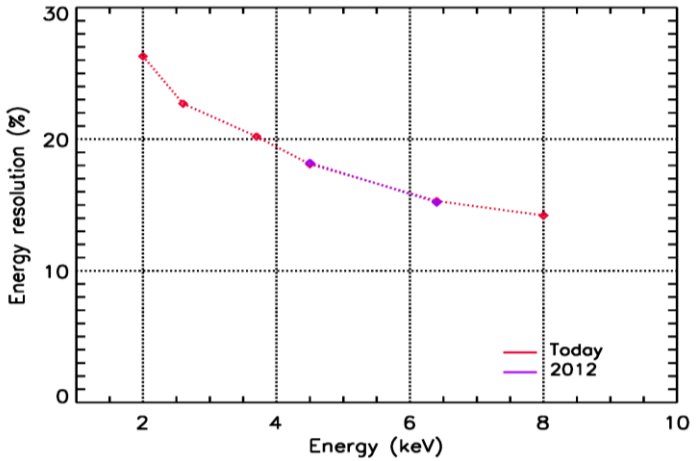
Image of a real photoelectron track. The use of the gas allows to resolve tracks in the X-ray energy band.







Stable operation over 3 years



Adequate spectrometer for continuum emission (16 % at 6 keV, Muleri et al. 2010

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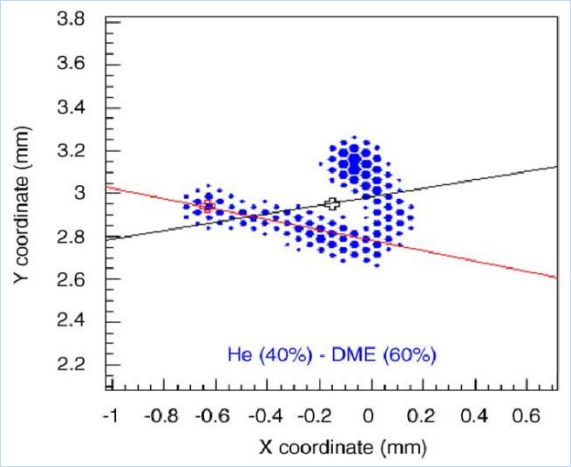
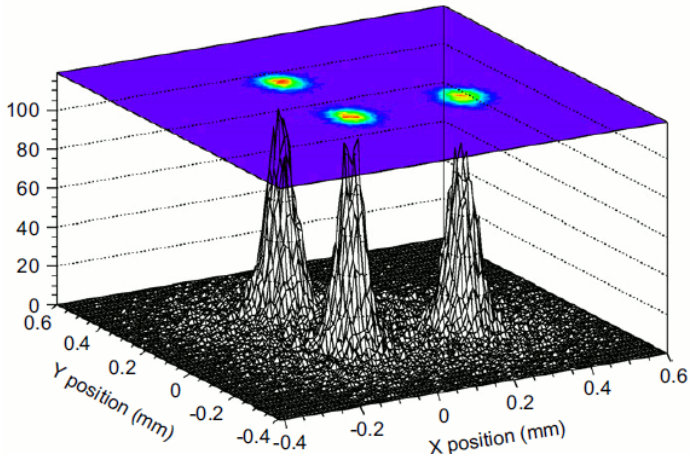
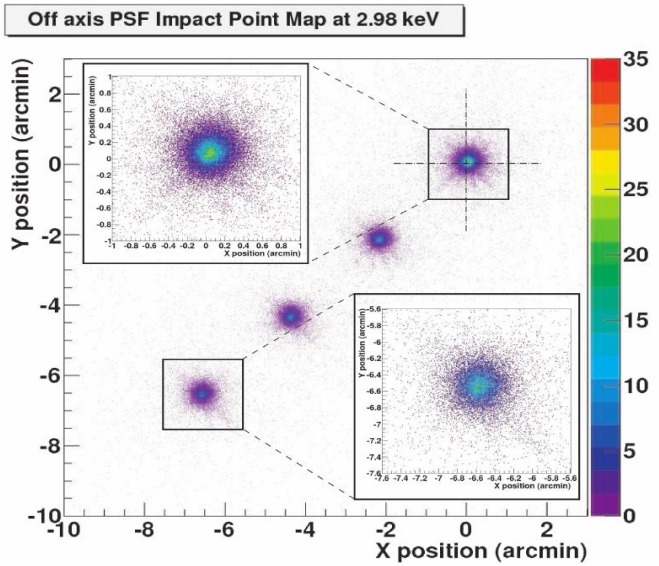
GPD RESPONSE: ABSORPTION POINT

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







- 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)

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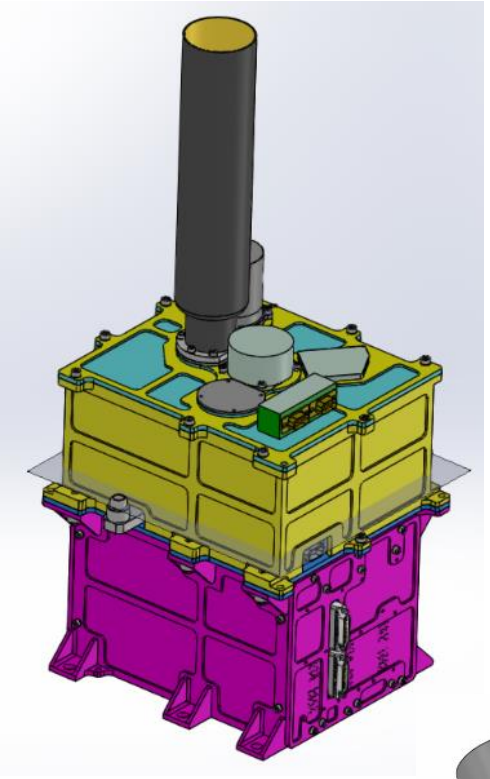
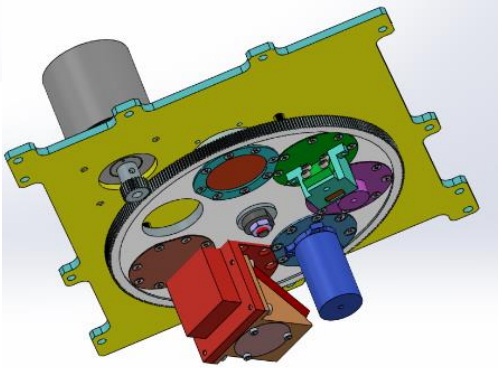
IXPE Instrument

- **The GPD is hosted in the Detector Unit**
  - Together with HV & interface
- **Each DU includes a Filter & Calibration Wheel (FCW)**
  - Filters, for specific observations
    - Open position (normal obs. mode)
    - Closed position (background)
    - Gray filter (very bright sources, >2 Crab)
  - Calibration source
    - Polarized (based on Bragg diffraction)
      - 2.6 keV + 5.9 keV
      - Polarization ≈90% or higher
      - Monitoring of modulation factor and gain
    - Unpolarized, collimated
      - ^{55}Fe @ 5.9 keV
      - monitoring of systematic effects
    - Unpolarized, not collimated
      - ^{55}Fe, for gain mapping
    - Not collimated #2
      - ^{55}Fe extracting Cl fluorescence, for gain mapping
- **The 3xDUs are interfaced with the spacecraft trough the DSU**





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IXPE SCIENTIFIC REQUIREMENTS

Scientific Measurement Requirements		Scientific Requirements		Projected Performance
Physical parameters	**Observables**	**Property**	**Value**	
Linear polarization	Degree Π, angle ψ	Sensitivity MDP_{99} ($F_{2\text{-}8} = 10^{-11}$ cgs, Δt = 10 d)	≤ 5.0%	4.4%
		Systematic error in polarization degree Π	≤ 0.3%	0.2%
		Systematic error in position angle ψ	≤ 1°	0.2°
X-ray flux	F	Absolute calibration error in F	≤ 20%	< 10%
Energy dependence	$F(E)$, $\Pi(E)$, $\psi(E)$	Energy band E_{min}–E_{max}	2–8 keV	1.5–9 keV
		Energy resolution ΔE (E = 2 keV), $\propto\sqrt{E}$	≤ 0.7 keV	0.54 keV
Spatial dependence	$F(k)$, $\Pi(k)$, $\psi(k)$	Angular resolution HPD (system-level)	≤ 30″	28″
		Field of view FOV >> HPD	≥ 8′ ∅	12.8′ × 12.8′
		Onboard pointing accuracy << FOV	≤ 1′	< 0.5′
Time dependence	$F(t)$, $\Pi(t)$, $\psi(t)$	Time accuracy << source pulse periods	≤ 0.25 ms	< 0.1 ms
Areal background rate	R_B/A_{det}	$R_B/A_{det} << R_S/A_S$ for low-intensity source	< 0.04 $s^{-1}cm^{-2}$	< 0.01 $s^{-1}cm^{-2}$

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OBSERVATION STRATEGY

- **Long staring observations of pre-definite targets**
  - Duration from <day to week(s)
  - Tens of sources observed in the first year
- **Data are made public after validation**
- **Targets of Opportunity possible in a few days**
- **Tools for analysis defined by SOC and distributed by HEASARC**

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WHO'S WHO

- **NASA (MSFC)**
  - PI, Project Management, System Engineering
  - Mirror Unit design and fabrication
  - Science Operation Center (SOC) (inc. data analysis)
  - Telescope calibration
- **NASA (HEASARC)**
  - Since Data Analysis distribution and Archiving
- **Laboratory for Astronomy & Space Physics (Boulder)**
  - Mission Operations
- **Stanford University & University Roma Tre –Theory**
- **McGill University/MIT – Co-Chair SWG & Co-Is**
- **Ball aerospace**
  - Spacecraft, AIV&AIT

- **Italian responsibilities (ASI, INAF, INFN)**
  - Italian-PI, Instrument management
    - Detector Unit, including calibration
    - Detectors Service Unit
  - Track reconstruction algorithm
  - Malindi Ground Station
  - **Contributions** to Science activities, pipeline, payload calibration & operation, …

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IXPE TEAM

Principal Investigator: **M. C. Weisskopf**

Co-Investigators: Brian D. Ramsey, Paolo Soffitta, Ronaldo Bellazzini, Enrico Costa, Stephen L. O'Dell, Allyn Tennant, Herman Marshall, Fabio Muleri, Jeffery Kolodziejczak, Roger W. Romani, Giorgio Matt, Victoria Kaspi, Ronald Elsner, Luca Baldini, Luca Latronico

Science collaborators: 66 members from 11 countries

Technical collaborators: >100 members from 3 countries (USA, Italy & Japan)

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SCIENCE OBJECTIVES

- **IXPE will increase sensitivity of X-ray polarimeter on-board OSO-8 by 2 orders of magnitude**

  + adding imaging capabilities
- **IXPE will observe a number of different classes of sources**
  - Neutron stars, stellar-mass black holes, X-ray binaries, …
- **For bright extended sources, IXPE will perform imaging polarimetry**
  - Pulsar Wind Nebulae (PWNe), Supernova Remnants (SNR), and large-scale jets in Active Galactic Nuclei (AGN) …

Mock observing plan:

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

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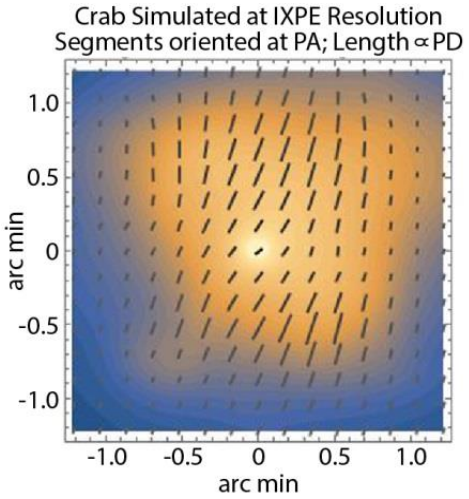
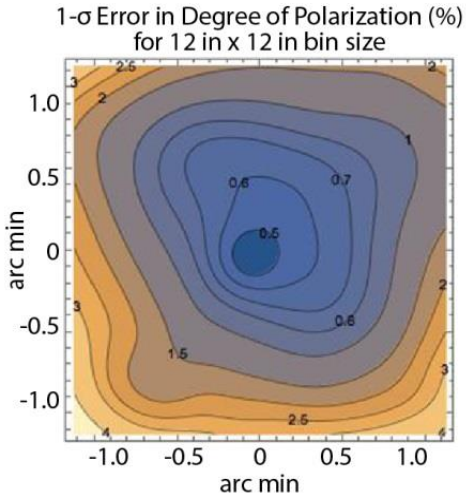
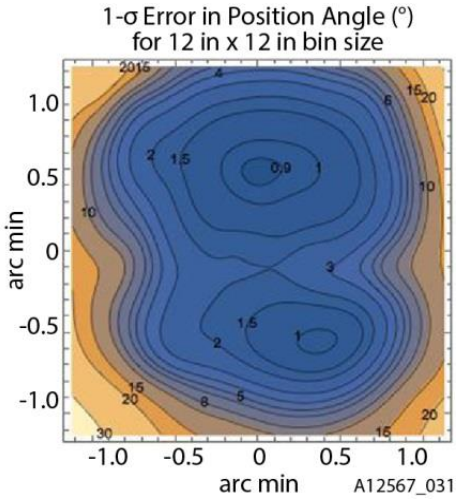
AN UNPRECEDENTED VIEW OF THE CRAB NEBULA & PULSAR

- **Map of the magnetic field in the nebula with unprecedented details**

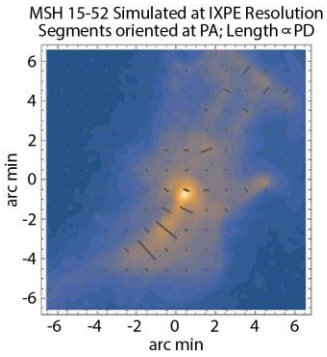


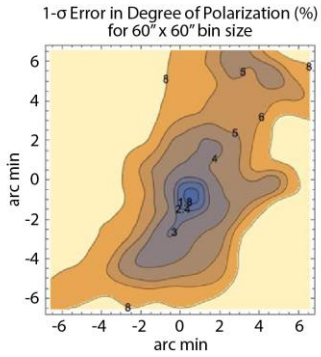


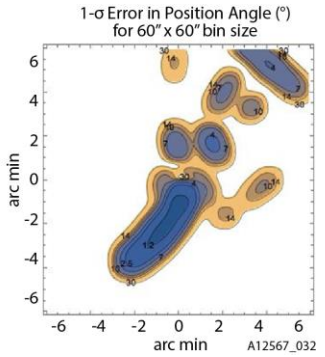


Other sources accessible e.g.,

- MSH 15-52 and pulsar B1598-58
- Vela PWN/PSR
- …







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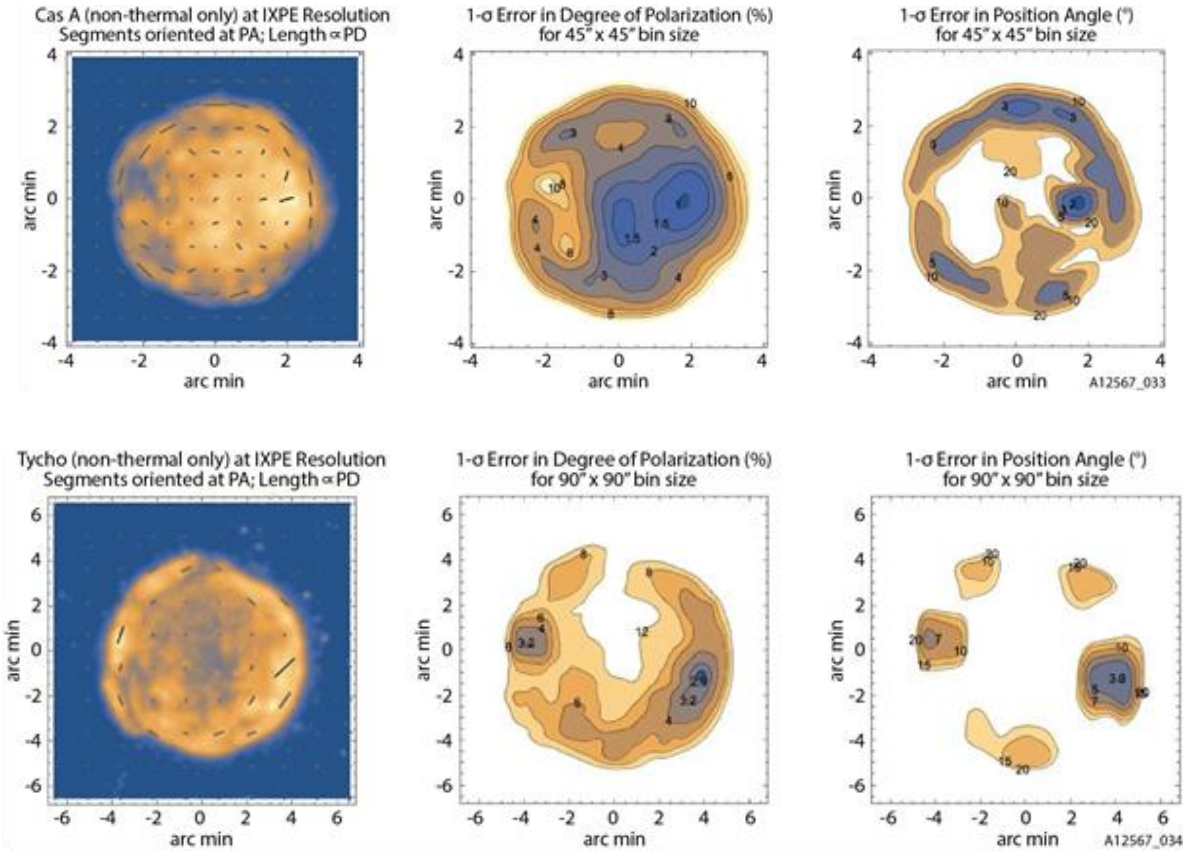
CAS A AND TYCHO OBSERVATION

- Spectral imaging allows to identify regions where particles are accelerated
- Other sources accessible



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ACCELERATION MECHANISMS IN JETS

Inverse Compton dominated Blazars
The origin of the seed photons:

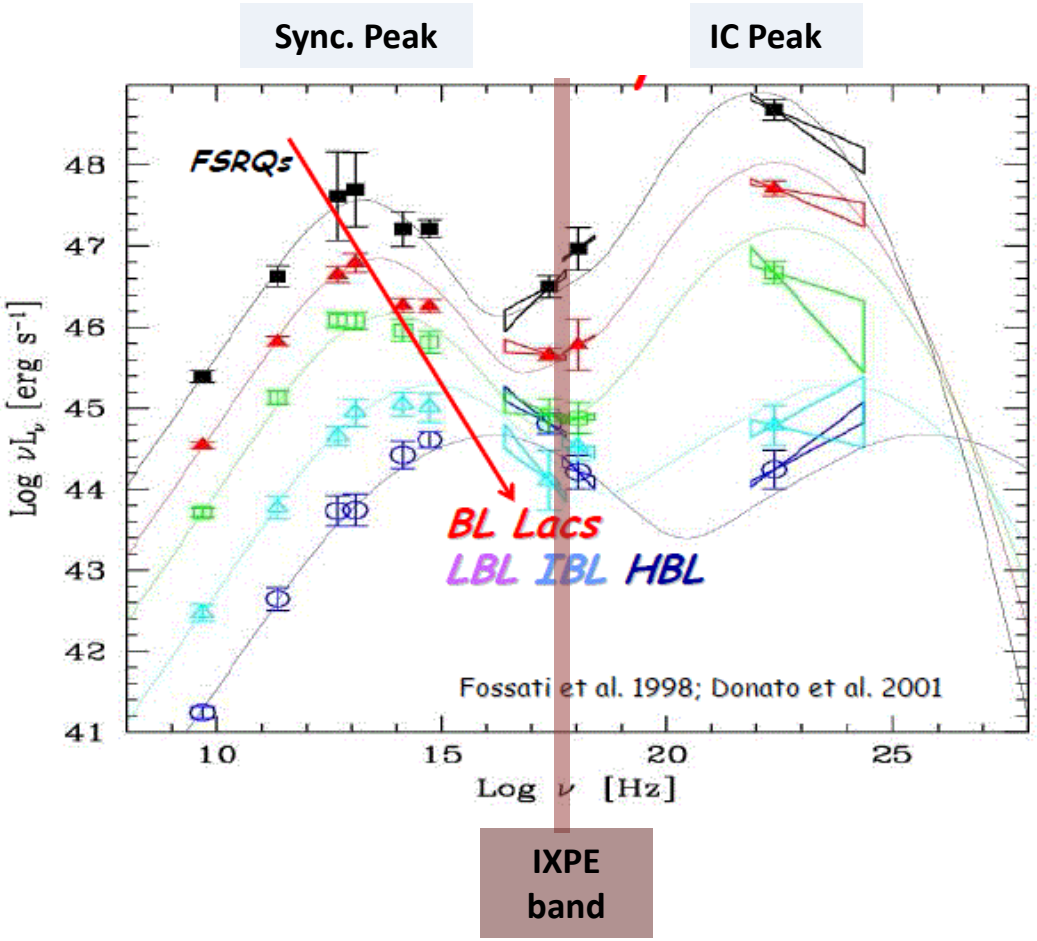
- Synchrotron-Self Compton (**SSC**) ?

The polarization angle is the same as for the synchrotron peak.

- External Compton (**EC**) ?

The polarization angle may be different.
The polarization degree determines the electron temperature in the jet.

Synchrotron-dominated X-ray Blazars
multi-wavelength polarimetry probes the structure of the magnetic field along the jet.



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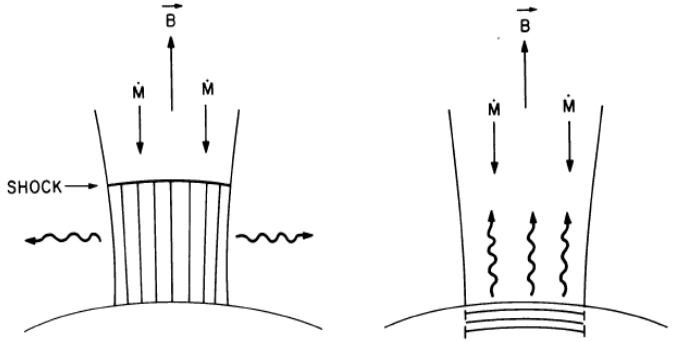
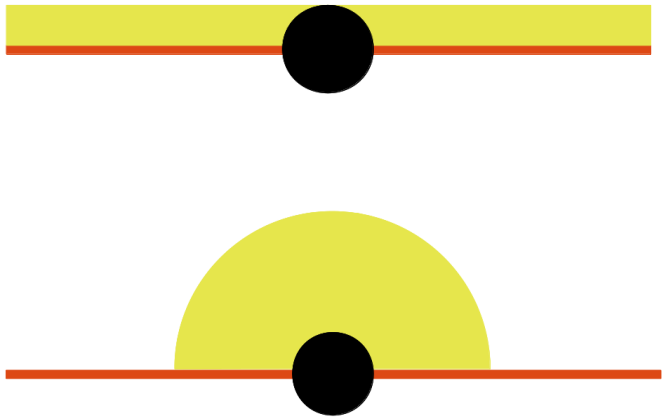
SCATTERING GEOMETRIES

- **IXPE will observe several galactic accreting sources (both with neutron stars and black holes)**
- **Polarization sensitive to inclination of the system and scattering geometry**
  - E.g. scattering on accreting column
- **Models to be updated to the state of the art:**
  - Meszaros et al. 1988: linear polarization up to 80% close to resonance lines, different signature for pencil/fan beam
  - Sazonov & Sunyaev 2001: scattering on the inner part of accretion disk
  - Viironen & Poutanen 2004: scattering on accretion column, >10%
  - Matt & Tamborra 2017: Polarization signature of corona geometry





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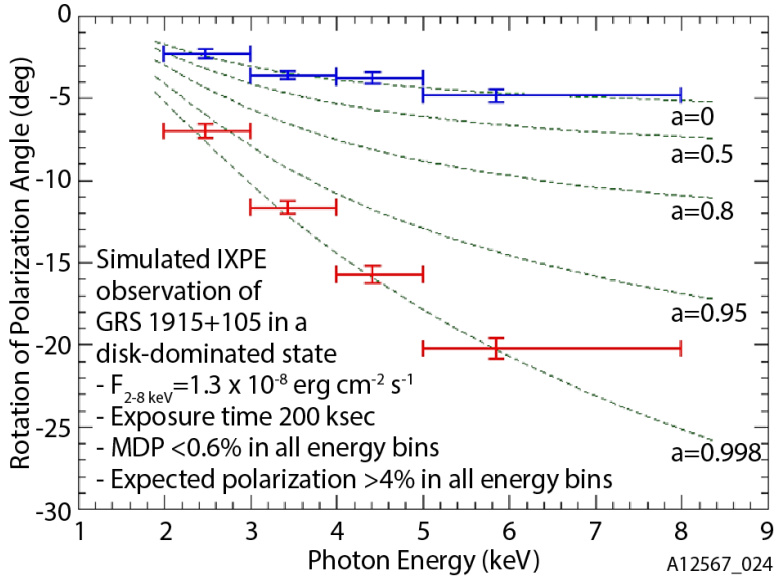
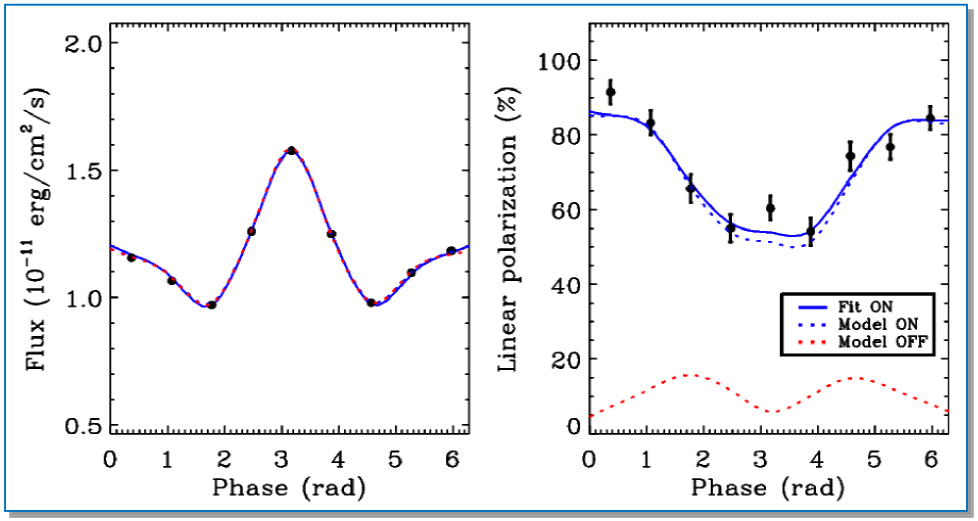
FUNDAMENTAL PHYSICS WITH IXPE

Provide an estimate of galactic BH spin through the rotation of the plane of polarization with energy



Detect peculiar signatures of QED effects in magnetar emission



CONCLUSIONS

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Photons to Data Products