Marshall Space Flight Center

IXPE
Imaging X-Ray Polarimetry Explorer

agenzia spaziale italiana

The Imaging X-ray Polarimetry Explorer (IXPE): Overview

Steve O'Dell (NASA Marshall Space Flight Center)
on behalf of the IXPE Team

INTERNATIONAL PARTNERSHIP

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

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Detector system funding, ground station

Ball
Spacecraft, payload structure, payload, observatory I&T

iaps · INAF Istituto Nazionale di Astrofisica – National Institute for Astrophysics · INFN
Polarization-sensitive imaging detector systems

CU · LASP
Mission operations

Roma Tre Università degli Studi · Stanford University
Scientific theory

McGill
Science Working Group Co-Chair

MIT Massachusetts Institute of Technology
Co-Investigator

A12567_151

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Explorer

SCIENCE TEAM

- **Co-Investigators**
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- **Collaborators**
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Mission summary (1/2)

- **Mission background**
  - Imaging x-ray polarimetry in 2–8 keV band
  - NASA Astrophysics Small Explorer (SMEX) selected in 2017 January
- **Orbit**
  - Pegasus-XL (airborne) launch in 2021, from Kwajalein
  - Equatorial circular orbit at $\gtrsim$ 540 km (620 km, goal) altitude
- **Flight system**
  - Spacecraft, payload structure, and integration by Ball Aerospace
    - Deployable payload boom from Orbital-ATK, under contract to Ball
  - X-ray Mirror Module Assemblies by NASA/MSFC
  - X-ray (polarization-sensitive) Instruments by IAPS/INAF and INFN

MISSION SUMMARY (2/2)

- **Ground system**
  - ASI Malindi ground station, with Singapore backup
  - Mission Operations Center at LASP (University of Colorado)
  - Science Operations Center at NASA/MSFC
  - Data archive at HEASARC (NASA/GSFC), mirror at ASI Data Center
- **Science**
  - Active galactic nuclei
  - Microquasars
  - Radio pulsars and pulsar wind nebulae
  - Supernova remnants
  - Magnetars
  - Accreting x-ray pulsars

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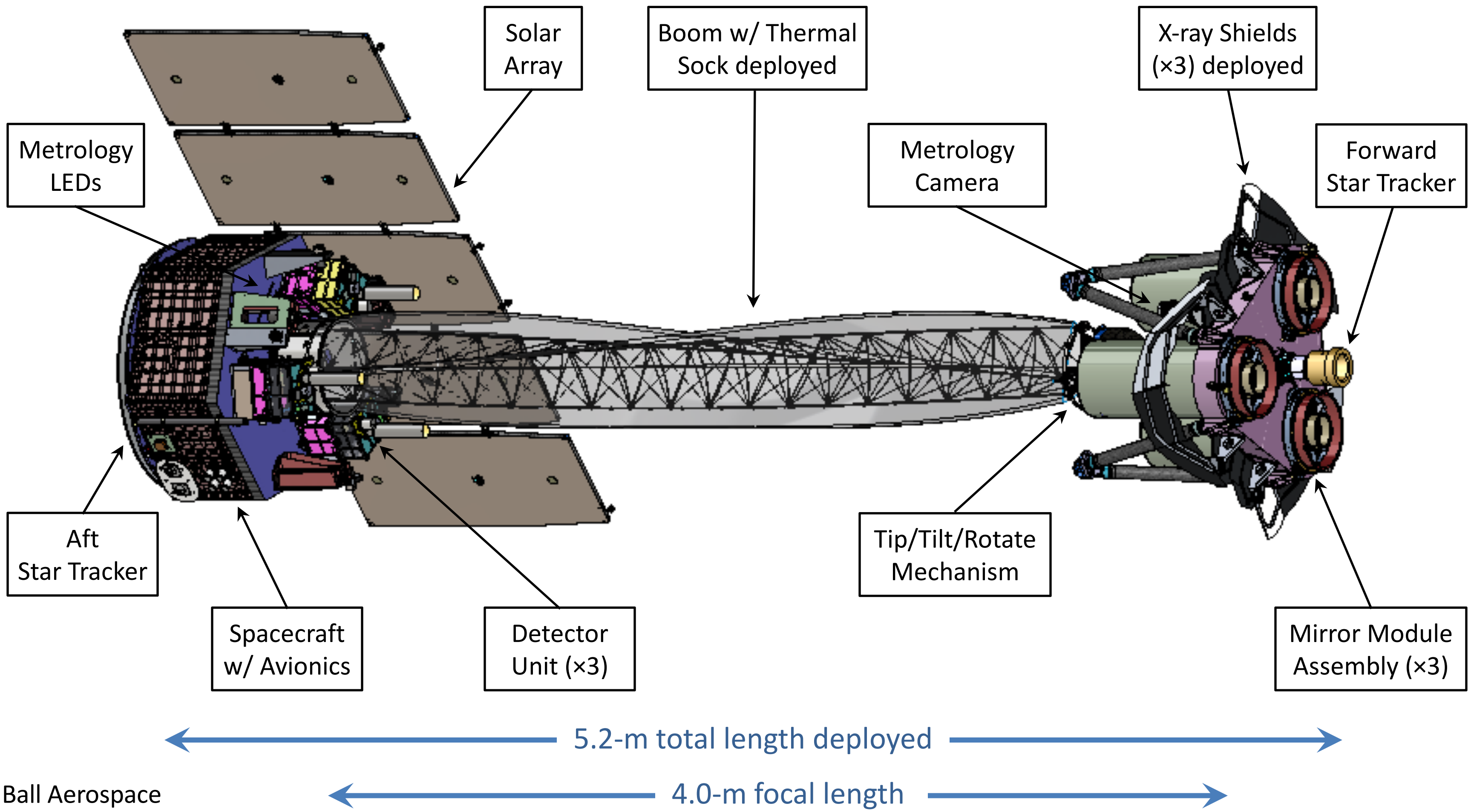
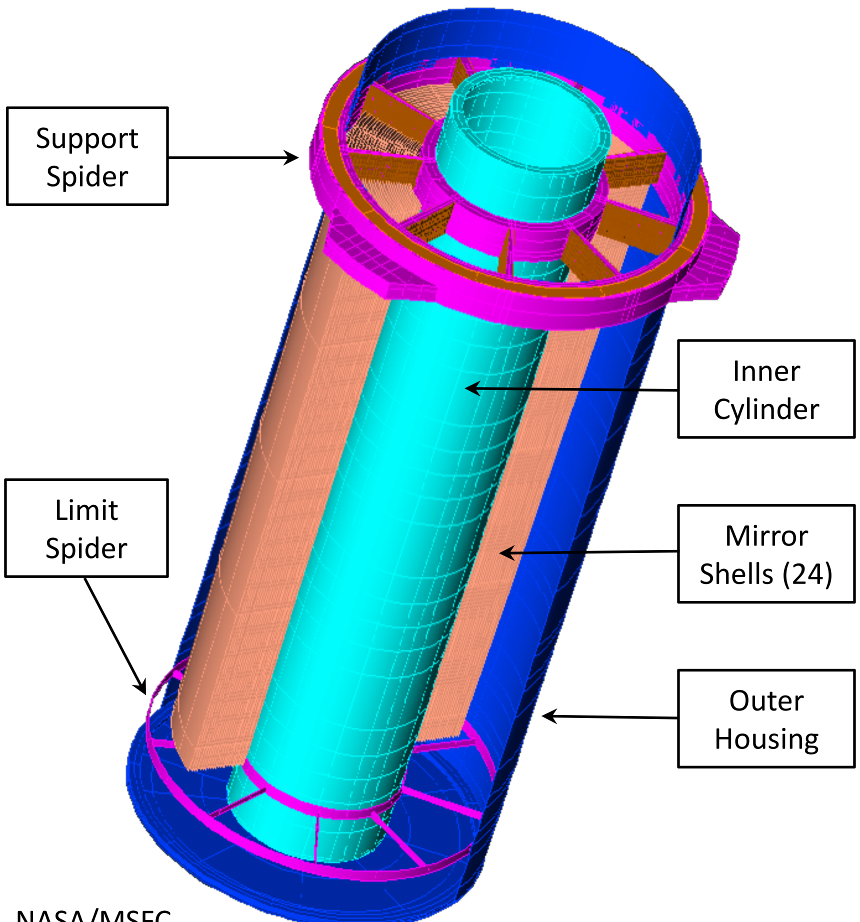
Major components of the Observatory



Ball Aerospace

Mirror Module Assembly (MMA)



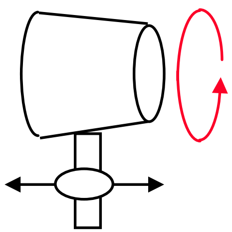
NASA/MSFC

Property	Value
Number of MMAs	3
Mirror shells per MMA	24
Focal length	4000 mm
Shell length (P+S combined)	600 mm
Inner–outer shell diameter	162–272 mm
Inner–outer shell thickness	0.18–0.26 mm
Shell material	Nickel-Cobalt alloy
Mass per MMA	30 kg (current best estimate)
Effective area per MMA	210 cm^2 (2.3 keV) > 230 cm^2 (3–6 keV)
Angular resolution	≤ 25 arcsec HPD
Field of view (detector-limited)	12.9 arcmin

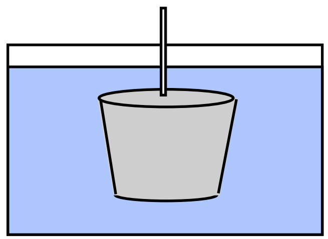
MIRROR PRODUCTION PROCESS

Mandrel fabrication

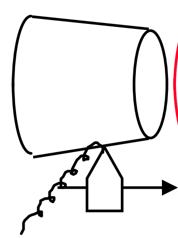
1. Machine mandrel from aluminum bar



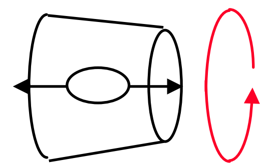
2. Coat mandrel with electroless nickel (Ni-P)



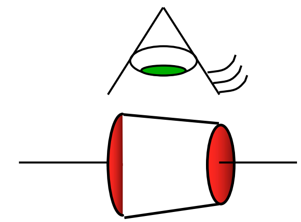
3. Diamond turn mandrel to sub-micron figure accuracy



4. Polish mandrel to 0.3-0.4 nm RMS

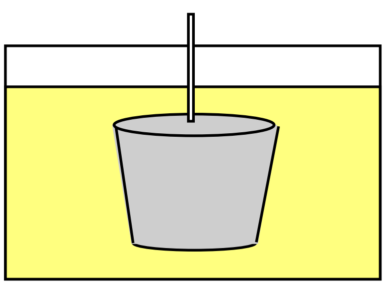


5. Conduct metrology on the mandrel

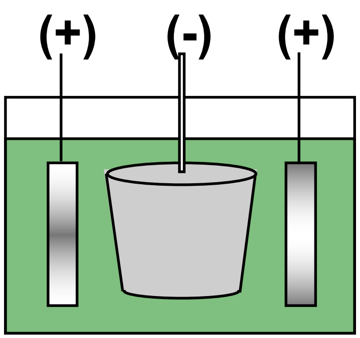


Mirror-shell forming

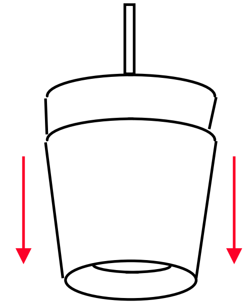
6. Passivate mandrel surface to reduce shell adhesion



7. Electroform Nickel/Cobalt shell onto mandrel

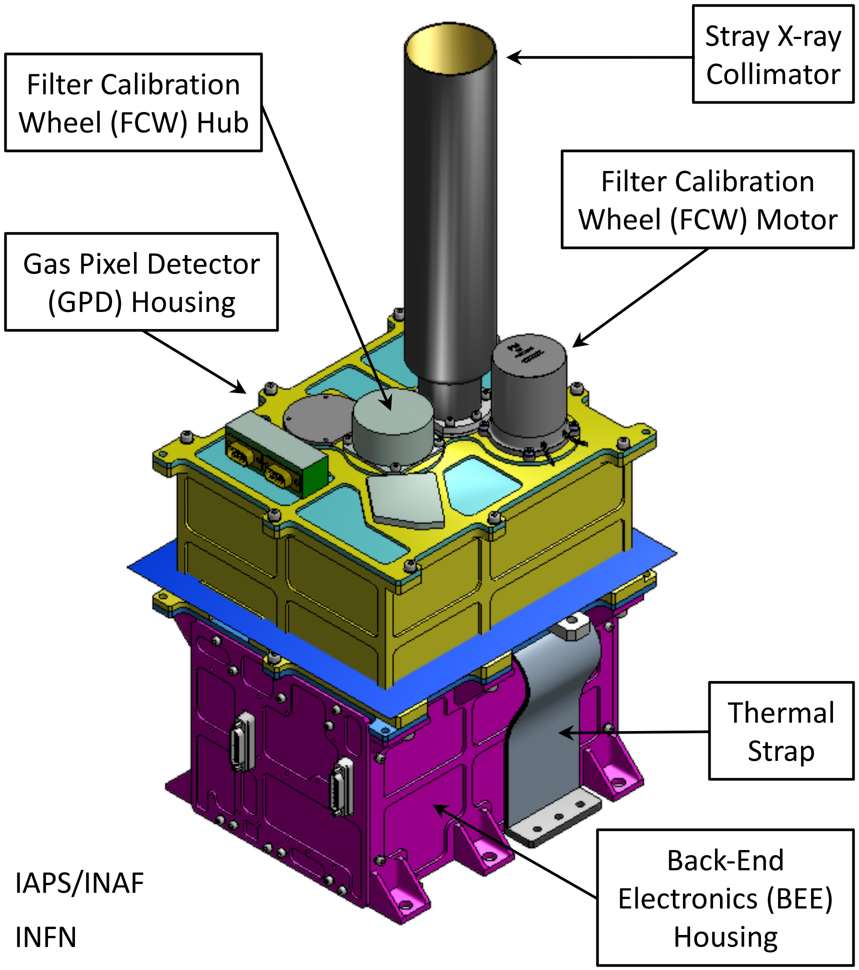


8. Separate shell from mandrel in chilled water



Ni/Co electroformed mirror shells

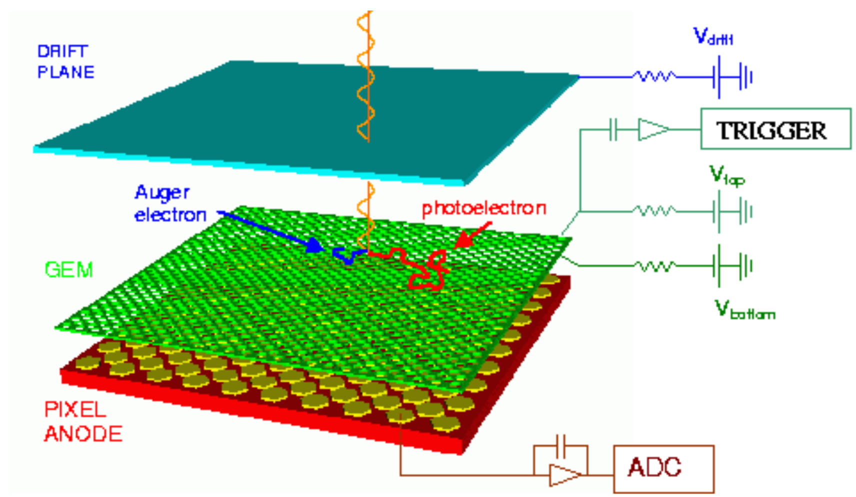
Instrument Detector Unit (DU)



IAPS/INAF

INFN

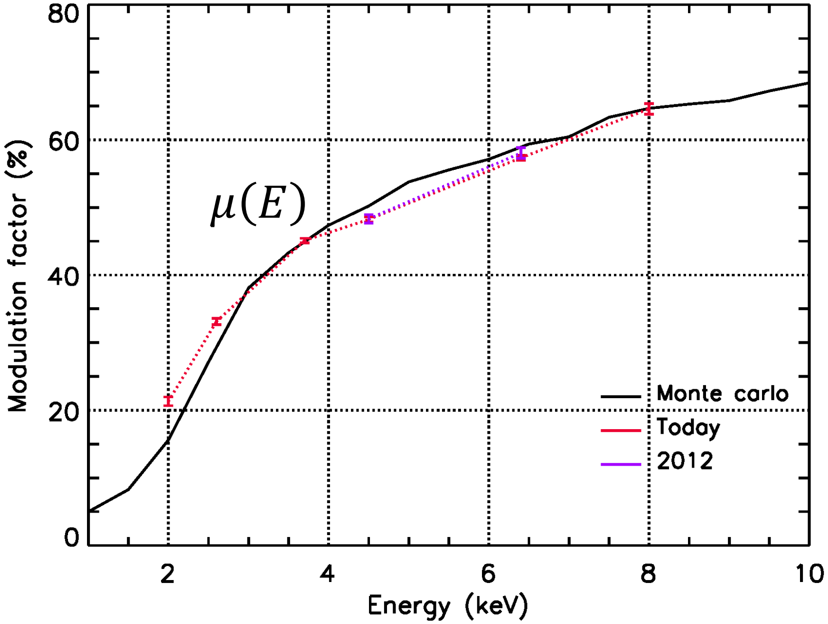
- **Gas Pixel Detector (GPD)**
  - Polarization sensitive
    - Initial photoelectron direction correlated to electric field

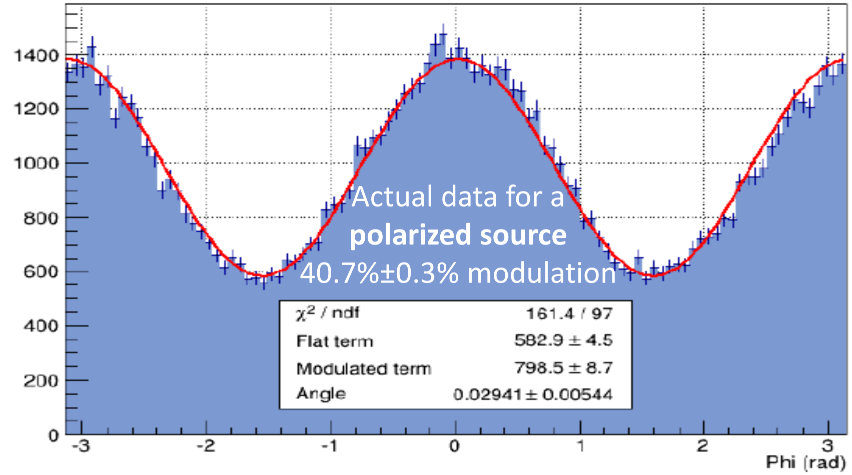


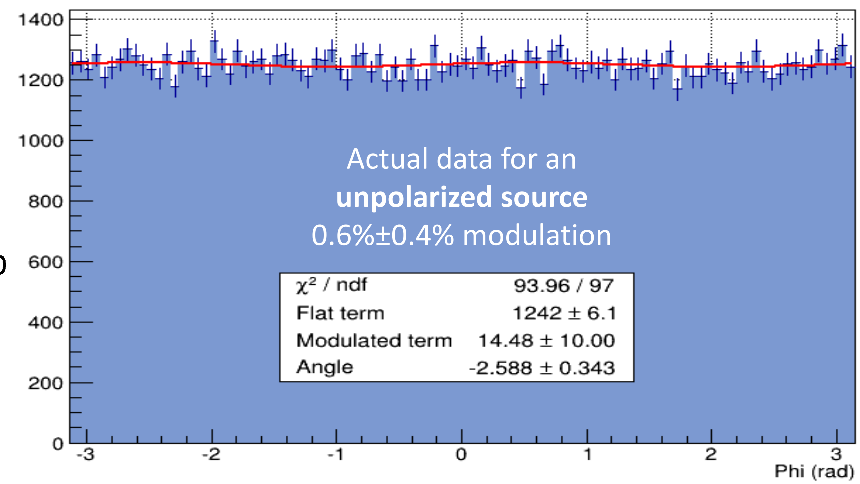
$$\frac{\partial \sigma}{\partial \Omega} = r_0^2 \frac{Z^5}{137^4} \left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$

Polarization from Modulation Histogram and Calibrated Modulation Factor

- **Polarization degree**
  - $\Pi = \text{Modulation}/\mu(E)$



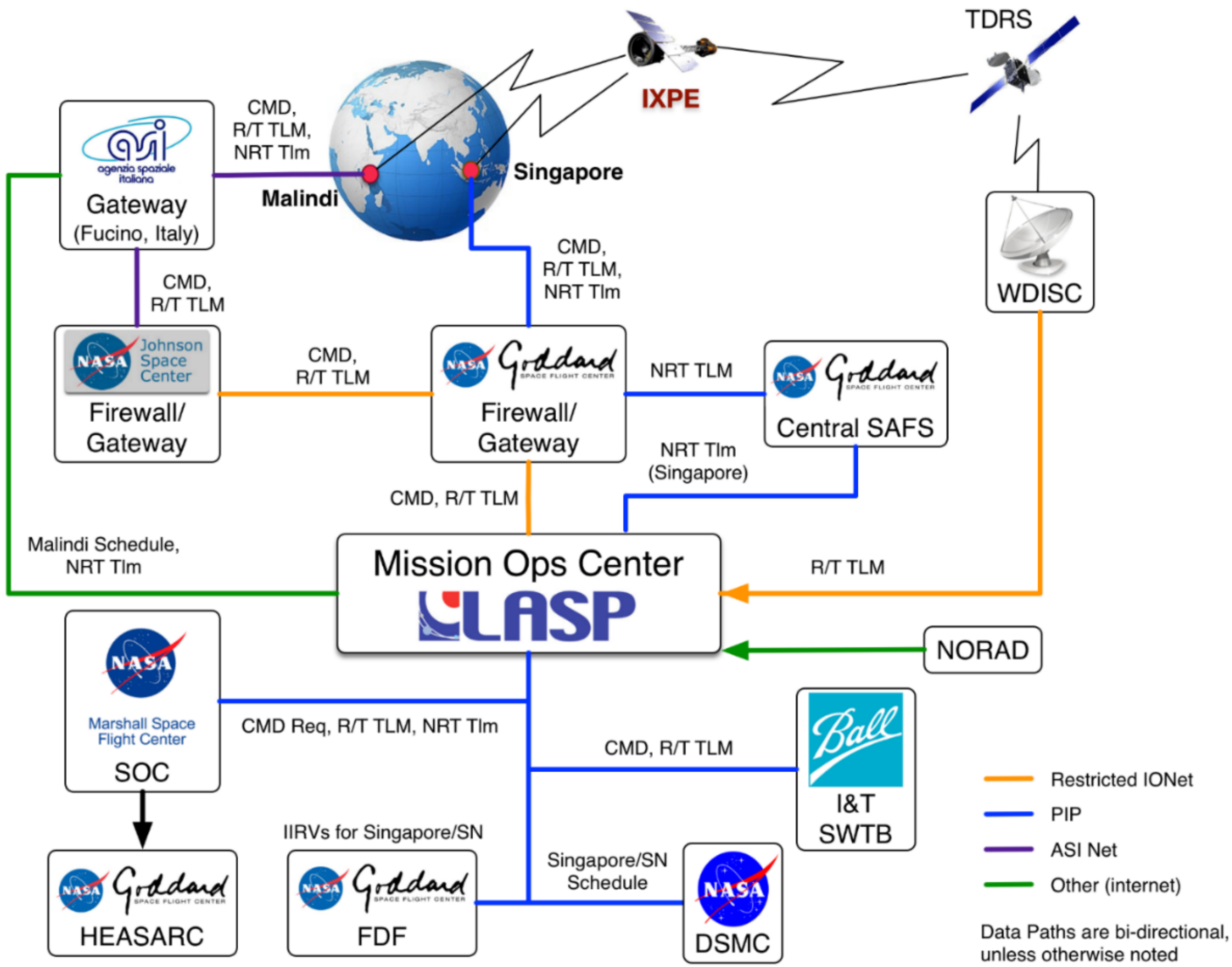




IAPS/INAF (Istituto di Astrofisia e Planetologia Spaziali / Istituto Nazionale di Astro Fisica)

INFN (Istituto Nazionale di Fisica Nucleare)

Ground System: Concept of Operations



End-to-end flow from detected photons to scientific data products

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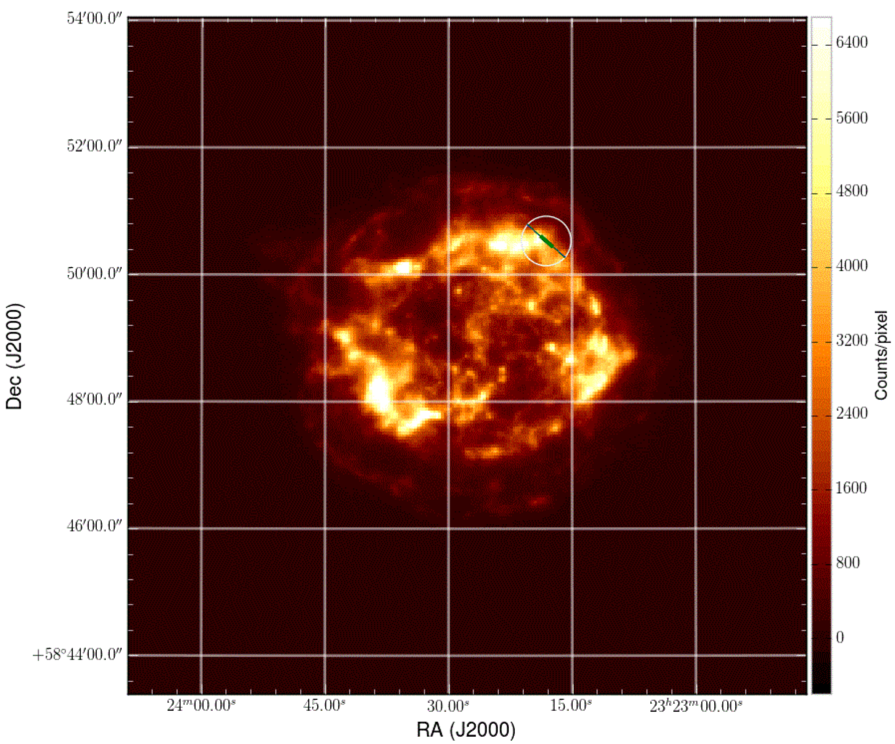
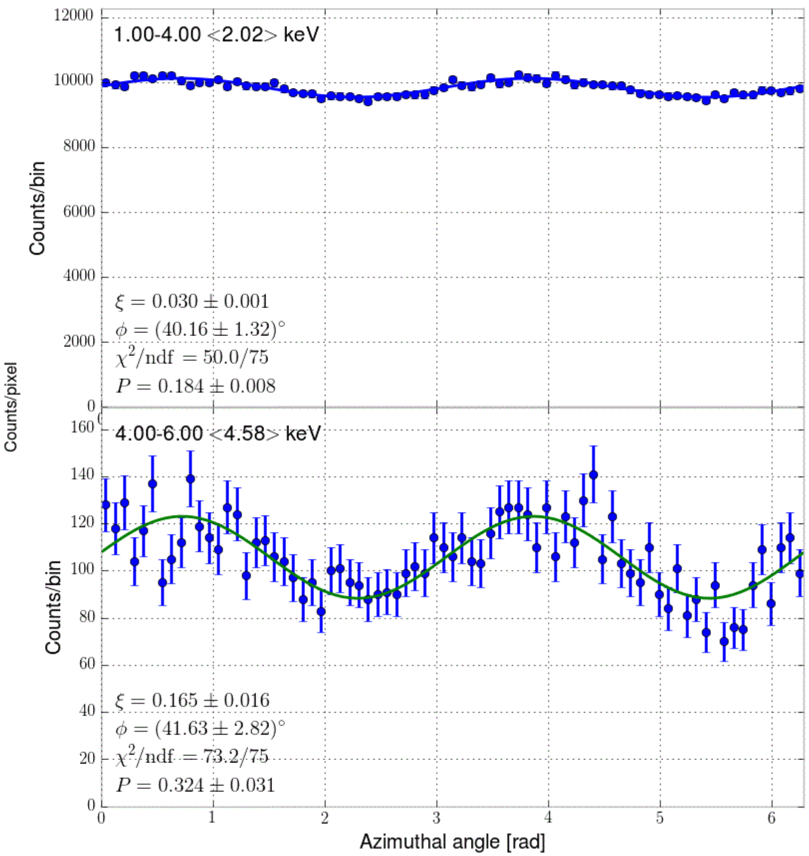
Photons to Data Products

MAP MAGNETIC FIELD OF THE BRIGHTEST EXTENDED SYNCHROTRON SOURCES

- **Cassiopeia A Supernova Remnant (SNR)**

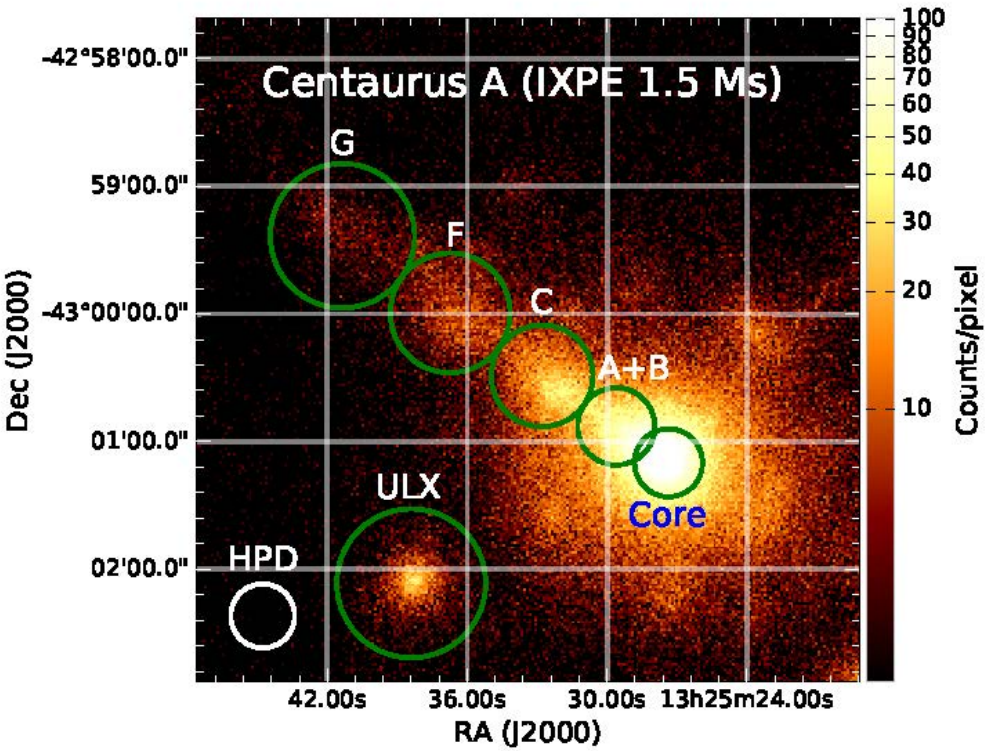


1.5-Ms IXPE (simulated) observation



CONSTRAIN POLARIZATION PROPERTIES OF AN IMAGED, BRIGHT AGN X-RAY JET

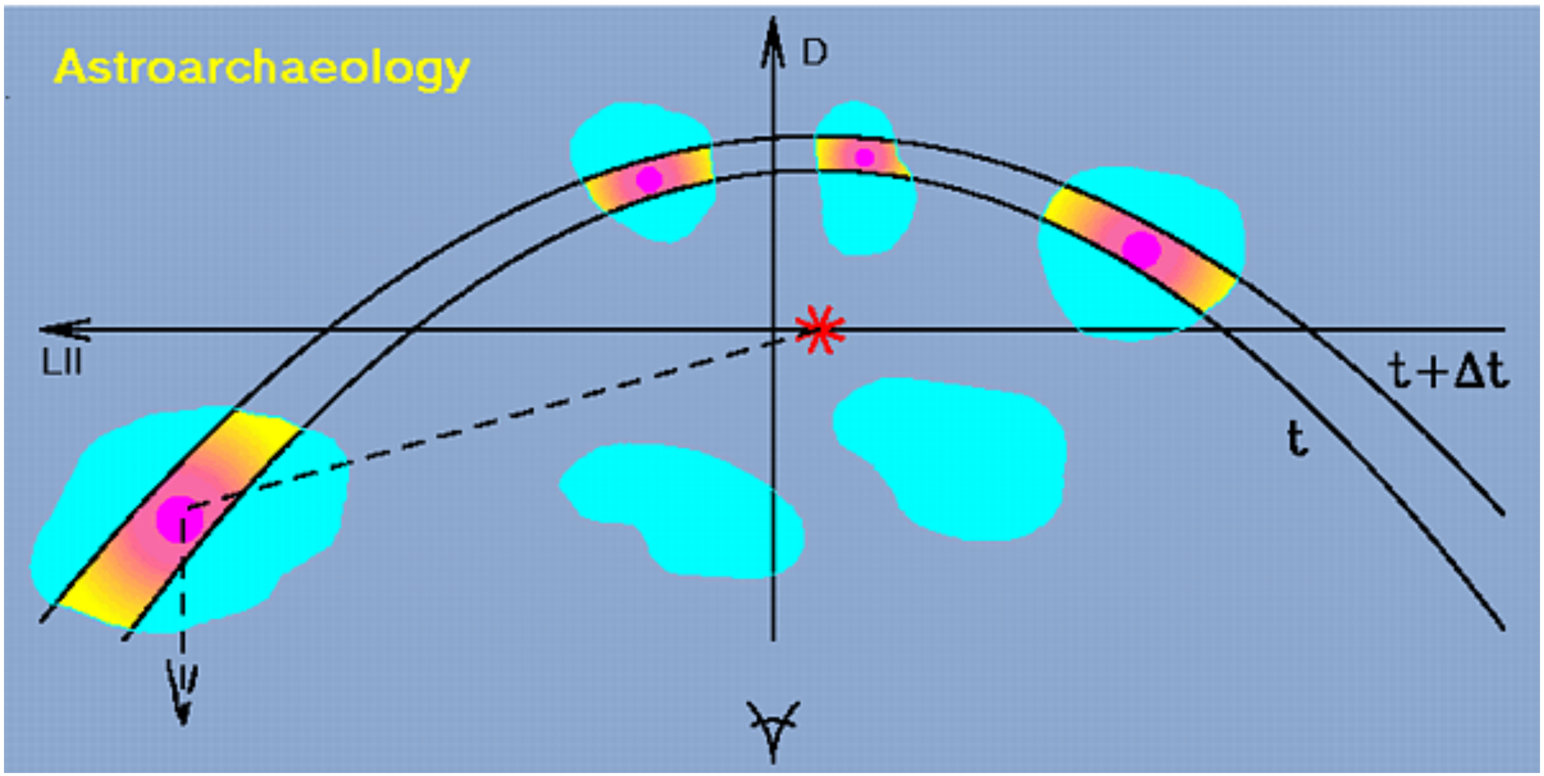
- **Centaurus A (NGC 5128) central region**
  - 1.5-Ms IXPE (simulated) observation



Region	MDP_{99}
Core	**<7.0%**
Jet	**10.9%**
Knot A+B	17.6%
Knot C	16.5%
Knot F	23.5%
Knot G	30.9%
ULX	**14.8%**

TEST REFLECTION-NEBULA HYPOTHESIS FOR X RAYS FROM GALACTIC-CENTER MOLECULAR CLOUDS

- **Does Sgr B2 echo Sgr A* x-ray activity?**
  - Time delay of a few-hundred years



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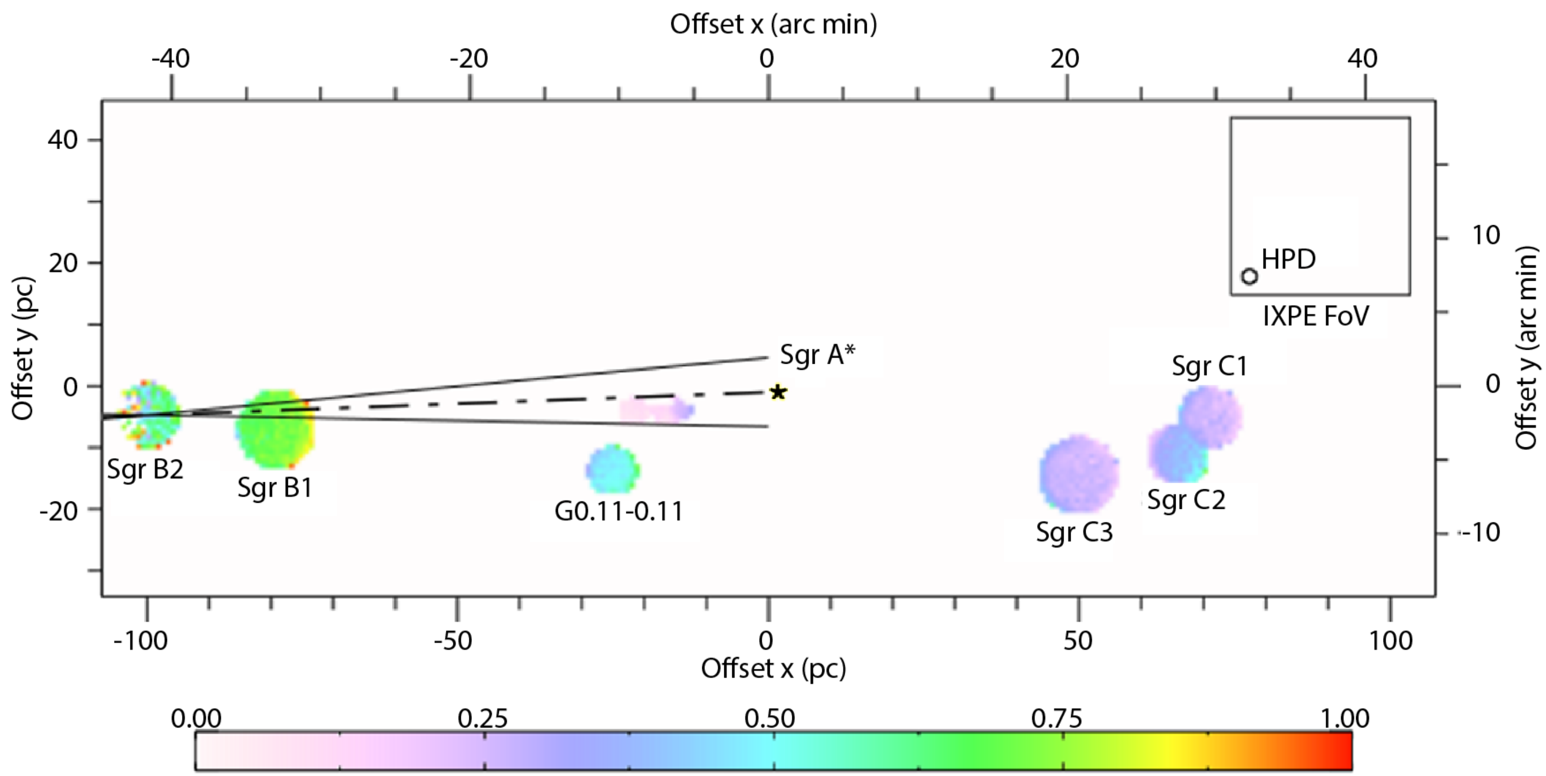
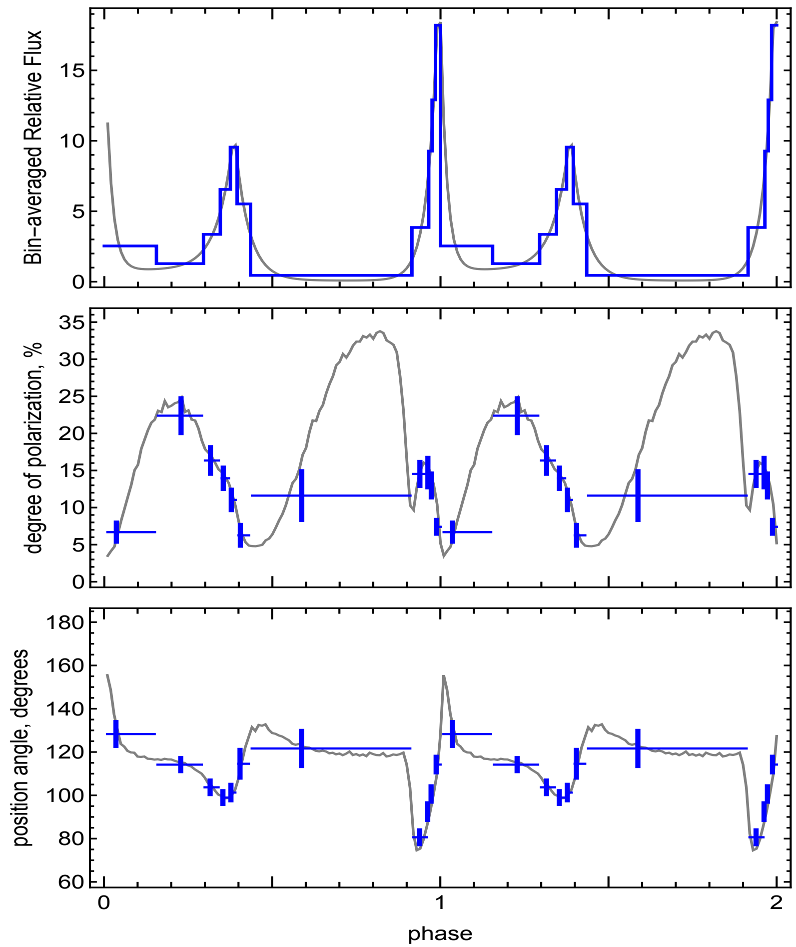
TEST REFLECTION-NEBULA HYPOTHESIS FOR X RAYS FROM GALACTIC-CENTER MOLECULAR CLOUDS

- **Does Sgr B2 echo Sgr A* x-ray activity?**
  - Highly polarized x radiation, if reflected (Thomson scattered)



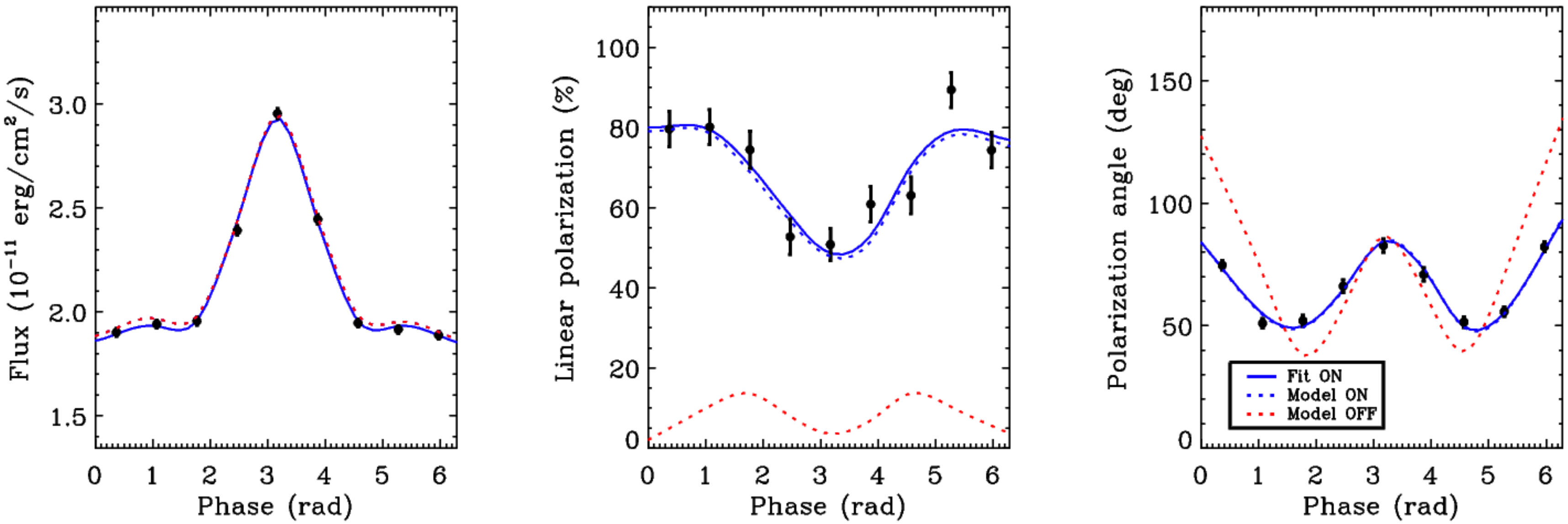
OBTAIN PHASE-RESOLVED POLARIMETRY OF BRIGHT PULSED X-RAY SOURCES

- **Isolated pulsars**
  - Example: Crab pulsar
    - In pulsar wind nebula (PWNe)
    - 34-ms pulse period
    - 140-ks IXPE (simulated) observation [blue]
      - Based upon visible-band polarization profiles [grey]
- **Accreting x-ray pulsars**
  - Classical (high-B) binaries
  - Millisec (low-B) binaries



MEASURE QUANTUM-ELECTRODYNAMIC BIREFRINGENCE IN A MAGNETIZED VACUUM

- **Magnetar (B_{surf} up to 10^{15} G)**
  - Example: 1RXS J170849.0-400910
    - 11-s pulse period
    - 250-ks IXPE (simulated) observation



Measure black-hole spin from polarization rotation in twisted space-time

- **Microquasar in accretion-dominated state**
  - Example: GRS 1915+105
    - 200-ks IXPE (simulated) observation
      - Uses prior disk-orientation information from radio jet