



**IXPE**

Imaging  
X-Ray  
Polarimetry  
Explorer

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# THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE): OVERVIEW



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



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X-Ray  
Polarimetry  
Explorer

## INTERNATIONAL PARTNERSHIP

 <p><b>Marshall Space Flight Center</b></p> <p>PI team, project management, SE and S&amp;MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving</p>	 <p><b>IAPS</b> <b>INAF</b> <b>INFN</b>      ISTITUTO NAZIONALE DI ASTROFISICA      NATIONAL INSTITUTE FOR ASTROPHYSICS</p> <p>Polarization-sensitive imaging detector systems</p>
 <p>Detector system funding, ground station</p>	 <p><b>LASP</b> Mission operations</p>
 <p>Spacecraft, payload structure, payload, observatory I&amp;T</p>	 <p><b>ROMA TRE</b> <b>Stanford University</b> <b>MIT</b>      UNIVERSITA' DEGLI STUDI</p> <p>Scientific theory</p>
	 <p><b>McGill</b> Science Working Group Co-Chair</p>
	 <p><b>Massachusetts Institute of Technology</b> Co-Investigator</p>

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## SCIENCE TEAM

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### ■ Co-Investigators

- M. Weisskopf (PI), P. Soffitta (IPI), L. Baldini, R. Bellazzini, E. Costa, R. Elsner, V. Kaspi, J. Kolodziejczak, L. Latronico, H. Marshall, G. Matt, F. Muleri, S. O'Dell, B. Ramsey, R. Romani, A. Tennant

### ■ Collaborators

- W. Baumgartner, A. Brez, N. Bucciantini, E. Churazov, S. Citrano, E. Del Monte, N. Di Lalla, I. Donnarumma, M. Dovčiak, Y. Evangelista, S. Fabiani, R. Goosmann, S. Gunji, V. Karas, M. Kuss, A. Manfreda, F. Marin, M. Minuti, N. Omodei, L. Pacciani, G. Pavlov, M. Pesce-Rollins, P.-O. Petrucci, M. Pinchera, J. Poutanen, M. Razzano, A. Rubini, M. Salvati, C. Sgrò, F. Spada, G. Spandre, L. Stella, R. Sunyaev, R. Taverna, R. Turolla, K. Wu, S. Zane, D. Zanetti



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## MISSION SUMMARY (1/2)

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### ■ 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



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## MISSION SUMMARY (2/2)

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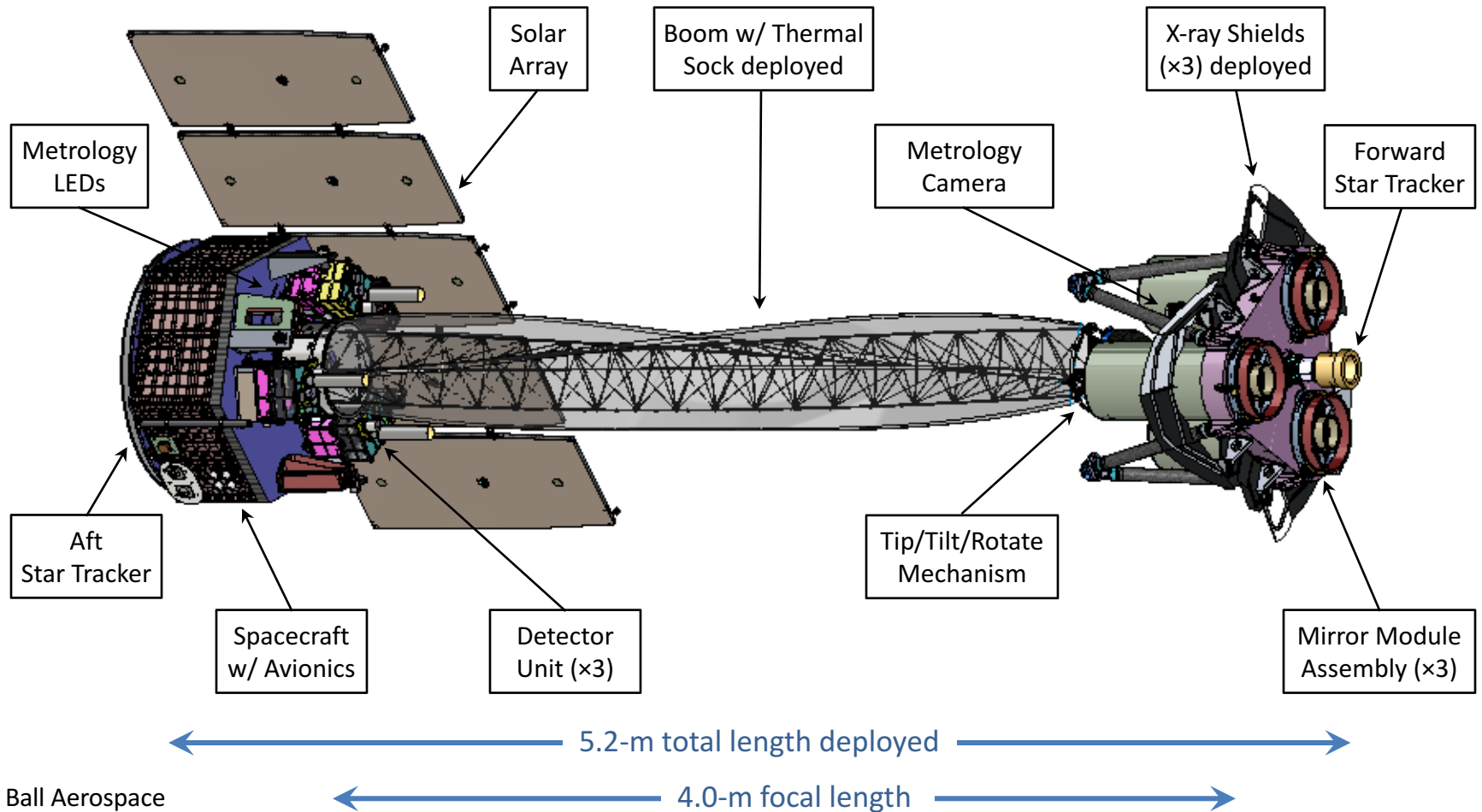
### ■ Ground system

- 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

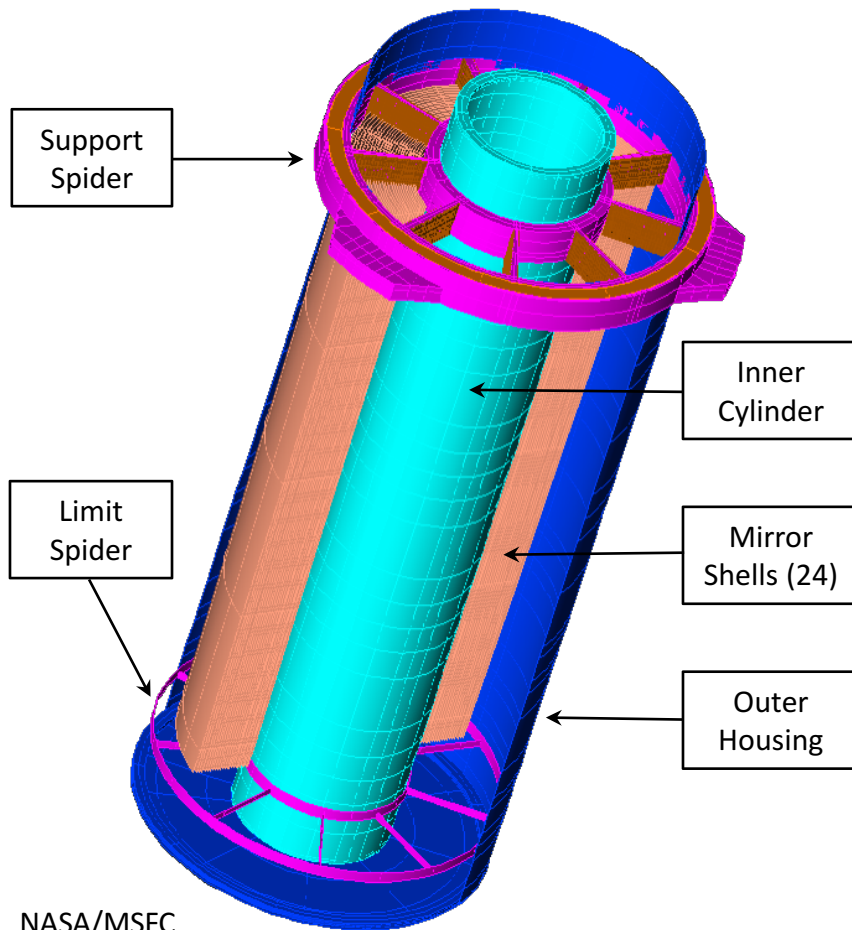
### ■ Science

- Active galactic nuclei
- Microquasars
- Radio pulsars and pulsar wind nebulae
- Supernova remnants
- Magnetars
- Accreting x-ray pulsars

## MAJOR COMPONENTS OF THE OBSERVATORY



## MIRROR MODULE ASSEMBLY (MMA)



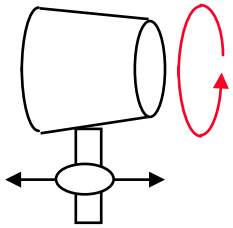
NASA/MSFC

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 <sup>2</sup> (2.3 keV) > 230 cm <sup>2</sup> (3–6 keV)
Angular resolution	≤ 25 arcsec HPD
Field of view (detector-limited)	12.9 arcmin

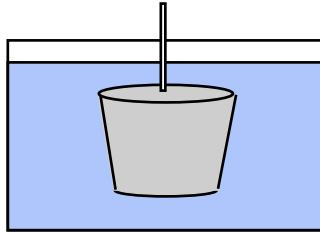
# MIRROR PRODUCTION PROCESS

## Mandrel fabrication

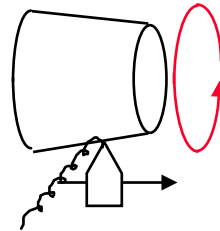
1. Machine mandrel from aluminum bar



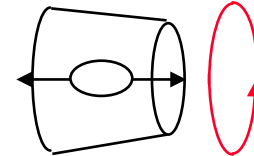
2. Coat mandrel with electroless nickel (Ni-P)



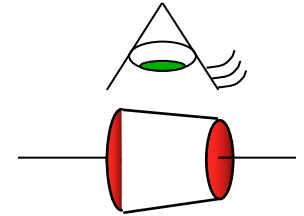
3. Diamond turn mandrel to sub-micron figure accuracy



4. Polish mandrel to 0.3-0.4 nm RMS

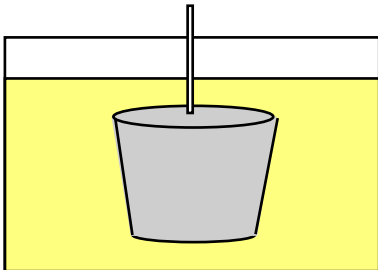


5. Conduct metrology on the mandrel

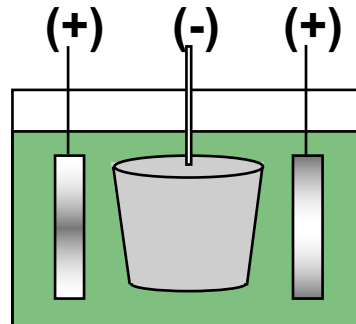


## Mirror-shell forming

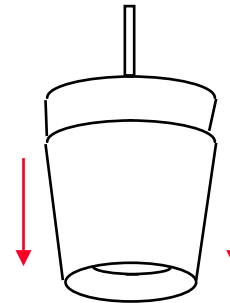
6. Passivate mandrel surface to reduce shell adhesion



7. Electroform Nickel/Cobalt shell onto mandrel



8. Separate shell from mandrel in chilled water

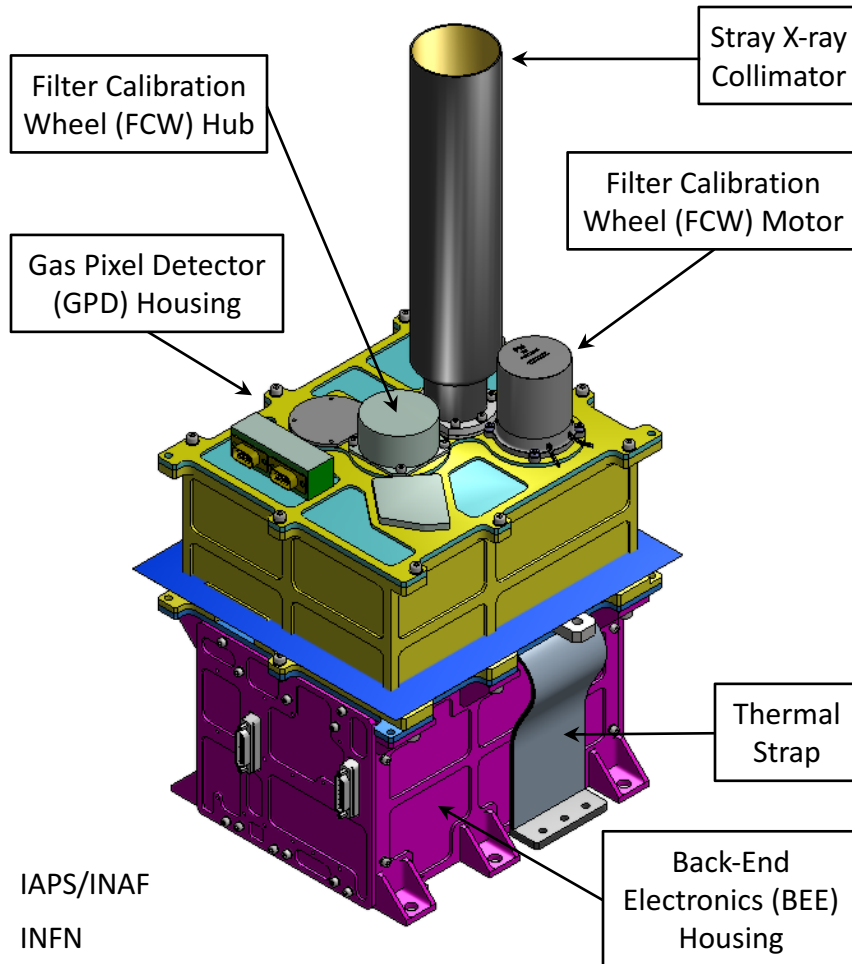


Ni/Co electroformed mirror shells



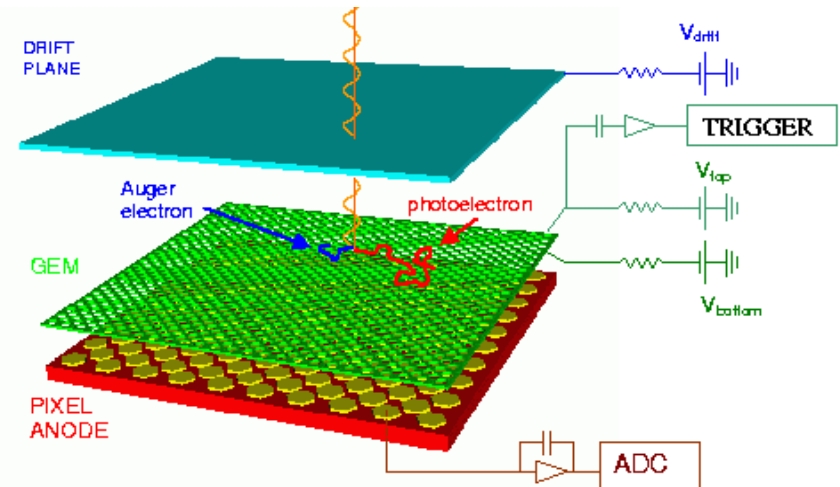


# INSTRUMENT DETECTOR UNIT (DU)



## Gas Pixel Detector (GPD)

- Polarization sensitive
  - Initial photoelectron direction correlated to electric field

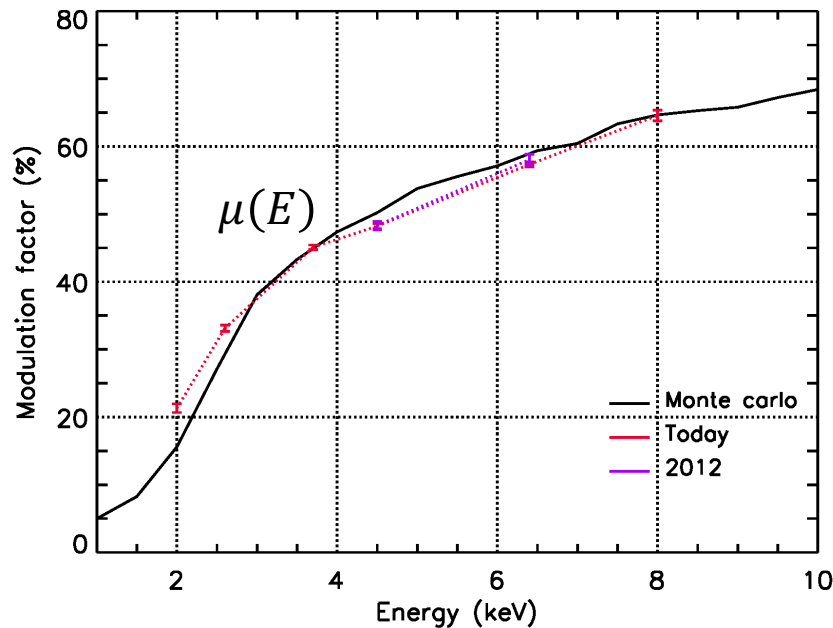


$$\frac{\partial \sigma}{\partial \Omega} = r_0^2 \frac{Z^5}{137^4} \left( \frac{mc^2}{h\nu} \right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1 - \beta\cos(\theta))^4}$$

# POLARIZATION FROM MODULATION HISTOGRAM AND CALIBRATED MODULATION FACTOR

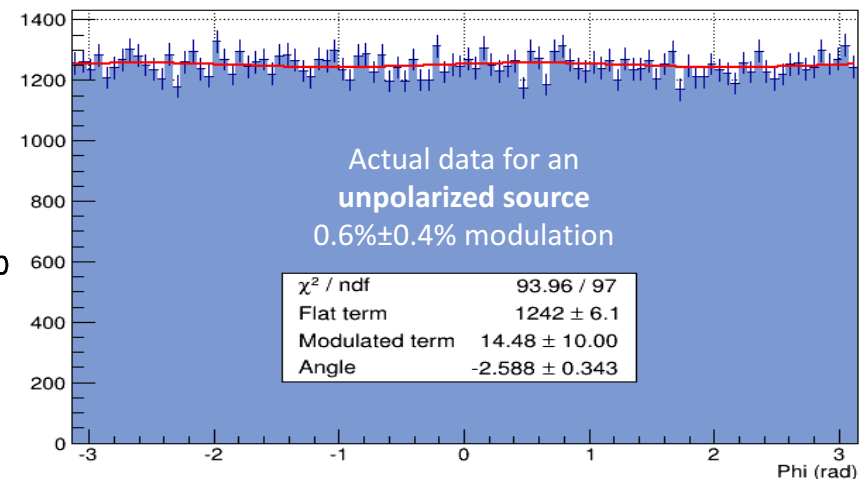
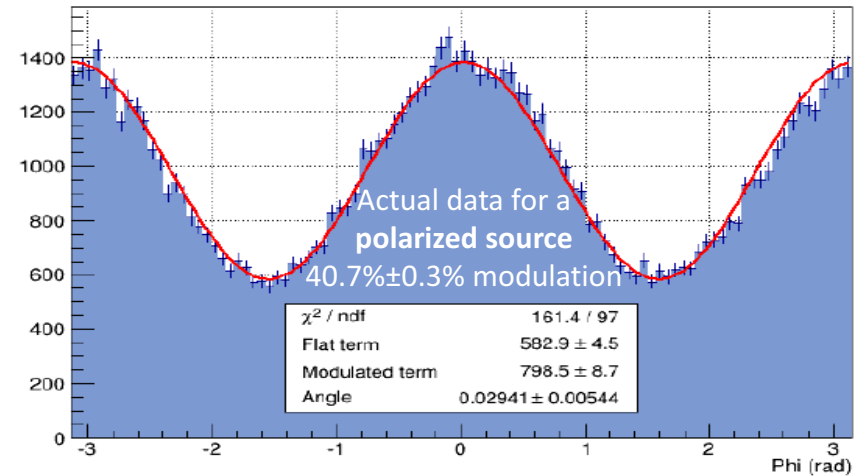
## ■ Polarization degree

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



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

INFN (Istituto Nazionale di Fisica Nucleare)

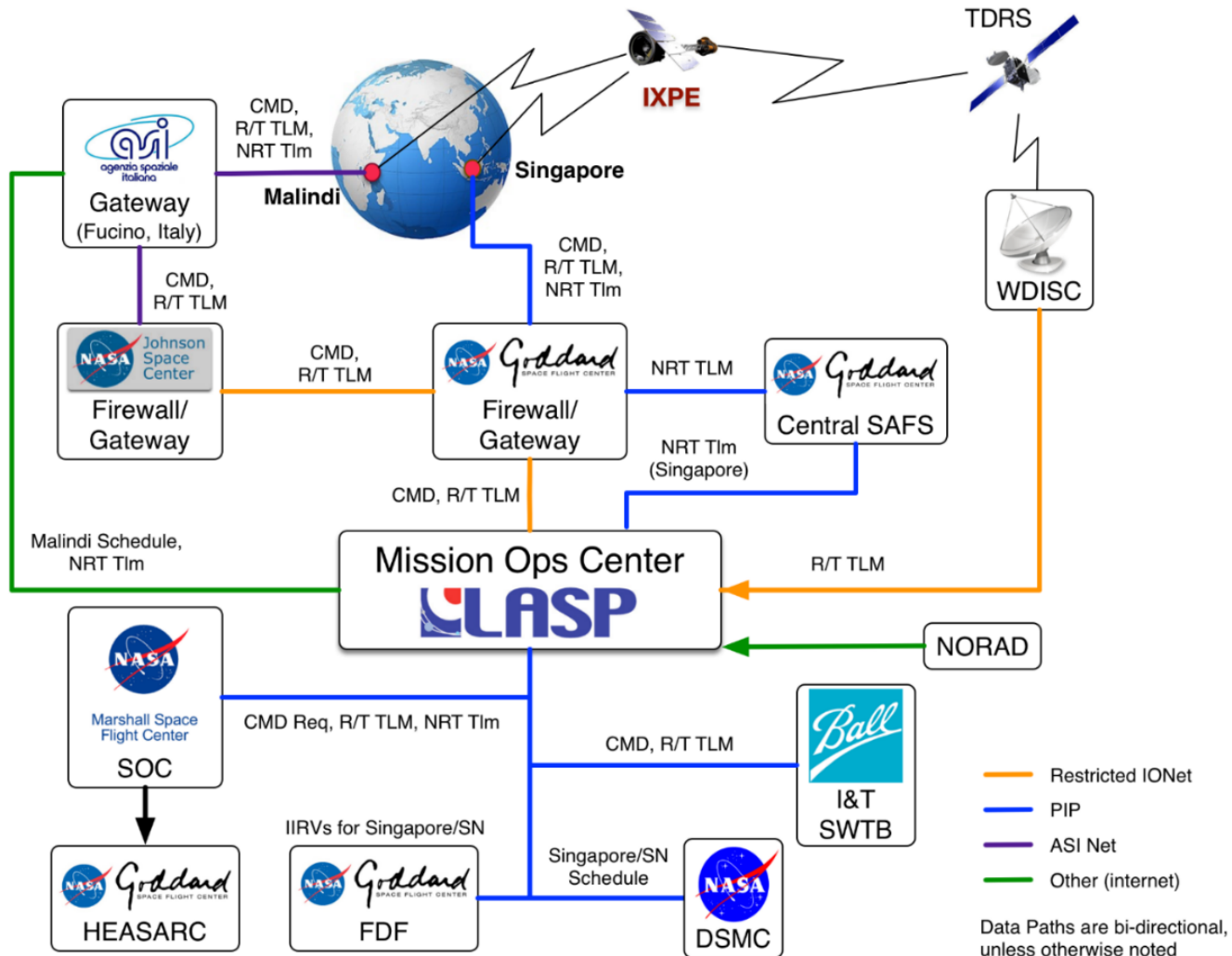




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## GROUND SYSTEM: CONCEPT OF OPERATIONS





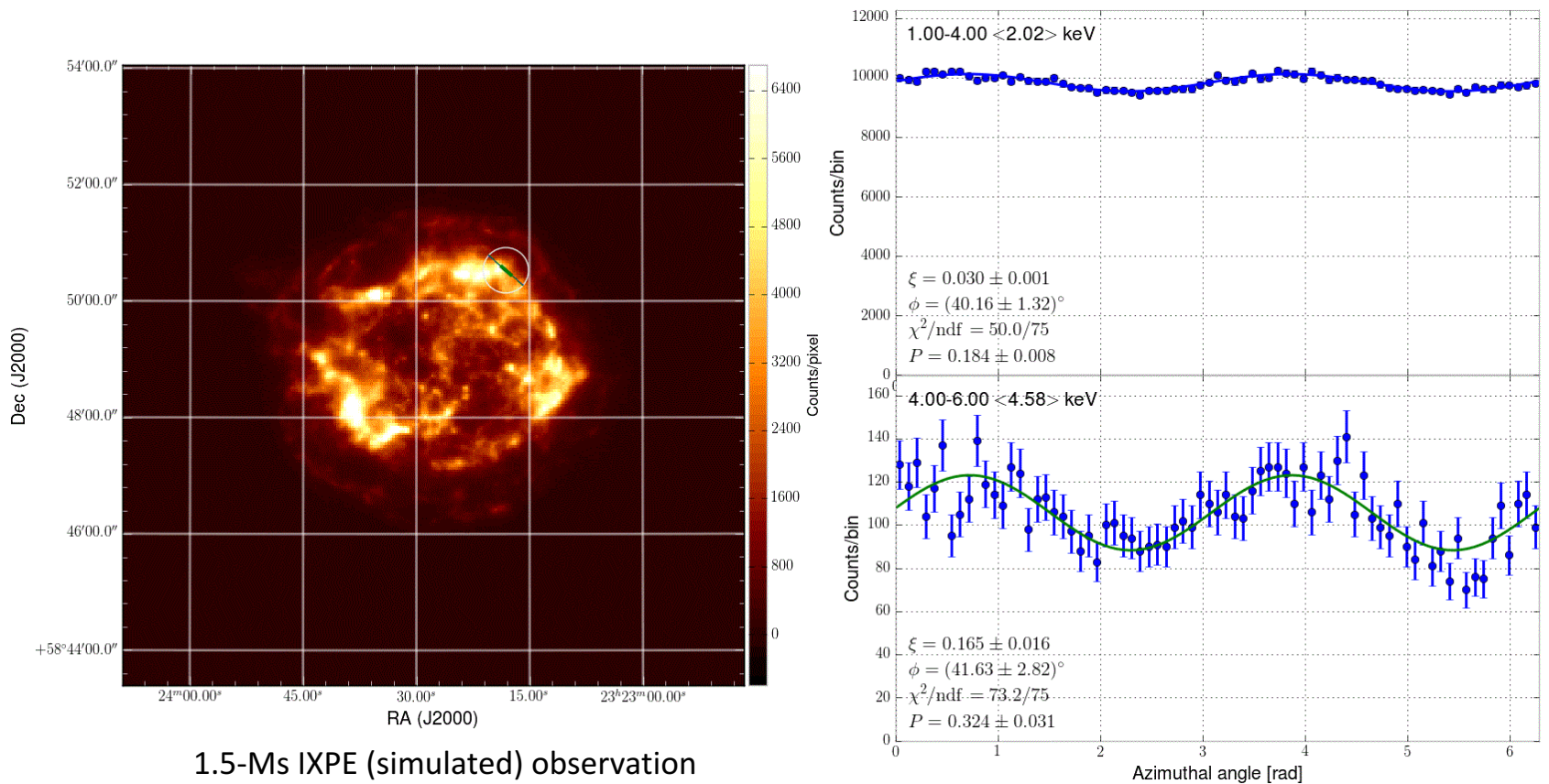
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# END-TO-END FLOW FROM DETECTED PHOTONS TO SCIENTIFIC DATA PRODUCTS

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Photons to Data Products

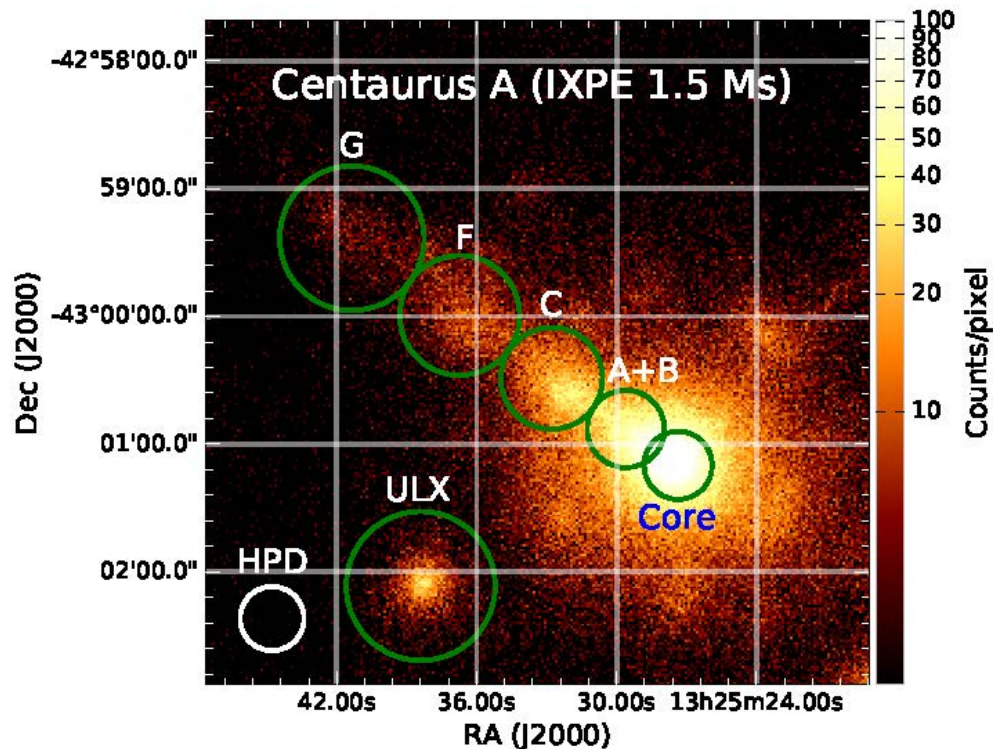
# MAP MAGNETIC FIELD OF THE BRIGHTEST EXTENDED SYNCHROTRON SOURCES

## ■ Cassiopeia A Supernova Remnant (SNR)



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

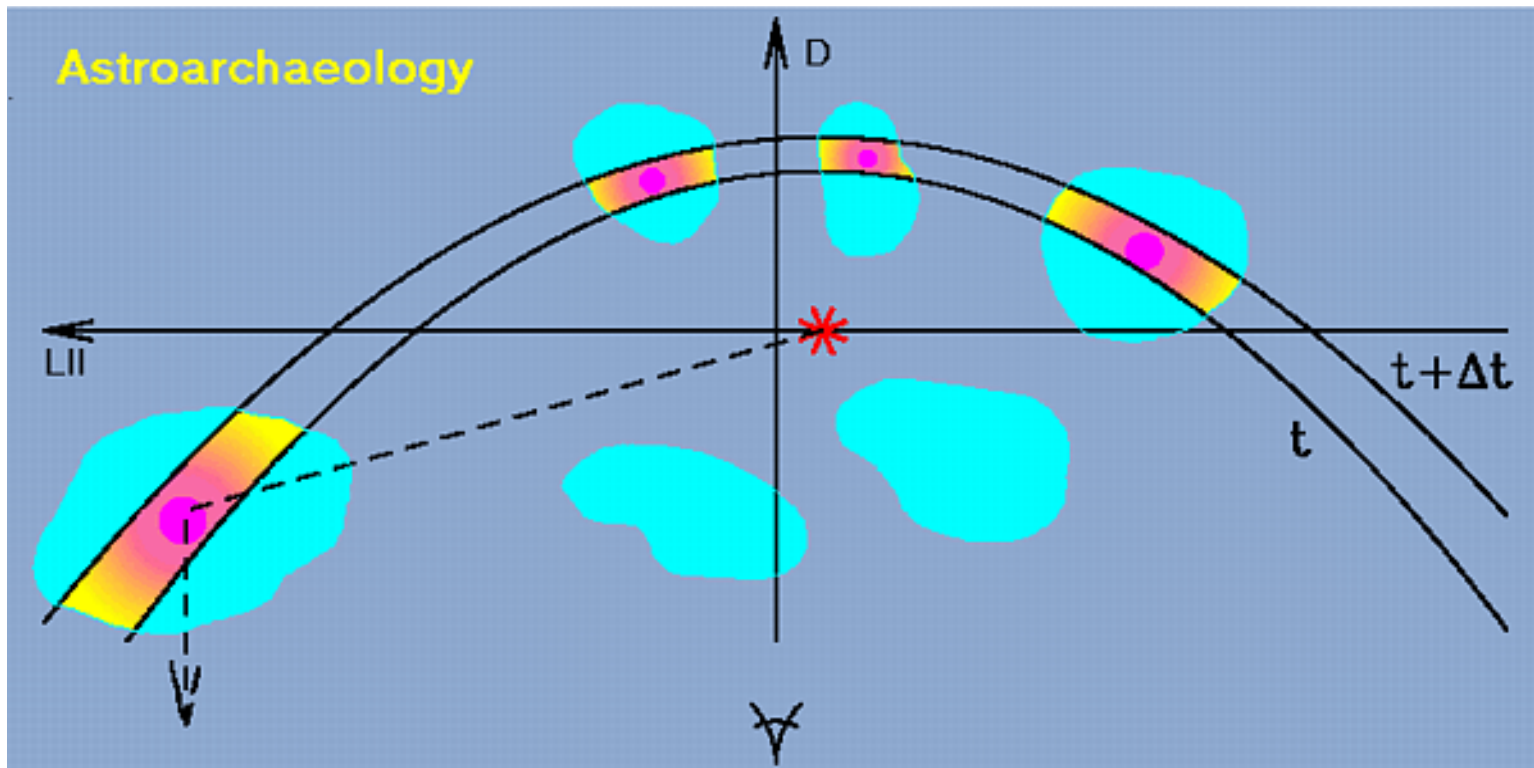
- Centaurus A (NGC 5128) central region
  - 1.5-Ms IXPE (simulated) observation



Region	MDP <sub>99</sub>
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

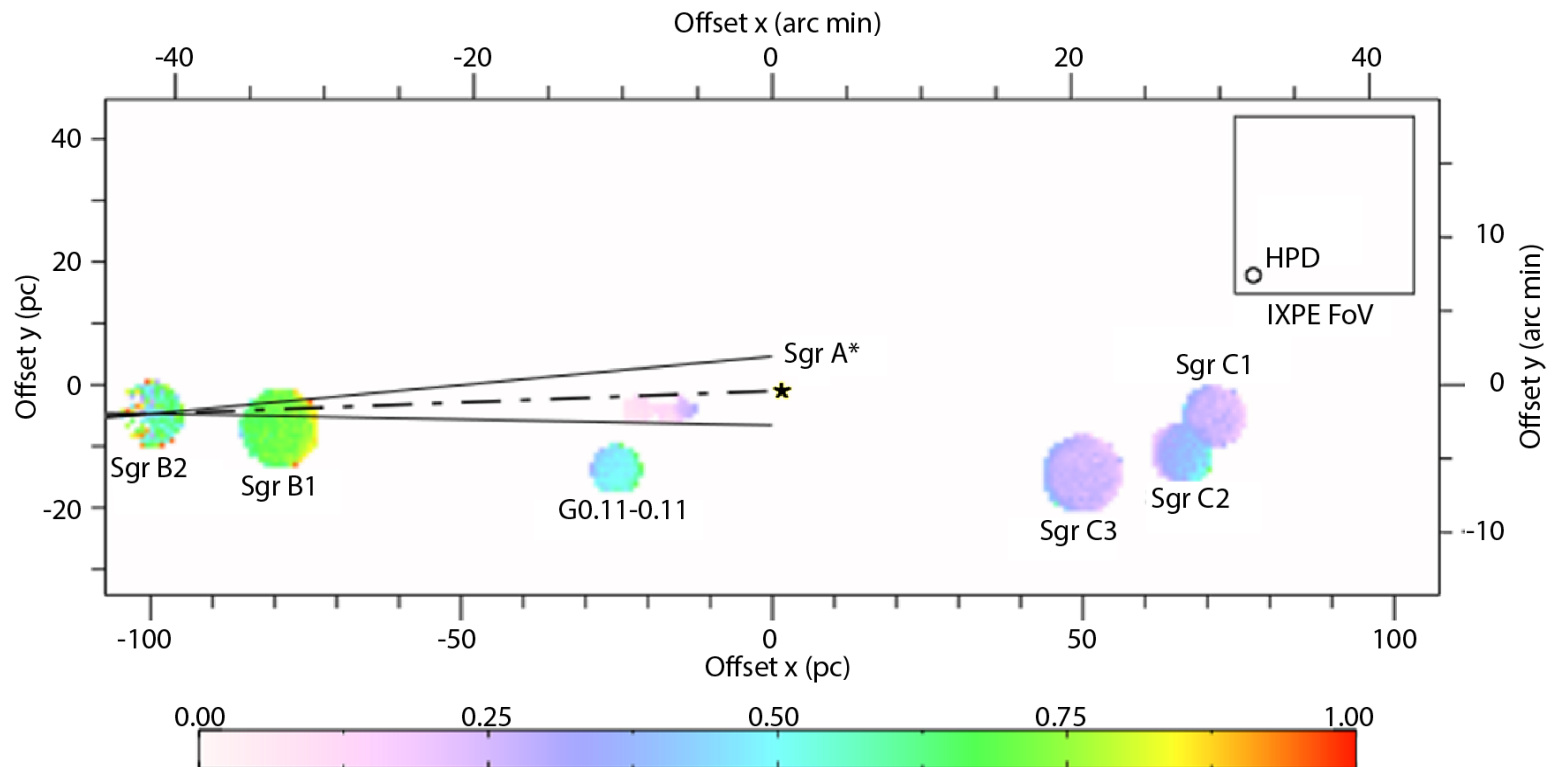
- **Does Sgr B2 echo Sgr A\* x-ray activity?**
  - Time delay of a few-hundred years



# 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)





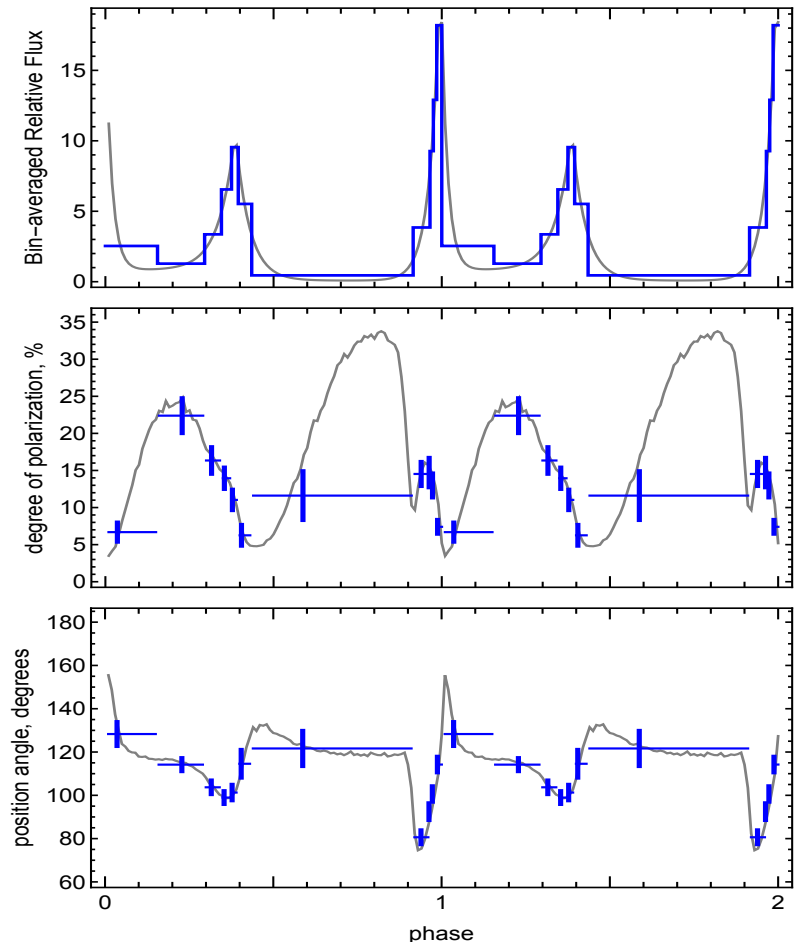
## OBTAIN PHASE-RESOLVED POLARIMETRY OF BRIGHT PULSED X-RAY SOURCES

### ■ 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]

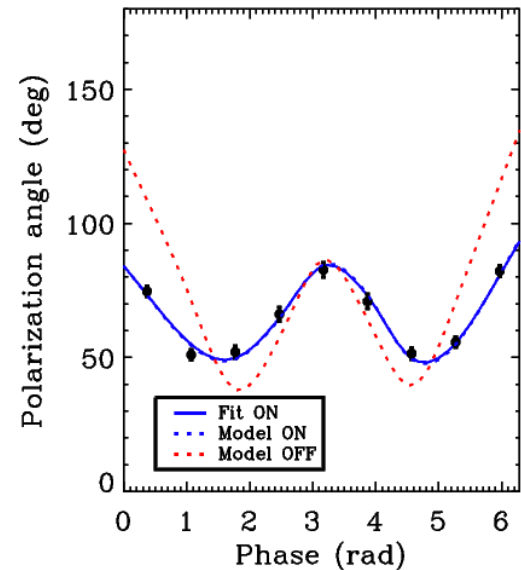
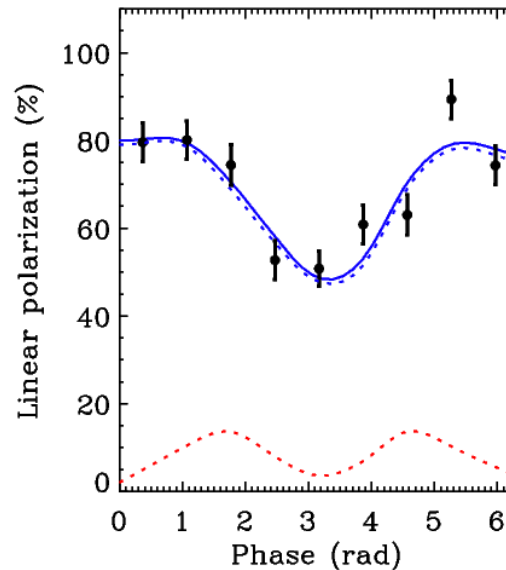
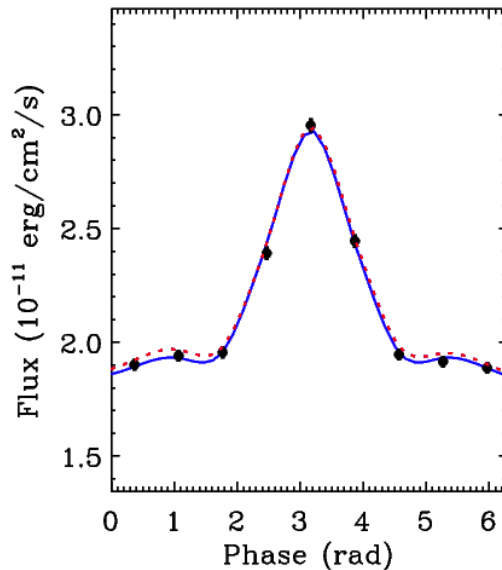
### ■ Accreting x-ray pulsars

- Classical (high-B) binaries
- Millisec (low-B) binaries



# MEASURE QUANTUM-ELECTRODYNAMIC BIREFRINGENCE IN A MAGNETIZED VACUUM

- **Magnetar ( $B_{\text{surf}}$  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

