IXPE
Imaging X-Ray Polarimetry Explorer

The Imaging X-ray Polarimetry Explorer

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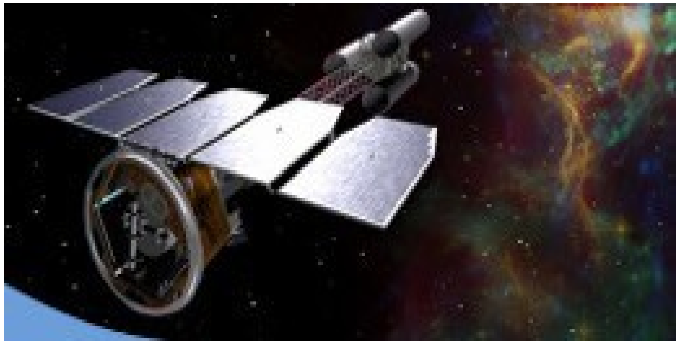
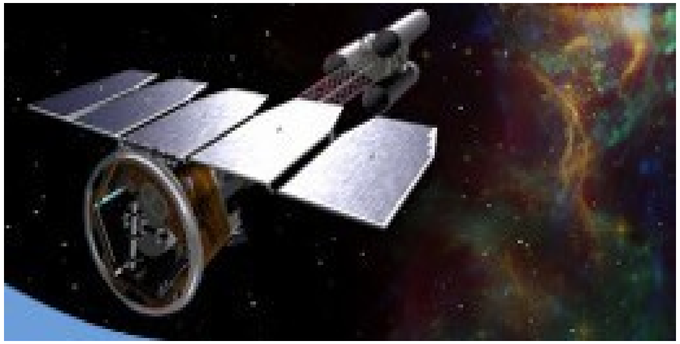
On behalf of the IXPE team
(PI: Martin Weisskopf, MSFC)



Selected by NASA in the Small Explorer Program (SMEX) for a lunch in 2020

First X-ray polarimetric mission after OSO-8 (70's)

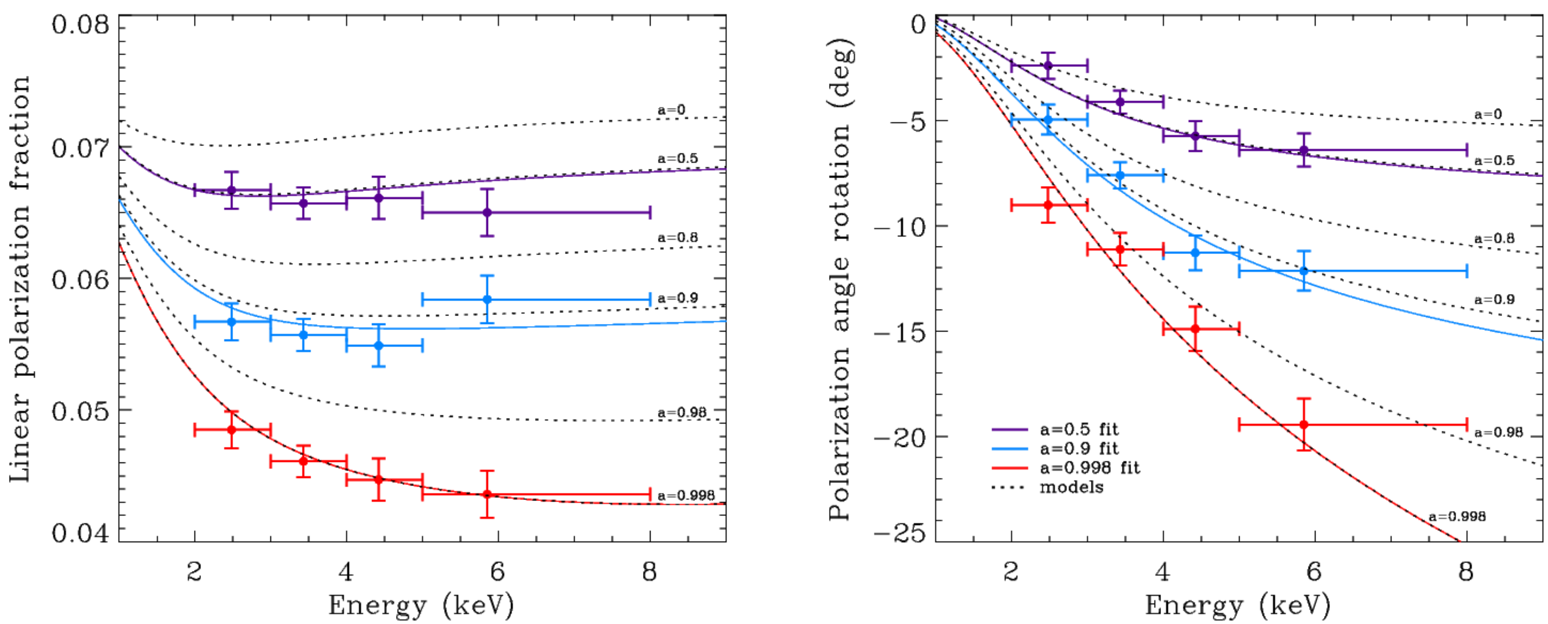


IXPE addresses key scientific objectives

- **Opens a new window on the universe — imaging (30") X-ray polarimetry**
  - Only one positive measurement so far – Crab Nebula (19%) with OSO-8
  - Increases information space and lifts modeling degeneracies
- **Addresses key questions, providing new scientific results and constraints**
  - What is the spin of a black hole?
  - What are the geometry and magnetic-field strength in magnetars?
  - Was our Galactic Center an Active Galactic Nucleus in the recent past?
  - What is the magnetic field structure in synchrotron X-ray sources?
  - What are the geometries and origins of X-rays from pulsars (isolated and accreting)?
- **Provides powerful and unique capabilities**
  - Reduces integration time by a factor of 100 over OSO-8 experiment
  - Simultaneously provides imaging, energy, timing, and polarization data
  - Devoid of instrument systematic effects at less than a fraction of a percent
  - Meaningful polarization measurements for a large number of sources of different classes

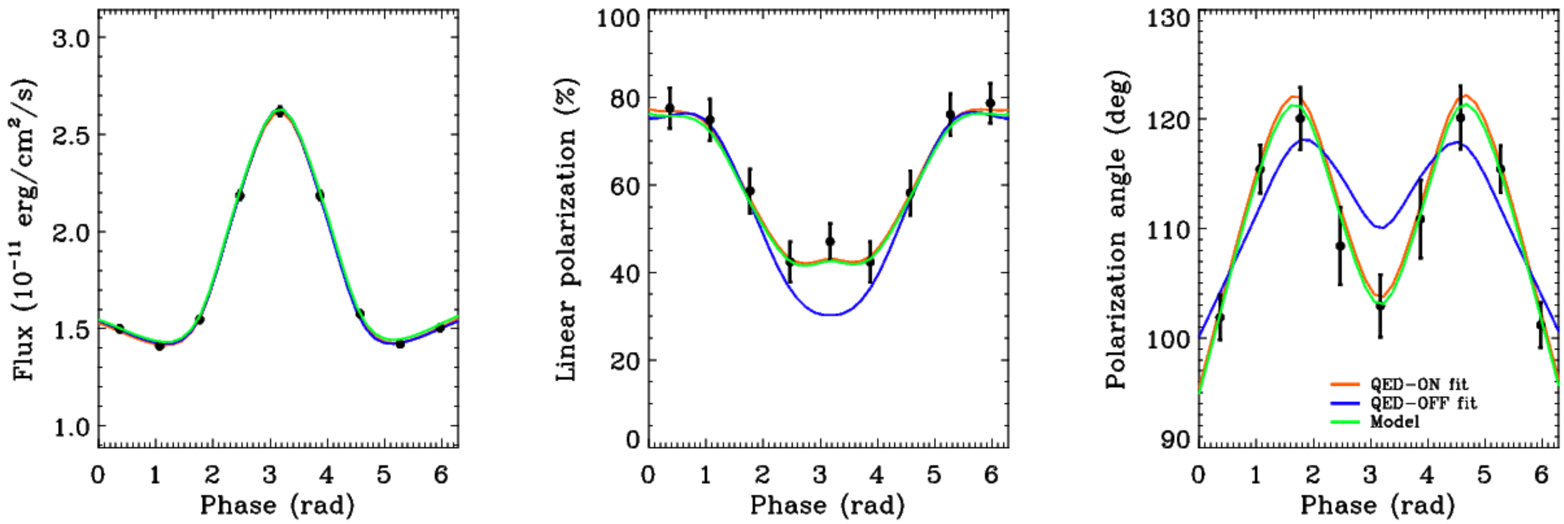
Measure black-hole spin from polarization rotation in twisted space-time

- **For an accreting Galactic BH in the soft state**
  - Scattering polarizes the thermal disk emission
  - Polarization rotation is greatest for emission from inner disk
    - Inner disk is hotter, producing higher energy X-rays
    - E.g. a = 0.50±0.04; a = 0.900±0.008; a = 0.99800±0.00003 in a 200 ks observation of GRS 1915+105



Test quantum electrodynamics (QED) in extreme magnetic fields

- **Magnetar is a neutron star with magnetic field up to 10^{15} Gauss**
  - Billion times the strongest laboratory field
  - Non-linear QED predicts magnetized-vacuum birefringence
    - Refractive indices different for the two polarization modes
    - Impacts polarization and position angle as function of pulse phase
    - Can exclude QED-off at better than 99.9% confidence



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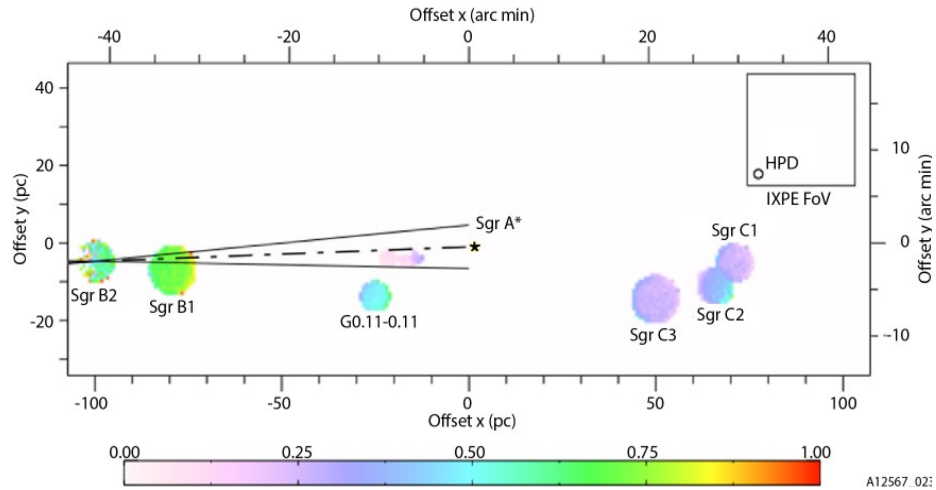
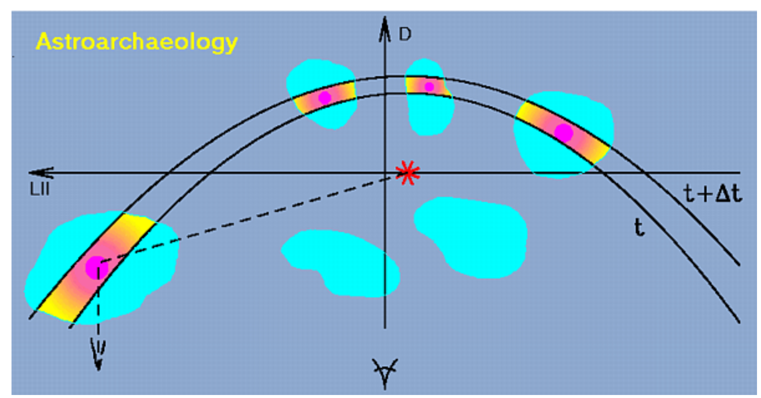
Was the Galactic Center (GC) nucleus 10^6 × more active in the recent past?

- **Galactic Center molecular clouds (MC) are known X-ray sources**
  - If MCs reflect X-rays from Sgr A* (supermassive black hole in the Galactic center)
    - X-radiation would be *highly polarized* perpendicular to plane of reflection and indicates the direction back to Sgr A*
    - Sgr A* X-ray luminosity was 10^6 larger ≈ 300 years ago
  - If not, still a discovery!





Map magnetic field of synchrotron sources to probe sites of cosmic-ray acceleration

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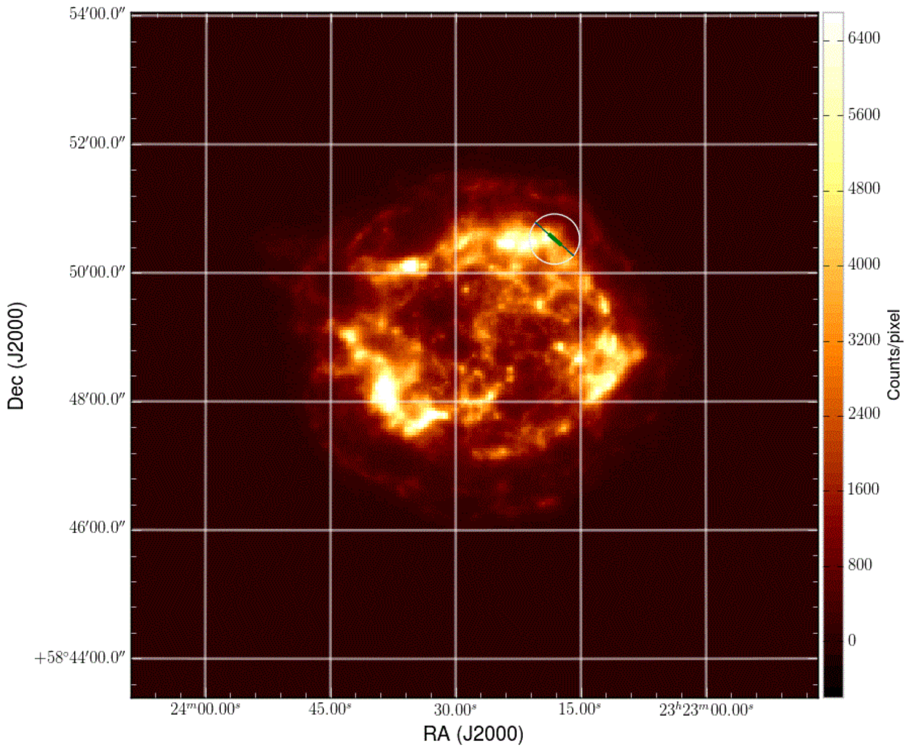
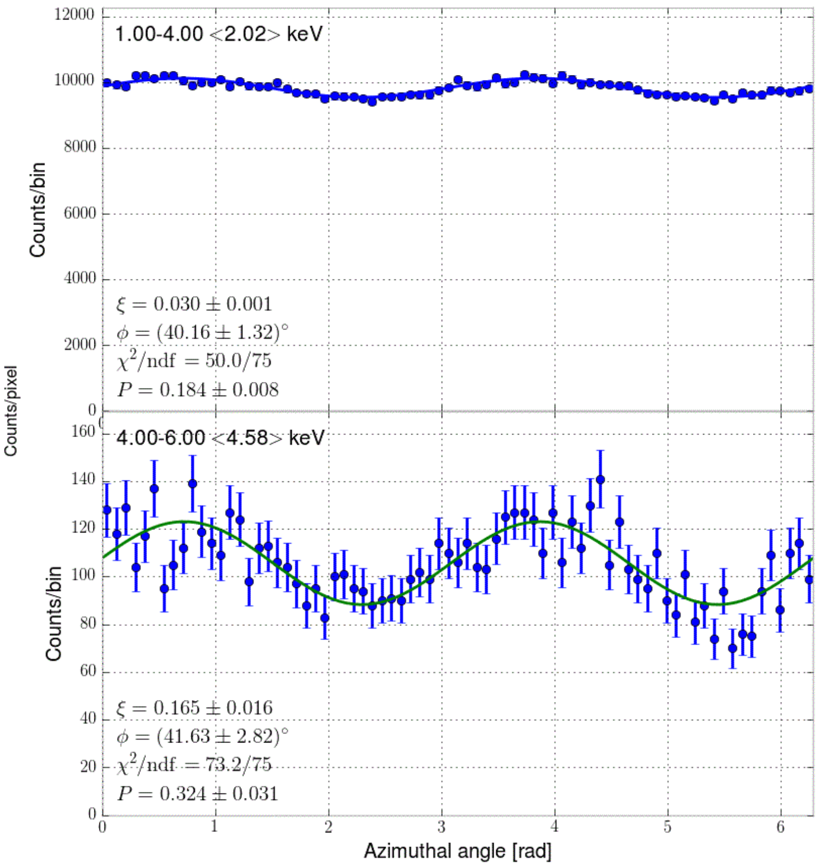
- **Lines and thermal continuum dominate 1-4 keV**
- **Non-thermal emission dominates 4-6 keV**



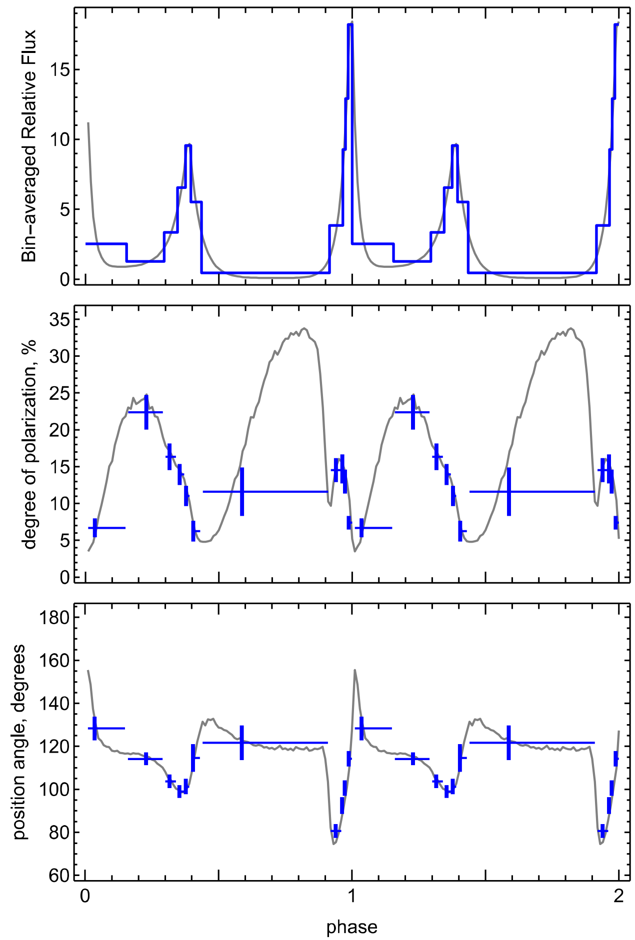


Cas A

Probe emitting regions of pulsars through phase-resolved polarimetry

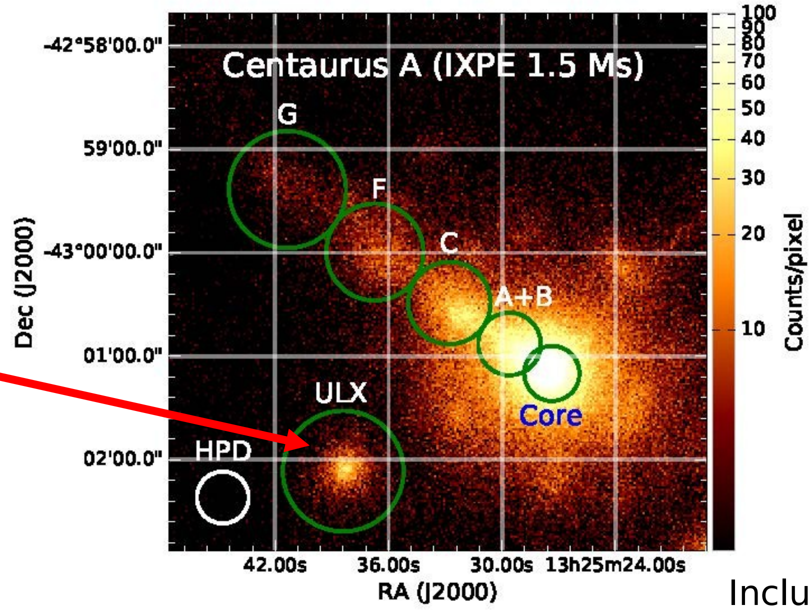
- **Emission geometry and processes are unsettled**
  - Competing models predict differing polarization behavior with pulse phase
- **X-rays provide cleaner probe of geometry**
  - Absorption likely more prevalent in visible band
  - Radiation process entirely different in radio band
    - We recently discovered no pulse phase-dependent variation in PD and PA @ 1.4 GHz

Grey optical



IXPE imaging avoids confusion and provides serendipitous benefits

- **Active galaxies are powered by supermassive BHs with jets**
  - Radio polarization implies the magnetic field is aligned with jet
  - Different models for electron acceleration predict different dependence in X-rays
- **Imaging Cen A allows isolating other sources in the field**
- **(2 Ultra Luminous X-ray sources)**



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%**

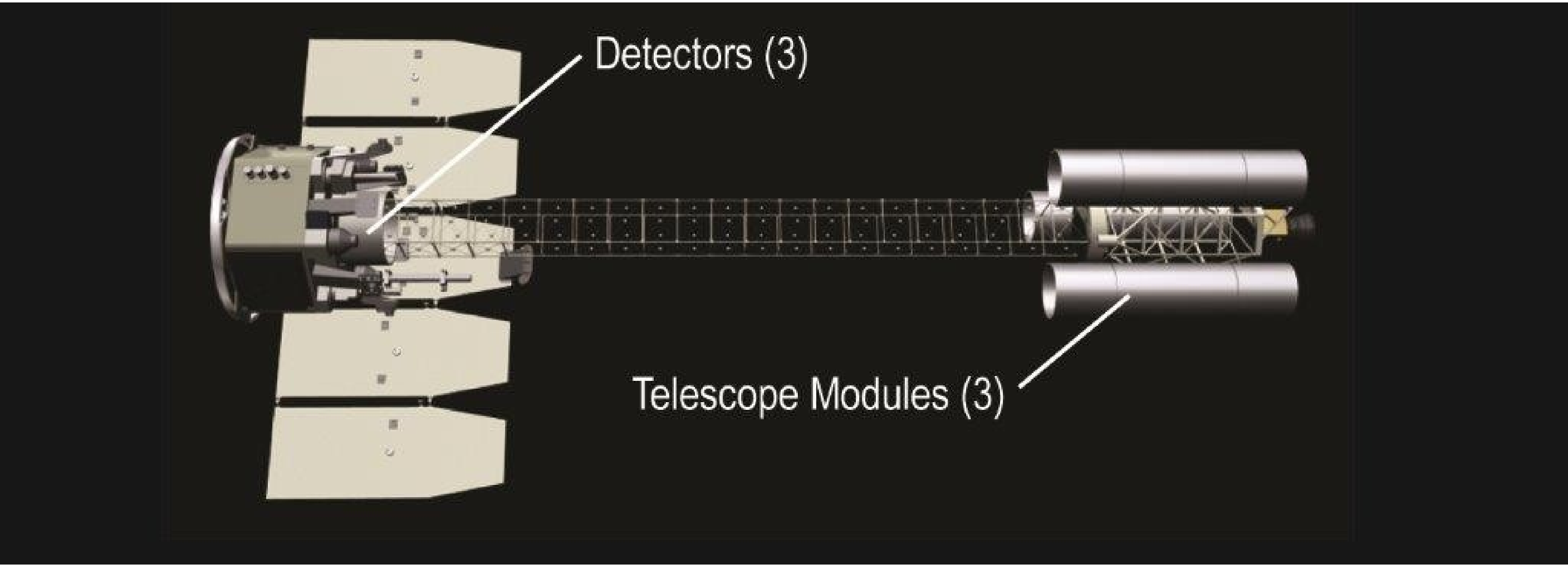
Includes effects of dilution by unpolarized diffuse emission

Many other scientific objectives

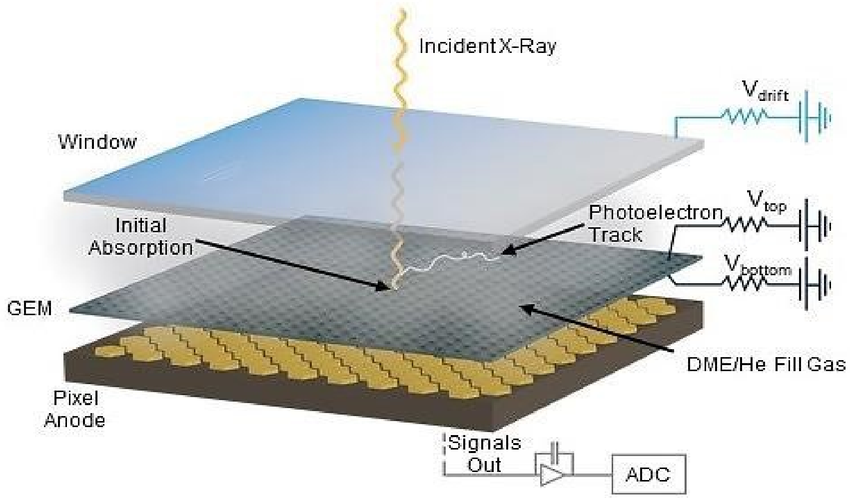
- Mapping of PWN (Crab)
- Multi-λ polarimetry of blazars
- Geometry of X-ray coronae in accreting BHs
- Role of jets in microquasars
- + ... (including fundamental physics: QG, Axion-like particles)

How does IXPE accomplish the science objectives?

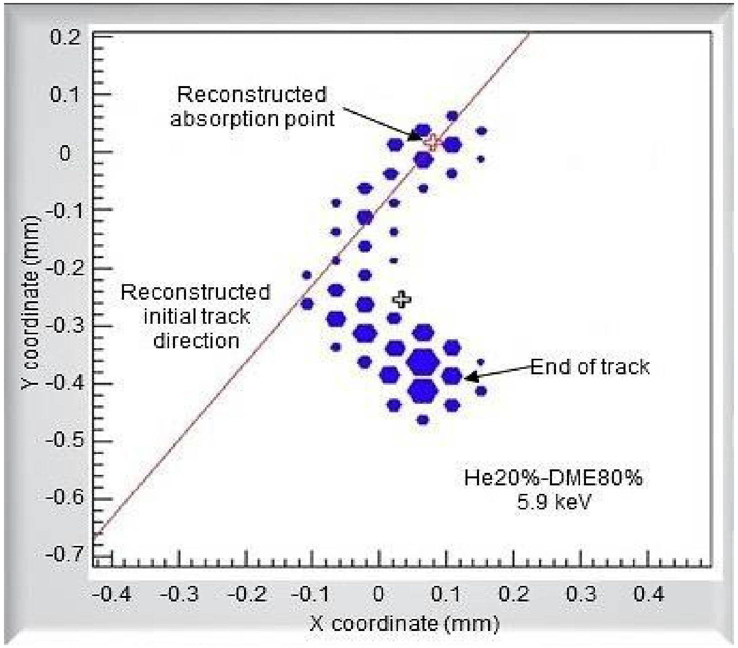
- Three redundant telescope-detector systems
- Gas pixel electron tracking detectors developed in Italy
- Replicated X-ray telescopes with < 30 arcsecond angular resolution (half-power diameter) developed at MSFC



How does IXPE accomplish the science objectives?



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



How does IXPE accomplish the science objectives?

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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

Detector system funding, ground station

Spacecraft, payload structure, payload, observatory I&T

INAF — Polarization-sensitive imaging detector systems

LASP — Mission operations

Roma Tre, Stanford University — Scientific theory

McGill — Science Working Group Co-Chair

Massachusetts Institute of Technology — Student collaboration

Science Advisory Team

- **Pegasus XL launch from Kwajalein in late 2020**
- **540-km circular orbit at 0° inclination**
- **2 year baseline mission, 1 year SEO**
- **Point-and-stare at known targets**

- **Science Operations Center at MSFC**
- **Mission Operations Center at CU/LASP**
- **Malindi ground station (Singapore Backup)**

How does IXPE accomplish the science objectives?

Science Team: Martin Weisskopf (MSFC) – PI
Brian Ramsey (MSFC) – Deputy PI and Payload Scientist
Stephen O'Dell (MSFC) – Project Scientist
Allyn Tennant (MSFC) – Science Data Ops Lead
Paolo Soffitta (IAPS, IT) – Co-I and PI for Italian effort
Ronaldo Bellazzini (INFN, IT) – Co-I and PI for INFN effort
Enrico Costa (IAPS, IT) – Senior Co-I
Victoria Kaspi (McGill, Can) – Co-I SWG Chair
Herman Marshall (MIT) – Co-I
Giorgio Matt (Univ. Roma Tre, IT) – Co-I Theory
Roger Romani (Stanford) – Co-I Theory

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The Imaging X-ray Polarimetry Explorer

With IXPE, polarimetry will at last join timing, imaging and spectroscopy to provide a full, comprehensive view of X-ray sources