The Imaging X-ray Polarimetry Explorer

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On behalf of the IXPE team
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The Imaging X-ray Polarimetry Explorer

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. $a = 0.50 \pm 0.04$; $a = 0.900 \pm 0.008$; $a = 0.99800 \pm 0.00003$ 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
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 $\approx$ 300 years ago
- If not, still a discovery!
Map magnetic field of synchrotron sources to probe sites of cosmic-ray acceleration

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

Cas A
• 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)

### Centaurus A (IXPE 1.5 Ms)

![Image with regions labeled: Core, Jet, Knot A+B, Knot C, Knot F, Knot G, ULX, Includes effects of dilution by unpolarized diffuse emission](image)

<table>
<thead>
<tr>
<th>Region</th>
<th>MDP&lt;sub&gt;99&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>&lt;7.0%</td>
</tr>
<tr>
<td>Jet</td>
<td>10.9%</td>
</tr>
<tr>
<td>Knot A+B</td>
<td>17.6%</td>
</tr>
<tr>
<td>Knot C</td>
<td>16.5%</td>
</tr>
<tr>
<td>Knot F</td>
<td>23.5%</td>
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<tr>
<td>Knot G</td>
<td>30.9%</td>
</tr>
<tr>
<td>ULX</td>
<td>14.8%</td>
</tr>
</tbody>
</table>
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?

\[ \frac{\delta \sigma}{\delta \Omega} = r_0^2 \frac{Z^5}{137^4} \left( \frac{mc^2}{h \nu} \right)^{7/2} \frac{4 \sqrt{2} \sin^2(\theta) \cos^2(\varphi)}{(1 - \beta \cos(\theta))^4} \]
How does IXPE accomplish the science objectives?

- 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 Advisory Team

- 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
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R. Turolla, K. Wu, S. Zane
With IXPE, polarimetry will at last join timing, imaging and spectroscopy to provide a full, comprehensive view of X-ray sources