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

Steve O’Dell (NASA Marshall Space Flight Center) on behalf of the IXPE Team
# International Partnership

<table>
<thead>
<tr>
<th>NASA Marshall Space Flight Center</th>
<th>INAF Istituto Nazionale di Astrofisica</th>
<th>INFN National Institute for Astrophysics</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI team, project management, SE and S&amp;MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving</td>
<td>Polarization-sensitive imaging detector systems</td>
<td></td>
</tr>
<tr>
<td>Detector system funding, ground station</td>
<td>LASP Mission operations</td>
<td></td>
</tr>
<tr>
<td>Spacecraft, payload structure, payload, observatory I&amp;T</td>
<td>Stanford University Scientific theory</td>
<td></td>
</tr>
<tr>
<td>McGill Science Working Group Co-Chair</td>
<td>MIT Massachusetts Institute of Technology Co-Investigator</td>
<td></td>
</tr>
</tbody>
</table>

**Flag Image**

- United States
- Italy
- France
- Canada
- Poland
- Finland
- France
- Germany
- Japan
- Russia
- United Kingdom

---

**Chart Information**

- **Chart**: 2
- **Date**: 2017-12-05
- **Location**: Astronomical X-Ray Optics (AXRO) Prague, Czech Republic
Co-Investigators


Collaborators

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 $\geq 540$ 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
**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
- Isolated pulsars and pulsar wind nebulae
- Supernova remnants
- Magnetars
- Accreting x-ray pulsars
MAJOR COMPONENTS OF THE OBSERVATORY

- Solar Array
- Boom w/ Thermal Sock deployed
- X-ray Shields (x3) deployed
- Forward Star Tracker
- Metrology Camera
- Metrology LEDs
- Tip/Tilt/Rotate Mechanism
- Detector Unit (x3)
- Mirror Module Assembly (x3)
- Spacecraft w/ Avionics
- Aft Star Tracker
- 5.2-m total length deployed
- 4.0-m focal length

Ball Aerospace

2017-12-05

Astronomical X-Ray Optics (AXRO) Prague, Czech Republic

Chart: 6
# Mirror Module Assembly (MMA)

## Properties and Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of MMAs</td>
<td>3</td>
</tr>
<tr>
<td>Mirror shells per MMA</td>
<td>24</td>
</tr>
<tr>
<td>Focal length</td>
<td>4000 mm</td>
</tr>
<tr>
<td>Shell length (P+S combined)</td>
<td>600 mm</td>
</tr>
<tr>
<td>Inner–outer shell diameter</td>
<td>162–272 mm</td>
</tr>
<tr>
<td>Inner–outer shell thickness</td>
<td>0.18–0.26 mm</td>
</tr>
<tr>
<td>Shell material</td>
<td>Nickel–Cobalt alloy</td>
</tr>
<tr>
<td>Mass per MMA</td>
<td>30 kg (current best estimate)</td>
</tr>
<tr>
<td>Effective area per MMA</td>
<td>210 cm² (2.3 keV) &gt; 230 cm² (3–6 keV)</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>≤ 25 arcsec HPD</td>
</tr>
<tr>
<td>Field of view (detector-limited)</td>
<td>12.9 arcmin</td>
</tr>
</tbody>
</table>
### 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 Ni–Co shell onto mandrel
8. Separate shell from mandrel in chilled water

Ni–Co electroformed mirror shells

---

2017-12-05
Astronomical X-Ray Optics (AXRO) Prague, Czech Republic
Chart: 8
**INSTRUMENT DETECTOR UNIT (DU)**

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

\[
\frac{\partial \sigma}{\partial \Omega} = \frac{r_0}{137^4} \left( \frac{mc^2}{\hbar \nu} \right)^{7/2} \frac{4 \sqrt{2} \sin^2(\theta) \cos^2(\varphi)}{(1 - \beta \cos(\theta))^4}
\]
**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)
GROUND SYSTEM: CONCEPT OF OPERATIONS
### Map Magnetic Field of the Brightest Extended Synchrotron Sources

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

![Image of Cassiopeia A (Cas A) Supernova Remnant (SNR)](image-url)

1.5-Ms IXPE (simulated) observation of Cas A
**Centaurus A (Cen A = NGC 5128) central region**

- 1.5-Ms IXPE (simulated) observation of Cen A

<table>
<thead>
<tr>
<th>Region</th>
<th>MDP$_{99}$</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>
</tr>
<tr>
<td>Knot G</td>
<td>30.9%</td>
</tr>
<tr>
<td>ULX</td>
<td>14.8%</td>
</tr>
</tbody>
</table>
Does Sagittarius B2 (Sgr B2) echo Sgr A* x-ray activity?

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

- Highly polarized x radiation, if reflected (Thomson scattered)
  - Polarization perpendicular to projected direction of source
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
- Millisecond (low-B) binaries
**Measure Quantum-Electrodynamical Birefringence in a Magnetized Vacuum**

- **Magnetar** \(B_{\text{surface}} \text{ up to } 10^{15} \text{ G}\)
  - Example: 1RXS J170849.0-400910
    - 11-s pulse period
    - 250-ks IXPE (simulated) observation
Microquasar in accretion-dominated state

- Example: GRS 1915+105
  - 200-ks IXPE (simulated) observation
    - Uses prior disk-orientation information from radio jet