The Imaging X-ray Polarimetry Explorer (IXPE): technical overview II

Steve O’Dell
NASA Marshall Space Flight Center
on behalf of the IXPE Technical Team
<table>
<thead>
<tr>
<th>Mission Partners</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>NASA Marshall Space Flight Center</td>
<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>
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<tr>
<td>IAPS</td>
<td>Polarization-sensitive imaging detector systems</td>
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<tr>
<td>INFN</td>
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<td>OAC</td>
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<td>OHB Italia</td>
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<tr>
<td>UI - LASP</td>
<td>Mission operations</td>
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<tr>
<td>Roma TRE</td>
<td>Scientific theory</td>
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<tr>
<td>Stanford University</td>
<td>Co-Investigator</td>
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<tr>
<td>McGill</td>
<td>Co-Investigator</td>
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<tr>
<td>MIT Massachusetts Institute of Technology</td>
<td>Co-Investigator</td>
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Science Advisory Team
## Mission Description and Technical Capabilities

<table>
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<tr>
<th>Mission name</th>
<th>Imaging X-ray Polarimetry Explorer (IXPE)</th>
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<tr>
<td>Mission category</td>
<td>NASA Astrophysics Small Explorer (SMEX), with Explorers Program Office (GSFC)</td>
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<tr>
<td>Launch</td>
<td>2021 on Space-X Falcon 9, from Cape Canaveral Air Force Station</td>
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<tr>
<td>Operational phase</td>
<td>2 years following 1 month commissioning; extension of operations possible with General Observer program</td>
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<tr>
<td>Orbital parameters</td>
<td>Circular at 540–620 km altitude, near equatorial (&lt; 3° inclination)</td>
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<tr>
<td>Ground stations</td>
<td>Malindi, Kenya (3°S, ASI contribution) primary; Singapore, Malaysia (1°N, KSAT commercial on NASA NEN) secondary</td>
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<tr>
<td>Spacecraft features</td>
<td>3-axis stabilized pointing (non-propellant) with forward and aft star trackers; dithering selectable</td>
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<tr>
<td>Science payload</td>
<td>3 x-ray telescopes, 4.0-m focal length (deployed), co-aligned to forward star tracker</td>
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<tr>
<td>Telescope optics (3+1)</td>
<td>24 monolithic (primary and secondary) Wolter-1 electroformed shells, coaxially nested in each mirror module assembly (MMA)</td>
</tr>
<tr>
<td>Telescope detector (3+1)</td>
<td>Polarization-sensitive gas pixel detector (GPD) to image photo-electron track, in each detector unit (DU)</td>
</tr>
<tr>
<td>Polarization sensitivity</td>
<td>Minimum Detectible Polarization (99% confidence) MDP&lt;sub&gt;99&lt;/sub&gt; &lt; 5.5%, for 0.5-mCrab in 10 days</td>
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<tr>
<td>Spurious modulation</td>
<td>&lt; 0.3% systematic error in modulation amplitude for an unpolarized source</td>
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<tr>
<td>Angular resolution</td>
<td>&lt; 30-arcsec system-level half-power diameter (HPD)</td>
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<td>Field of view (FOV)</td>
<td>10-arcmin diameter overlapping fields of view for 3 detectors’ polarization-sensitive areas</td>
</tr>
<tr>
<td>Energy band; resolution</td>
<td>2–8 keV; (∆E/E) ≈ 20% @ 5.9 keV</td>
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<tr>
<td>Timing accuracy</td>
<td>20 μs, using GPS pulse-per-second signal and on-board clocks</td>
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<tr>
<td>X-ray calibration</td>
<td>Each MMA and DU separately, at least one MMA-DU together on-ground; DUs on-orbit with radioactive calibration sources</td>
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</table>
OBSERVATORY CONFIGURATIONS

STOWED

INITIALIZATION

DEPLOYED

1.1 m

5.2 m

f = 4.0 m

2.6 m

1.8 m
Introduction

Payload

Spacecraft

Calibration

Operations

Conclusion
PAYLOAD COMPONENTS

+Z Star Tracker
MMA Thermal Shield
Deployed X-ray Shields
Mirror Module Support Structure (MMSS) Deck

Payload Deployable Assembly
Mirror Module Assembly (MMA)
Center Tube
Tip/Tilt/Rotate (TTR) Mechanism

Payload Top Deck Assembly
Boom Canister
Detectors Service Unit (DSU) (mounted on bottom side of deck)
Detector Unit
DU Radiator and Thermal Straps

Spacecraft Top Deck
Bipod Struts
Launch Locks
Deployable Boom with Thermal Sock

Spacecraft components shown ghosted
Mirror Module Assemblies (MMAs)

Mirror Module Assembly (MMA)

- Thermal Shield (Nagoya Univ.)
- Front Spiders & Mounting Flange
- Outer Housing Tube
- 24 Ni-Co shells
  - 2 × 30 cm long
  - 16–27 cm diam
- Central Support Tube
- Rear Spiders

Mirror Module Support Structure (MMSS)

- X-ray Shield (deployed)
- Center Tube
- TTR Mechanism
- Boom with Thermal Sock

SPIE 11119-2: IXPE mirror module assemblies
Brian Ramsey (MSFC)
The Imaging X-ray Polarimetry Explorer: technical overview II

**Detector Units (DUs)**

- **Top Deck**
  - Detector Unit (DU) mounted on Top Deck front
  - Detectors Service Unit (DSU) mounted on Top Deck back

**Diagram Notes:**
- Detector Unit (DU)
- Top Deck
Filter & Calibration Wheel (FCW)

- Open, Attenuator, Closed positions
- Four $^{55}$Fe-powered calibration sources
  - Cal A: Polarized 2.98 keV and 5.89 keV
  - Cal B: Unpolarized 5.89 keV (spot)
  - Cal C: Unpolarized 5.89 keV (flood)
  - Cal D: Unpolarized 1.74 keV (flood)

Gas Pixel Detector (GPD)

- DME in gas cell absorbs x-ray photon
  - Photoelectron correlates to polarization
- GEM amplifies ionization track
- ASIC provides pixelated readout
Star trackers (STs)
- Orient +Z ST orthogonal to MMSS
- Orient -Z ST orthogonal to -Z top deck

Mirror Module Assemblies (MMAs)
- Orient each MMA parallel to +Z ST
- Align MMA nodes to nominal positions
- Precisely measure MMA-node positions

Detector Units (DUs)
- Orient each DU orthogonal to top deck
- Precisely position DUs
  - DU-node triangle must be congruent to MMA-node triangle

Tip/Tilt/Rotate (TTR) mechanism
- Translate/rotate DU triangle to align with MMA triangle along +Z ST LOS.
SPACECRAFT COMPONENTS

Spacecraft components

Payload components shown ghosted

Solar array restrain and release system

Spacecraft top deck

LV PAF

Solar Array

Spacecraft components

Payload Assembly

Spacecraft components

Spacecraft top deck
(-Z side shown)

Spacecraft Bus Assembly

Spacecraft structure
Integrated Avionics Unit (IAU)
- Administers most spacecraft functionality

Mechanical; Structural; Thermal

Power; Electrical & Harnessing

Telecommunications

Command & Data Handling (CDHS)
- Functions
  - Computational services
  - Data handling and memory management
  - Telemetry management
  - Time messaging
  - Communication with the Instrument’s Detectors Service Unit (DSU)
- Functionality resides in the IAU

Attitude Determination & Control (ADCS)
- Functions
  - 3-axis stabilized pointing, dithering capable
  - Slewing and momentum management
  - Precise timing and position information
- Components supporting ADCS functions
  - Star trackers (+Z & -Z), shared electronics
  - Coarse sun sensors (12, $4\pi$ coverage)
  - Reaction wheels (3, orthogonally oriented)
  - Torque rods (3, orthogonally oriented)
  - Magnetometer (3-axis unit)
  - GPS (1 receiver, 2 antennae)
- Functionality administered by the IAU
X-ray Calibration

INAF IAPS

- Instrument calibration equipment (ICE)
  - Unpolarized and polarized x-ray sources
  - Stages for positioning sources over DU

- Calibration requirement
  - All 4 DUs (3 flight + 1 spare)

- Filter & calibration wheel (FCW) sets
  - All 4 DUs, 4 sources (Cal A, B, C, D) per set

NASA MSFC

- Facility and equipment
  - 100-m x-ray test facility
  - Unpolarized and polarized x-ray sources
  - Hexapod and stages
  - CCD and SDD x-ray detectors

- Calibration requirement
  - All 4 MMAs (3 flight + 1 spare)
  - At least 1 telescope (MMA + DU)
ORBITAL CONSIDERATIONS

- Inclination near 0°
  - Ground stations
    - Malindi (ASI) at 3° S
    - Singapore (KSAT/NEN) at 1° N
  - South Atlantic Anomaly (SAA)
- Altitude near 600 km
  - Orbital lifetime 10 years or so
  - Re-enters within 25 years
    - Required for uncontrolled re-entry
- Orbital Debris Assessment Report
  - Complicates orbit optimization
Ground Network

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<tr>
<th>Date</th>
<th>Event</th>
<th>Event description</th>
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<tr>
<td>2015 August</td>
<td>Phase-A selection</td>
<td>Selection by Science Mission Directorate (SMD) for Concept Study Report (1 of 3)</td>
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<tr>
<td>2017 January</td>
<td>Phase-B selection</td>
<td>Down-selection by Science Mission Directorate (SMD) for mission formulation</td>
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<tr>
<td>2017 September</td>
<td>M-SRR</td>
<td>Mission System Requirements Review</td>
</tr>
<tr>
<td>2018 June</td>
<td>M-PDR</td>
<td>Mission Preliminary Design Review</td>
</tr>
<tr>
<td>2018 November</td>
<td>KDP-C</td>
<td>Key Decision Point – C (Confirmation Review)</td>
</tr>
<tr>
<td>2019 March</td>
<td>GS-PDR</td>
<td>Ground System Preliminary Design Review</td>
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<tr>
<td>2019 June</td>
<td>M-CDR</td>
<td>Mission Critical Design Review</td>
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<tr>
<td>2019 November</td>
<td>GS-CDR</td>
<td>Ground System Critical Design Review</td>
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<tr>
<td>2020 April</td>
<td>M-SIR</td>
<td>Mission System Integration Review</td>
</tr>
<tr>
<td>2020 May</td>
<td>KDP-D</td>
<td>Key Decision Point – D</td>
</tr>
<tr>
<td>2021 March</td>
<td>ORR and MRR</td>
<td>Operational Readiness Review and Mission Readiness Review</td>
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<tr>
<td>2021 April</td>
<td>Launch</td>
<td>Launch on Falcon-9 from Cape Canaveral Air Force Station (CCAFS)</td>
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<tr>
<td>2021 May</td>
<td>Phase-E start</td>
<td>Start of operational phase, to last at least 2 years</td>
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