Imaging X-ray Polarimetry Explorer (IXPE) Mirror Module Assembly

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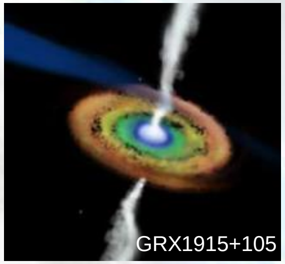
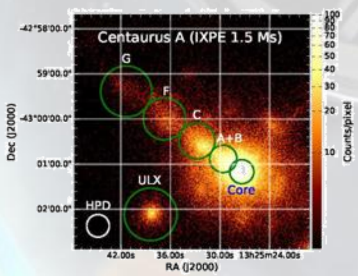
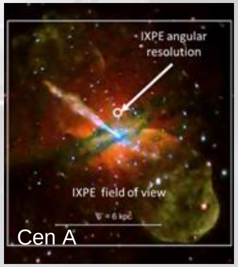
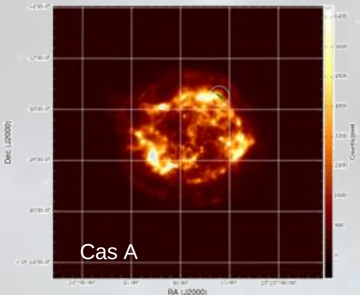
IXPE addresses key scientific objectives

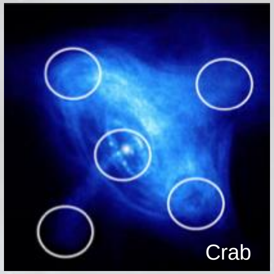
- Opens a new window on the universe — imaging (30“) X-ray polarimetry
  - The science driver that advances and impacts high-energy astrophysics
  - Increases information space and lifts modeling degeneracies
- Addresses key questions, providing new scientific results and constraints that trace back to the Astrophysics Roadmap and the Decadal Survey
  - 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 our 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, as evidenced by our Design Reference Mission











IXPE Team and Mission

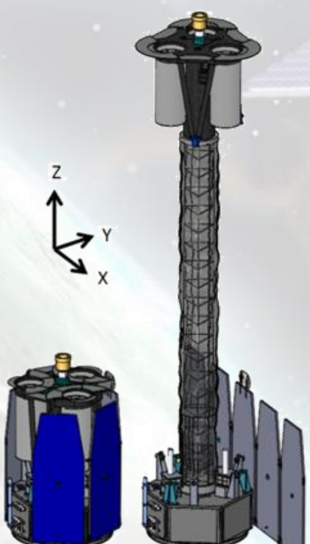
IXPE

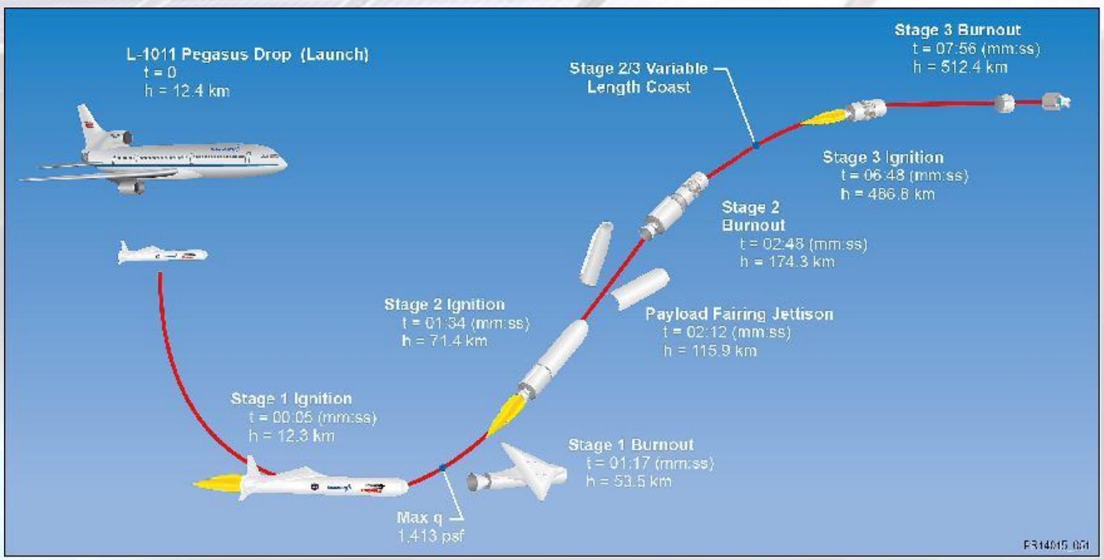
Institutional Roles and Responsibilities are Clearly Defined

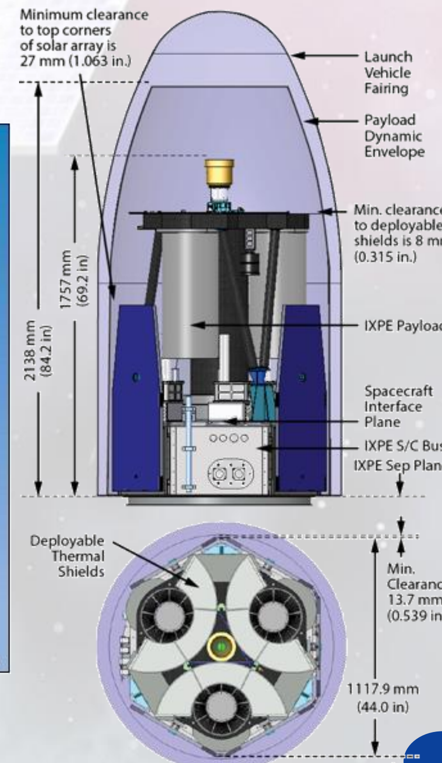
Marshall Space Flight Center: PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving	iaps, INAF Istituto Nazionale di Astrofisica National Institute for Astrophysics, INFN: Polarization-sensitive imaging detector systems
	LASP: Mission operations
asi agenzia spaziale italiana: Detector system funding, ground station	Roma Tre Università degli Studi, Stanford University: Scientific theory
	McGill: Science Working Group Co-Chair
Ball: Spacecraft, payload structure, payload, observatory I&T	Massachusetts Institute of Technology: Student collaboration

Mission Design and Operations Concept are Straightforward

- NASA Explorer Mission, cost capped at $175M (FY15)
- Class D Mission managed by MSFC
- XL launch from Kwajalein
- 540-km circular orbit at 0° inclination
- 2 year baseline mission, 1 year SEO
- PI: Martin Weisskopf, MSFC
- Launch ready by end of 2021





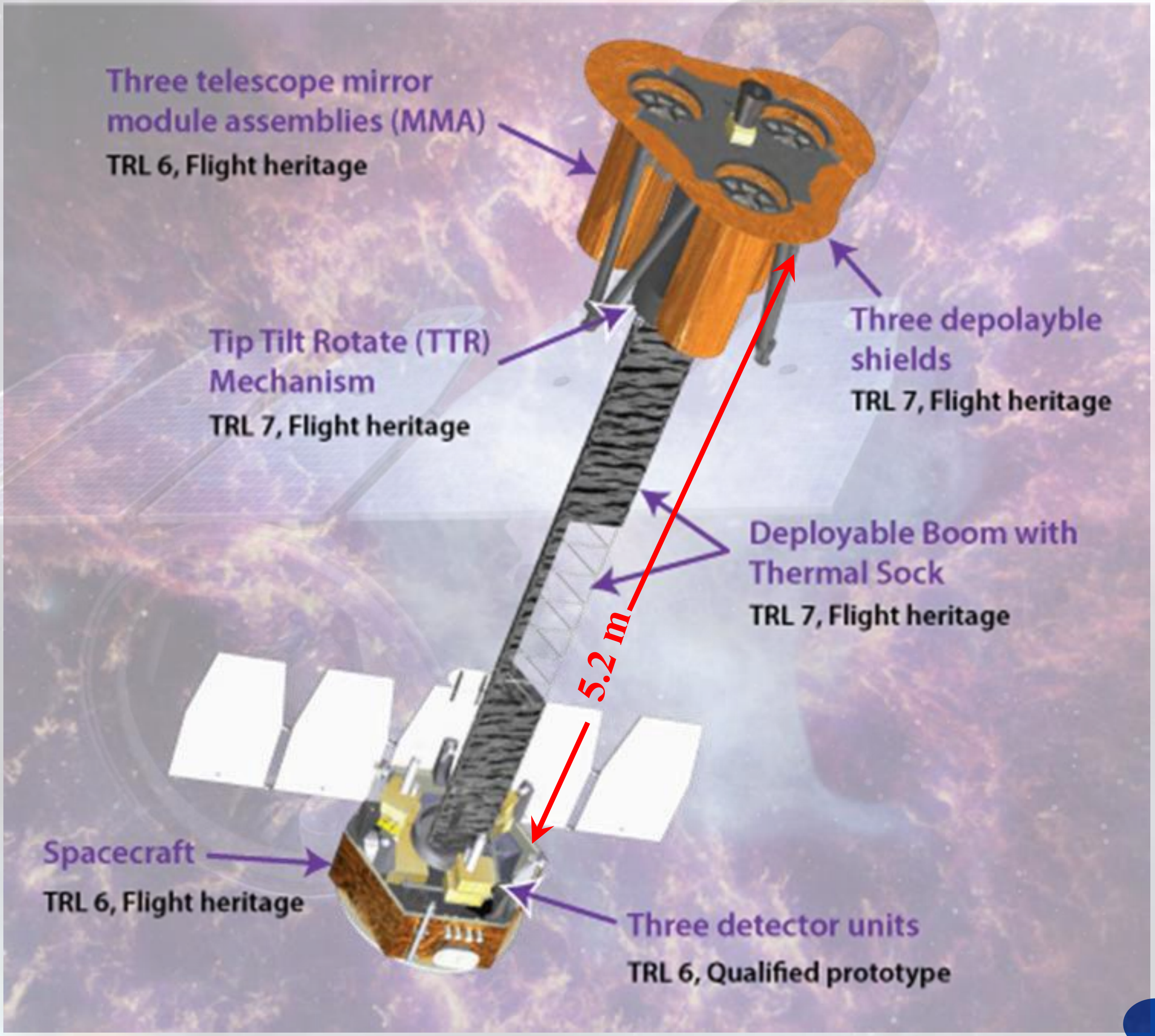


IXPE INSTRUMENT DESCRIPTION

IXPE

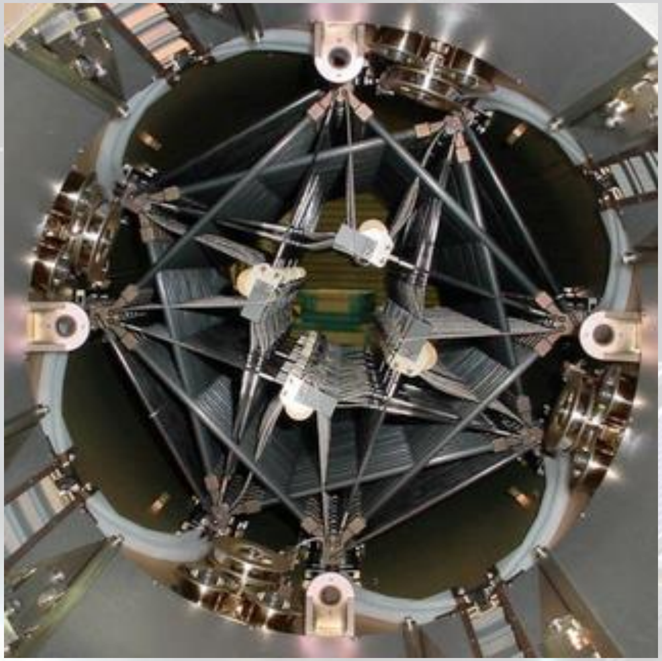
Measures spatial, spectral, timing, and polarization state of X-rays from a selection of known targets (~50)

- Set of three mirror module assemblies focus x rays on to three corresponding focal plane detector units.
- Mirror modules provide imaging and background reduction
- Detectors provide position, energy and polarization information, photon by photon, plus time stamp



IXPE Deployment

Mast Deployment – used successfully on multiple missions



IXPE Boom Stowed and Deployed with thermal sock

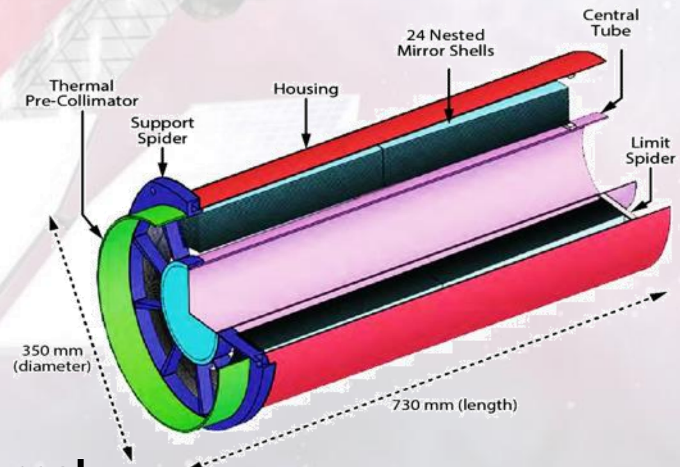
Property	**Value**
Mass	**4.9 kg**
Length	**3.64 m**
Deployment repeatability	**Length: 0.2 mm, Translation: 0.07 mm Twist: 0.27º**

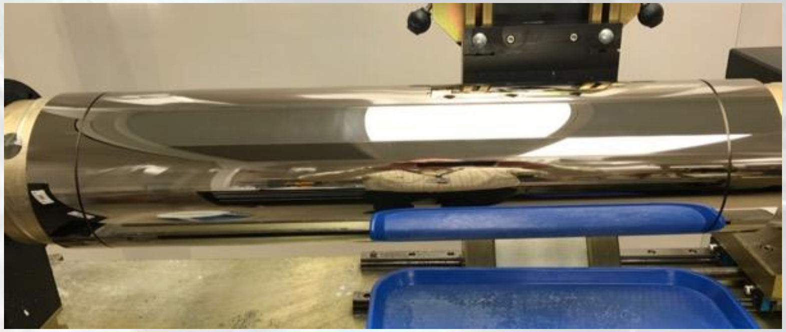
IXPE Mirror Module Assembly

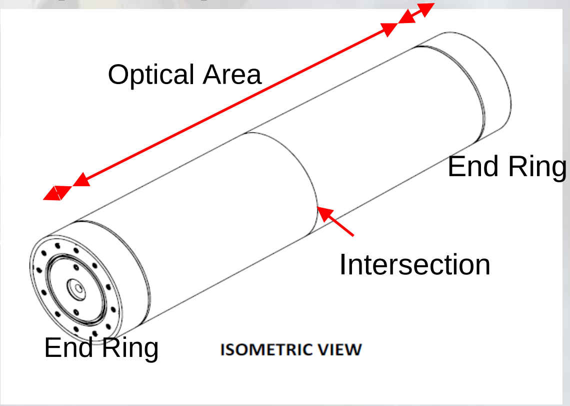
MMA Optical Requirements	
MMA-7	The combined effective area of all three MMAs with their thermal shields shall be greater than 589 cm^2 at 2.3 keV, and greater than 686 cm^2 at 4.5 keV.
MMA-9	The focal length of each MMA shall be 4000 +/- 1 mm, measured from the node of the optical assembly.
MMA-8	The HPD of each mirror module assembly shall be no greater than 26 arcseconds at 2.3 keV and 4.5 keV on axis.

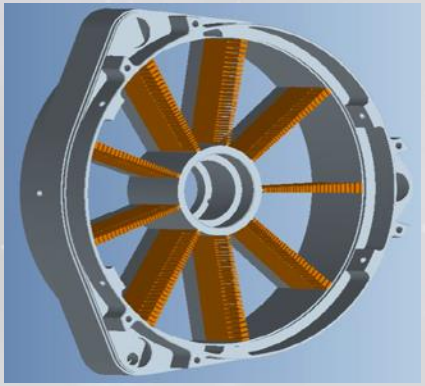
MSFC will fabricate:

- **24 mandrels**
- **<u>1 engineering unit</u> consisting of 6 shells, 3 mass simulators, 2 external thermal shields, 1 support spider /combs & 1 end capture spider**
- **96-102 Nickel – Cobalt (not Ir coated) very thin shells**
- **<u>4 flight units (3 + spare) with</u> w/ 24 nested shells, 2 external thermal shields, spider /combs & end capture spider**



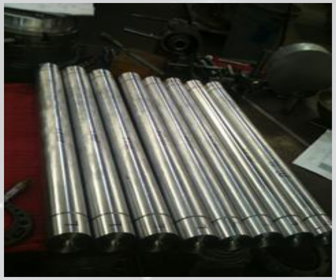






Replicated Optics Manufacturing at MSFC IXPE

1. CNC machine, mandrel formation from Al Bar



2. Chemical clean and activation & Electroless Nickel (EN) plate

Currently contracted out

3. Precision turn to sub-micron figure accuracy

4. Polish and superpolish to 3-4 Å finish

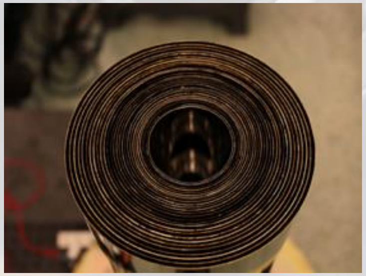
5. Metrology – repeat Step 4 until surface finish met

6. Ultrasonic clean & passivation to remove surface contaminants

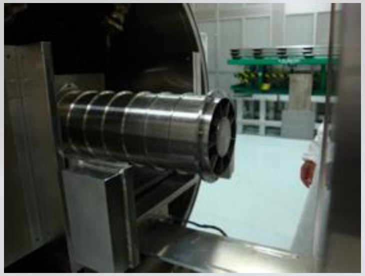
7. Electroform nickel shell onto mandrel

8. Separate optic from mandrel – reuse mandrel for next shell

8. Align shells into module



9. Test module



Mandrel Error Budget Allocations

PARAMETER	SENSITIVITY	ALLOWANCE	HPD (ARCSEC)
CIRCULARITY (OUT OF ROUNDNESS)	100 ARCSEC HPD / MM	0.0125 MM (0.0005”)	1.2
P-H SLOPE ERROR	0.6 ARCSEC HPD / MRAD	10 MRAD	5.8
INTERSECTION SHIFT	2.5 ARCSEC HPD / MM	0.5 MM (0.020”)	1.25
RADIUS ERROR	73 ARCSEC HPD / MM	0.025 MM (0.001”)	1.8
AXIAL FIGURE PROFILE	1 ARCSEC / ARCSEC	10 ARCSEC	10.0
BOW (PARABOLA)	2 ARCSEC / MICRON (NOT LINEAR)	1.5 MICRON	3.0
TOTAL (RSS)			12.2

These specifications have been routinely achieved in previous programs.

Based on past experience with similar mandrels:

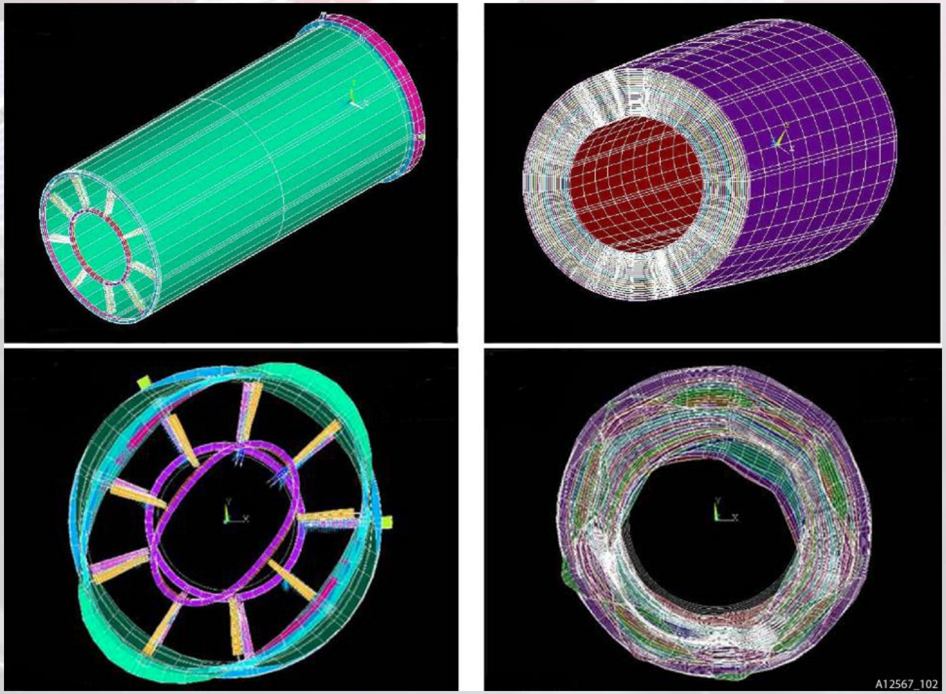
ART-XC **(25 arcsec HPD modules from 15 arcsec mandrels)**
FOXSI **(20 arcsec modules from 10 arcsec mandrels)**
HERO **(25 arcsec from 8 arcsec mandrels but with no alignment system)**

IXPE EDU Status

Engineering Development Unit consist of the inner 3 (M1-M3) and outer 3 (M22-M24) shells and mass simulators for the 18 shells in between. This will be x-ray tested, vibrated at launch qualification levels and x-ray tested again to verify the shells remain bonded and aligned.

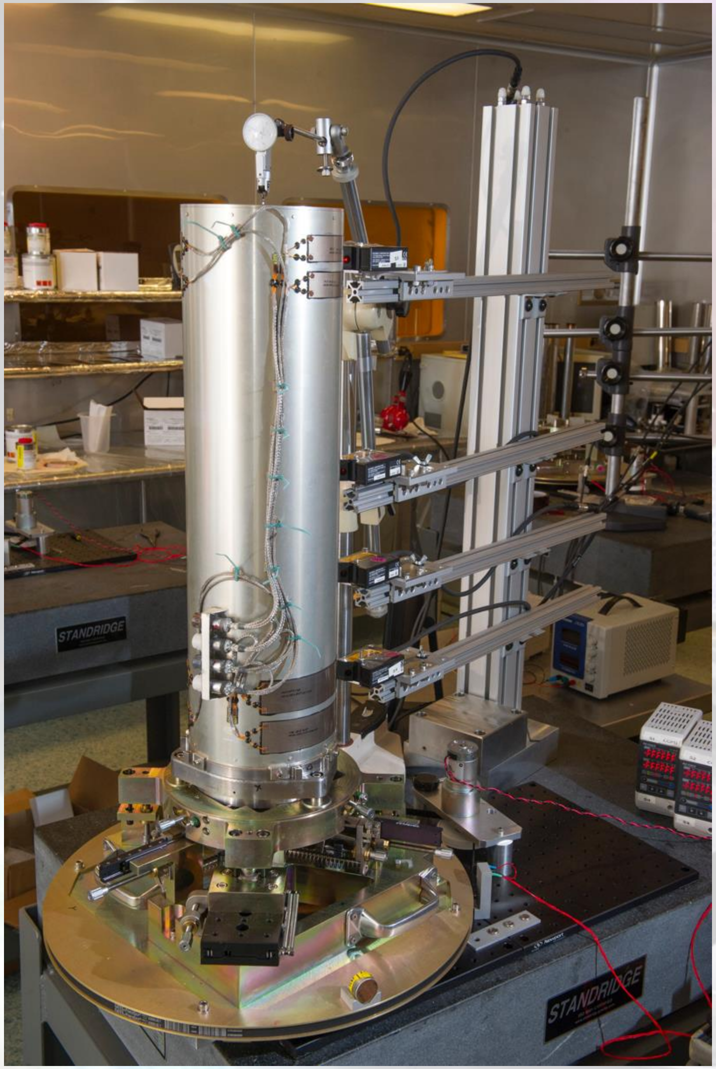
Currently M1-M3 and M22 are in the polishing cycle and M23 and M24 are in the diamond turning process.

ART-XC Mass Simulator

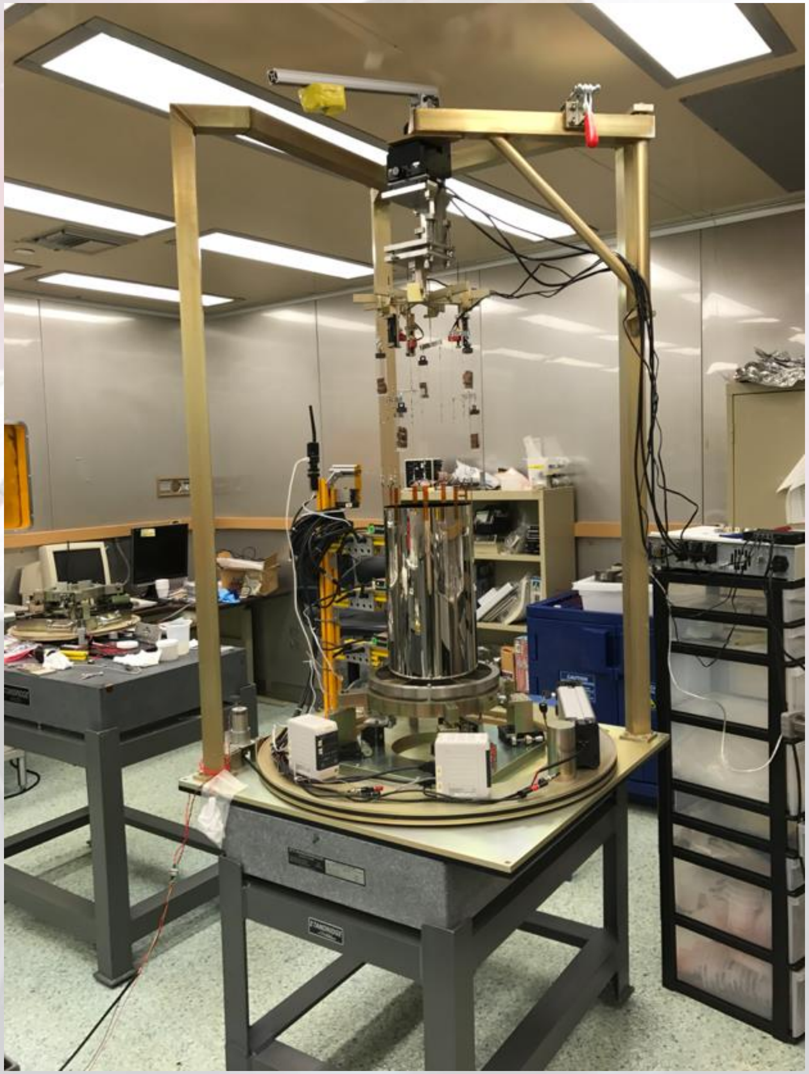


Top panels show model of MMA structure and mirror shells. Bottom panels show a typical mode excited during launch (displacements magnified for clarity).

IXPE Alignment System



ART-XC shells supported from 3 points during the alignment and bonding process



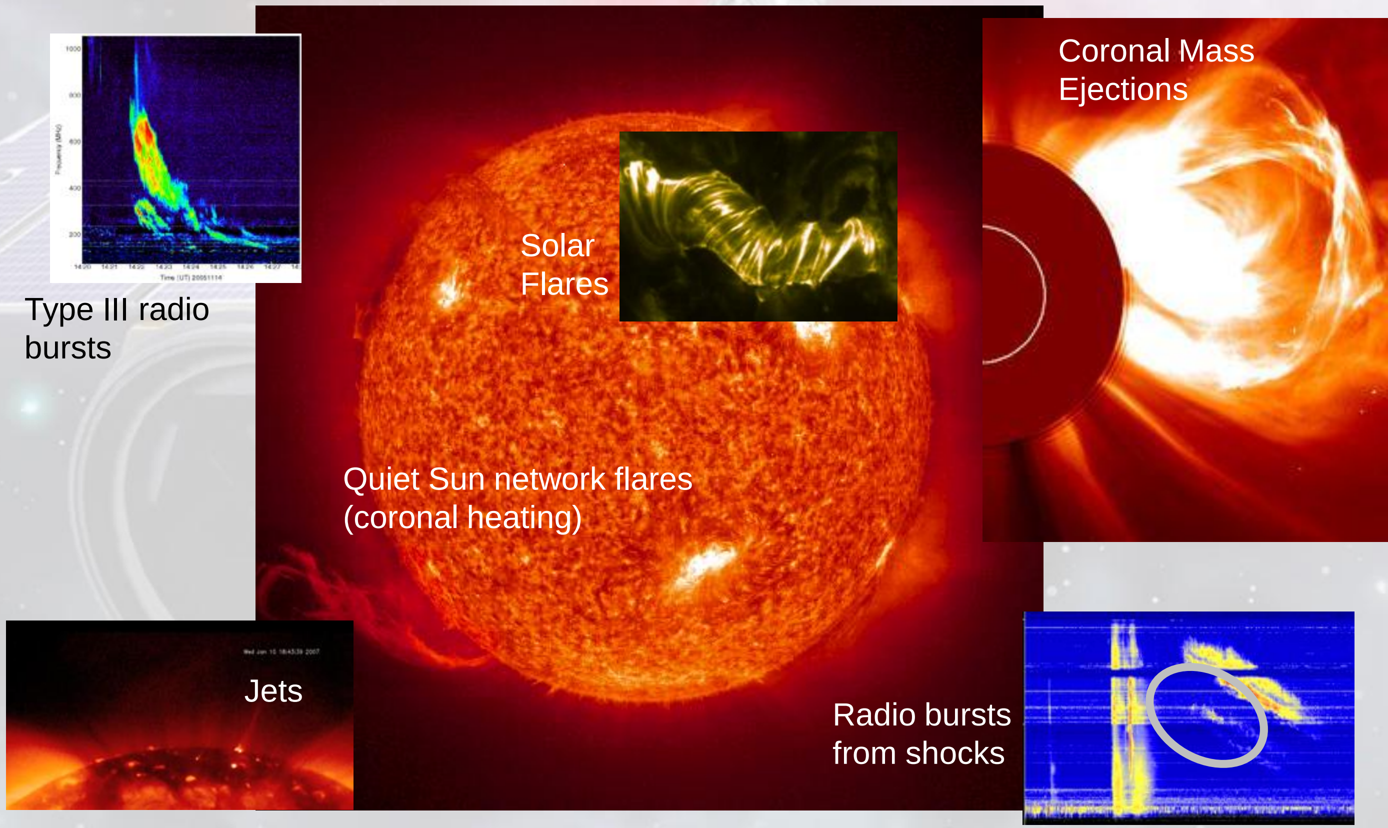
IXPE shells are thinner than ART and will be gravity off-loaded during the alignment and bonding process

MSFC X-ray Optics Heritage

Parameter	FOXSI -1 (-2 & 3)	ART-XC	IXPE
Number of mirror modules	7	7 (plus 1 spare)	3 (plus 1 spare)
Number of shells per mirror module	7 **(10 for selected modules)**	28	24
Focal length	2000 mm	2700 mm	4000 mm
Total shell length	600 mm	580 mm	600 mm
Range of shell diameters	76 – 104 mm	50 – 150 mm	162 – 272 mm
Range of shell thicknesses	0.25 mm	0.25 - 0.35 mm	0.18 – 0.26 mm
Shell material	Electroformed nickel–cobalt alloy Coating: > 30 nm of iridium (> 90% bulk density)	Electroformed nickel–cobalt alloy Coating: > 10 nm of iridium (> 90% bulk density)	Electroformed nickel–cobalt alloy
Effective area per mirror module	150 cm^2 **(200)** at 8 keV, 14 cm^2 **(40)** at 15 keV	≥ 65 cm^2 at 8 keV (on axis)	197 cm^2 (at 2.3 keV); > 230 cm^2 (at 3–6 keV)
Angular resolution (HPD)	10 arcsec	25 arcsec HPD on axis (measured)	≤ 25 arcsec HPD on axis

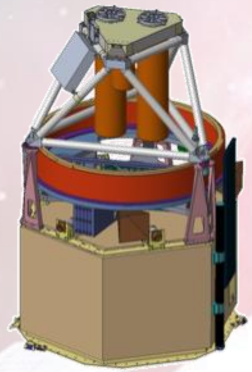
FOXSI Free Flyer Science Objectives

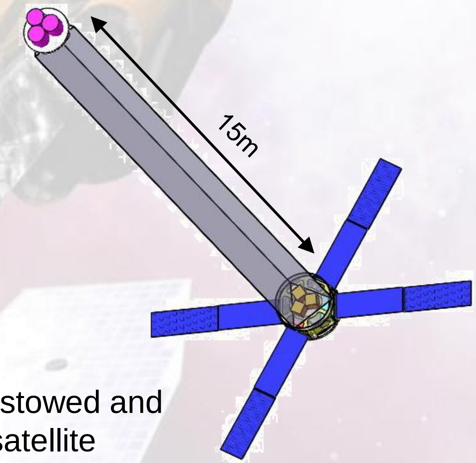
- FOXSI Free Flyer currently in Phase A study
- FOXSI Free Flyer addresses the fundamental processes of impulsive energy release and particle acceleration in the solar corona.
- FOXSI will achieve this through focused hard X-ray imaging with **100 times better sensitivity and dynamic range** than previous instruments (e.g. RHESSI).
- FOXSI will observe emission from energetic electrons:
  - directly in the acceleration site in the corona such as near flare reconnection sites or CME shocks,
  - as they travel through the corona,
  - where they are stopped in the chromosphere, and
  - as they escape into interplanetary space.



FOXSI Free Flyer Hardware

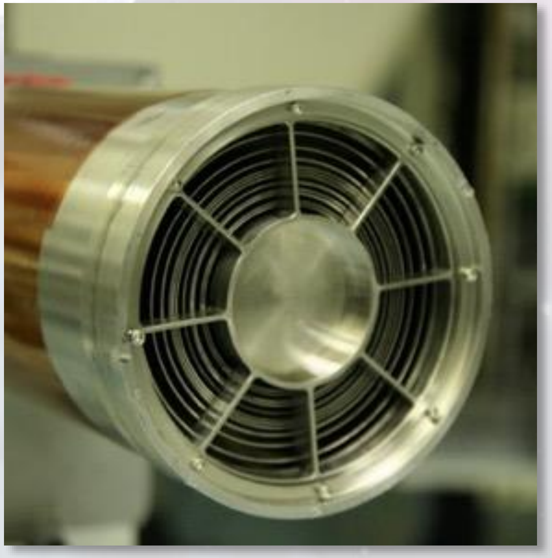
- If selected MSFC will provide 2 flight modules + 1 spare module, fully calibrated, each with 15 or 20 shells
- X-ray optics is a Tier 1 for Scientific Research at MSFC
- FOXSI science requires high-resolution hard x-ray optics, niche area for MSFC – no domestic competitors
- Sub-Orbital Development (significant)
  - FOXSI rocket flights (Nov. 2012, Dec. 2014), FOXSI-3 on schedule
  - HERO(ES) balloon flight (May, 2001 and Sept. 2013)
- Orbital Development
  - ART-XC fabricated and delivered by MSFC
  - IXPE SMEX under development





Schematic representations of stowed and deployed FOXSI SMEX satellite

Seven FOXSI Mirror Modules mounted on rocket



HERO (balloon) Mirror Module fabricated at MSFC