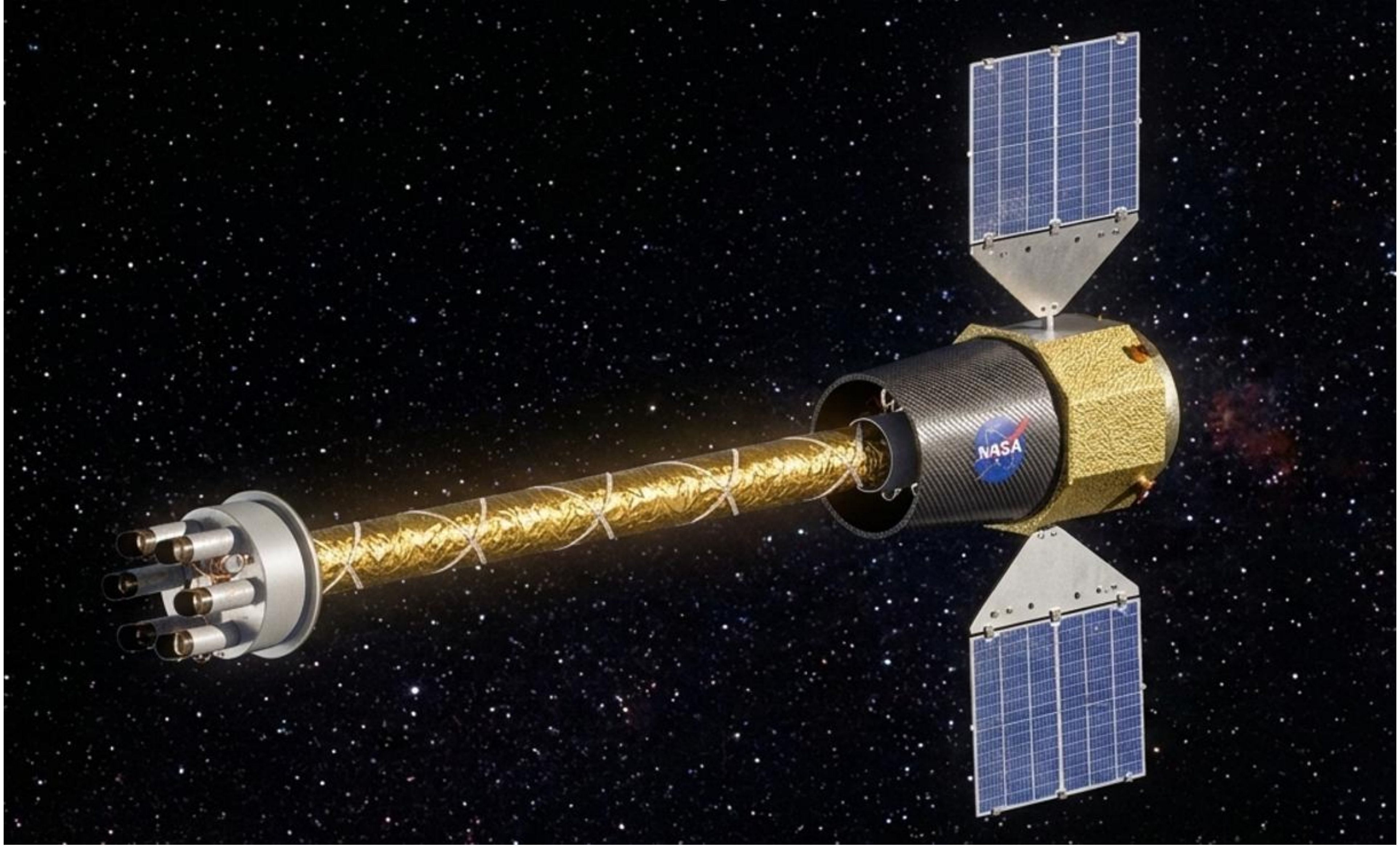


High EneRgy Observatory for Imaging X-rays (HEROIX) Mission Concept

Nick Thomas(1), Chien-Ting Chen(2,1) on behalf of the HEROIX Mission Concept Team
(1) NASA Marshall Space Flight Center, (2) Universities Space Research Association
August 8th, 2026

The High Energy Universe in High-Resolution

- Hard X-ray probes photons generated by physical processes in extreme astrophysical environments, from accreting of stellar mass compact objects to shock waves and jets in galaxy clusters
- *NuSTAR* pioneered this field as the first focusing hard X-ray mission in orbit, albeit limited by its ~arcmin half power diameter
- An order-of-magnitude improvement in angular resolution will lead to exciting discoveries

NASA

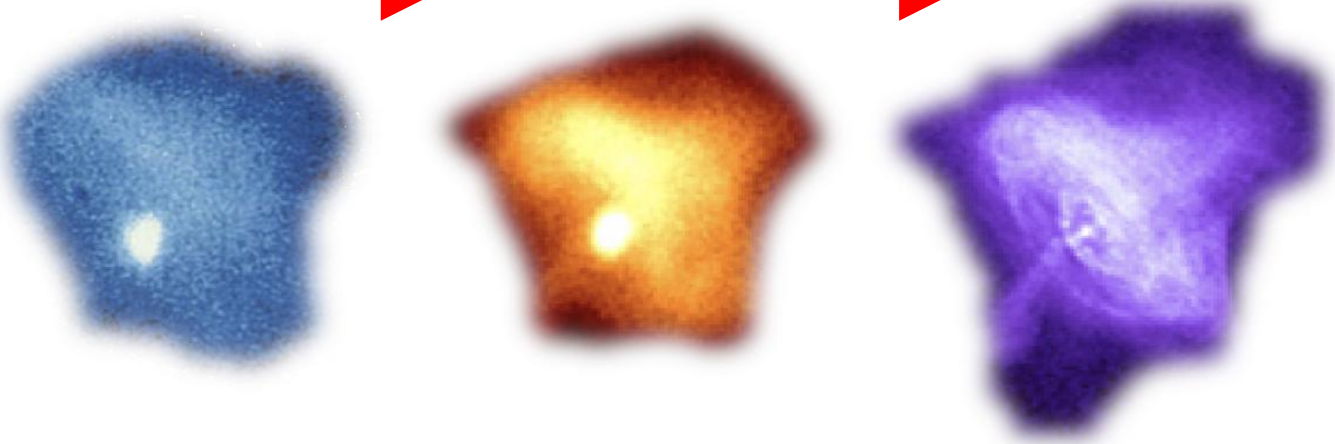
Einstein

German Aerospace Center

ROSAT

NASA

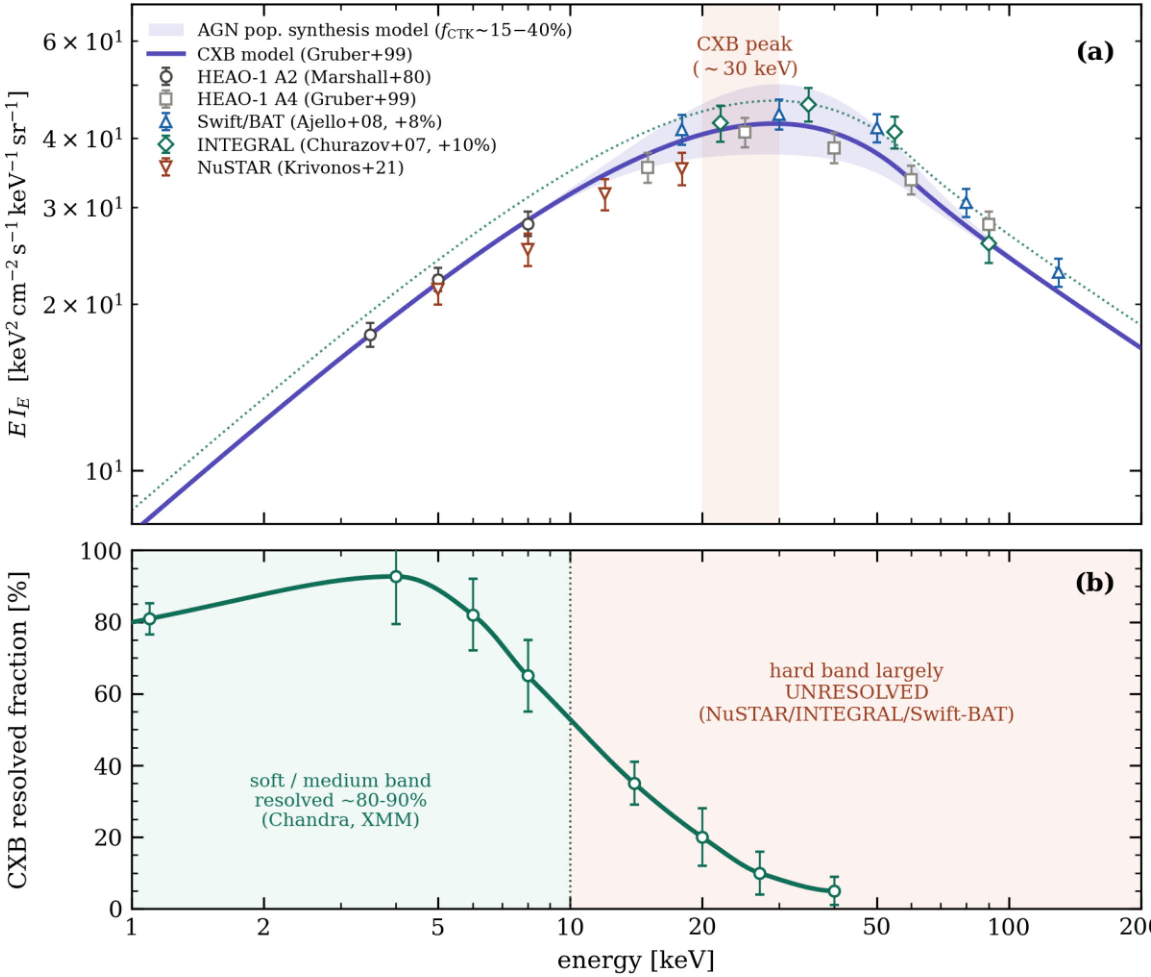
Chandra

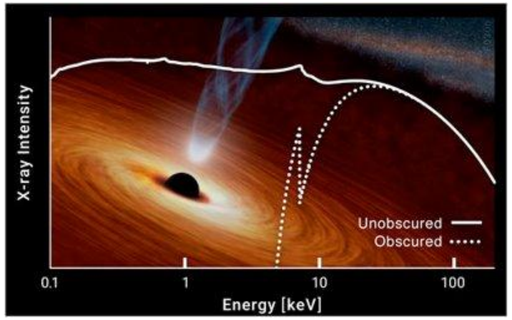


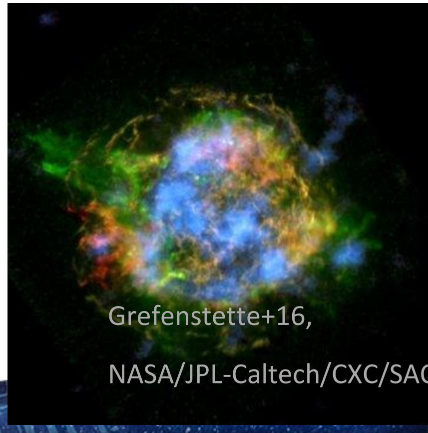
The Broadband X-ray Universe

A next-generation, broadband, high resolution X-ray observatory will unlock a new frontier in high-energy astrophysics:

- Resolve the Cosmic X-ray Background at its peak of ~30 keV
- Understand dust-enshrouded X-ray population, including X-ray binaries and AGN
- Particle acceleration in extreme environments such as shock waves and jets from celestial objects of all sizes
- Accretion physics with broad-band X-ray spectroscopy
- And many more discoveries





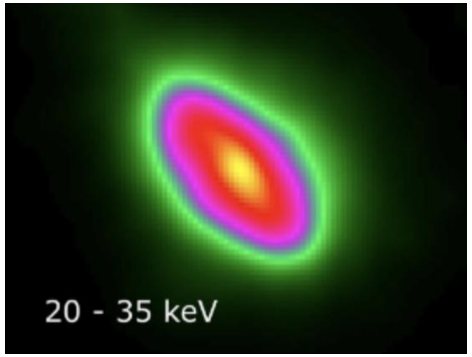


The Hard-X-Ray Universe in High-Resolution

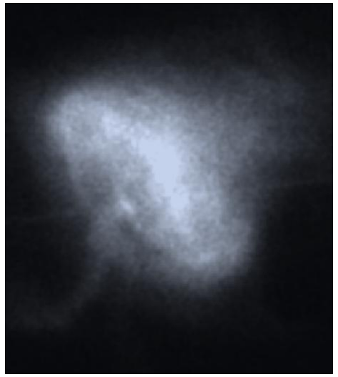
Open science questions addressed by a high-angular-resolution, hard-x-ray observatory include.
  - o What are the physics of supernova?
  - o X-ray binary population in Sgr* Complex
  - o How do supermassive blackholes grow? How does this influence galaxy evolution?
- Strategy
  - o The *SuperHERO* X-ray telescope balloon mission. Inaugural flight in the fall of 2028 from North America.
  - o Propose future *SuperHERO* missions for long duration balloon flights with increased technical capabilities.
  - o Continued work on the ISFM package and other MSFC's suborbital missions will further progress high angular resolution, replicated NiCo technology.
- MSFC's x-ray optics will provide over an order of magnitude improvement to the state-of-the-art, enabling future space-based mission with increased effective area and high-angular resolution.
  - o ***High EneRgy Observatory for Imaging X-rays (HEROIX) Mission Concept***

60 arcsec
State-of-art

10 arcsec
Future-mission

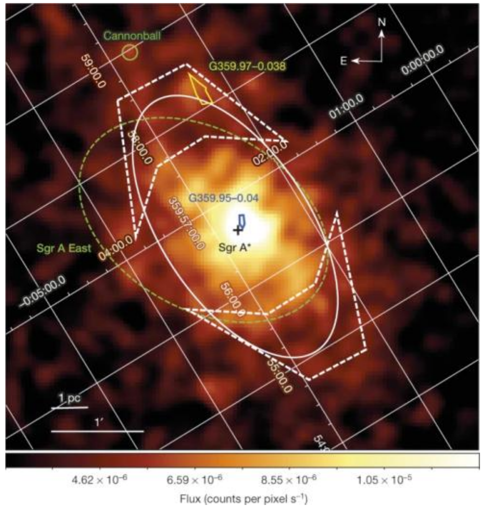


Harrison et al. 2013, Madsen et al. 2015

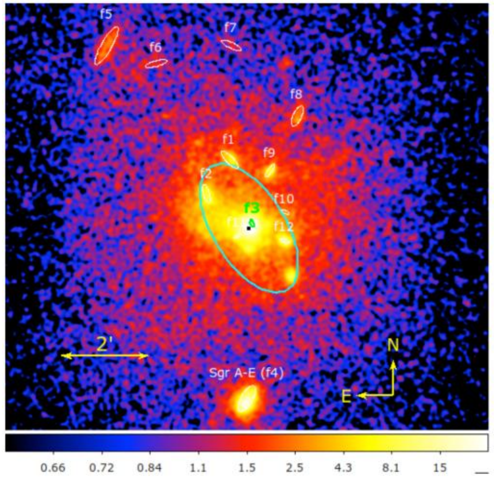


Projected by Chien-Ting Chen Chandra Data
Mori et al. 2002, Weisskopf et al. 2012

The Crab Nebula



Perez et al. 2015



Mori et al. 2023

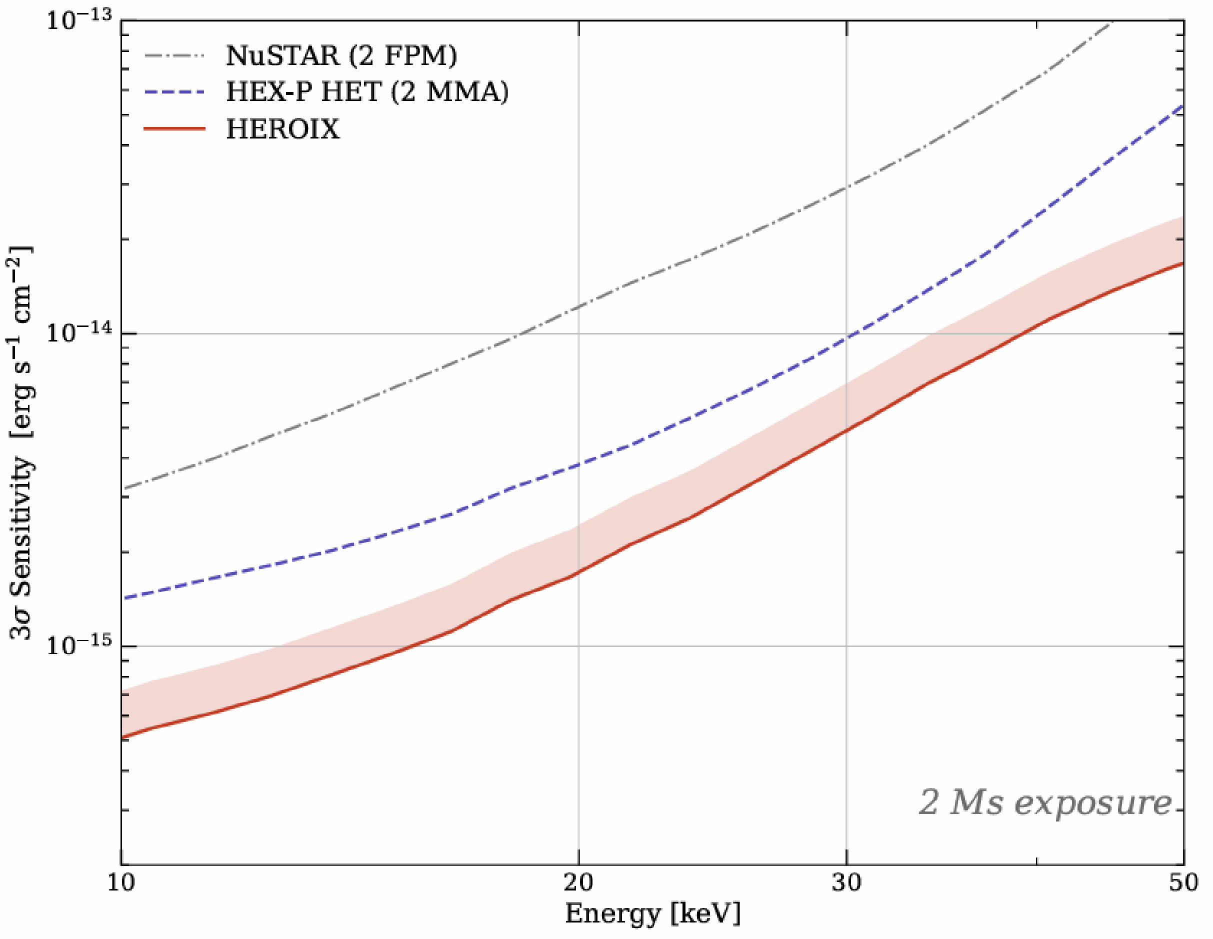
Sgr* Complex

The HEROIX mission concept

- Six co-aligned broadband X-ray telescopes
- 5 arcsecond HPD
- 570 cm^2 @ 30 keV effective area
- Field of View: 12 arcmin
- Hybrid Focal Plane Assemblies
  - 1 keV to 80 keV
  - Developed for *FORCE* Mission
- 12-meter focal length
- MIDEX class mission

Initial NASA MSFC Advance Concept Office (ACO) study completed in June 2026

HEROIX Sensitivity Curve



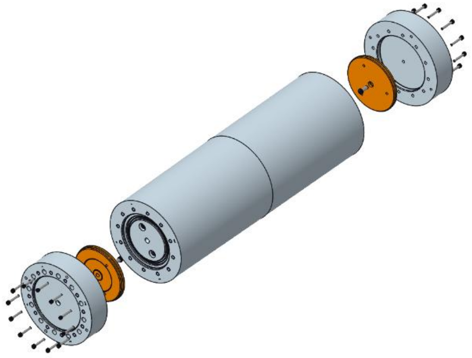
Harrison et al, 2013 (*NuSTAR*)
Civano et al, 2025 (*HEX-P*)

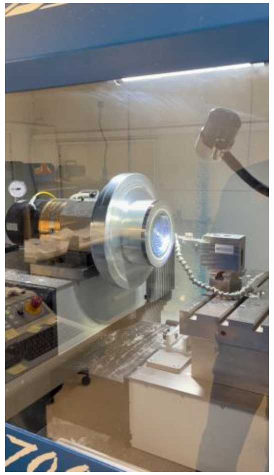
HEROIX Integrated Mission Requirements

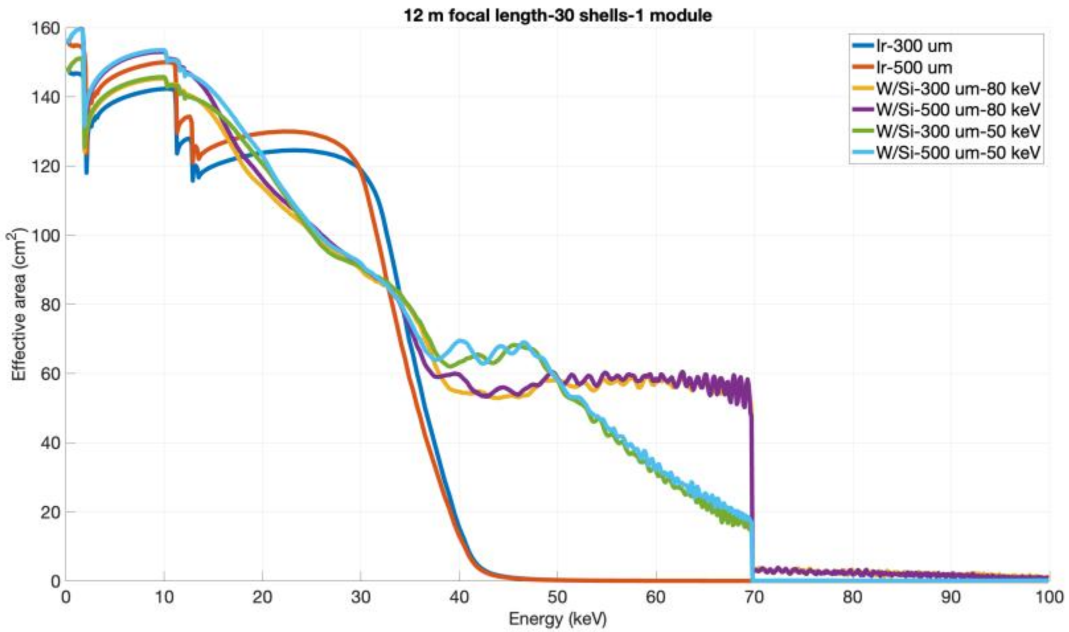
- Launch date: 8 years after selection
  - Telescope delivered by NASA's Launch Service Program
- Mission lifetime: 3 years with option to extend
- Low background
  - Avoid proton activation of focal plane
- Point Knowledge Requirements (Pitch & Yaw):
  - 0.6 arcsec RMS, 0.81 arcsec HPD
- Pointing Target Requirement: 1 arcmin
- Sun Avoidance Angle: 45 deg
  - Thermal baffling
- Slew Rate: 4 degrees a minute
- Data rate: 3 GB/day (10 GB/day Max)
- Download frequency: 4 times a day
- Spacecraft bus and commercially available components meet thermal, mechanical, and electrical requirements for science payload

High Resolution Hard X-ray Telescope

- Six Mirror Module Assemblies (MMAs)
- 30 High-Resolution Mandrels
  - Similar scope to *IXPE*, identical prescription to *SuperHERO*
  - CNC deterministic polished
- 12-meter focal length
- Shell diameters range from 200 mm to 271 mm at the node
- Shell wall thickness: 0.5 mm
- Shell P and H each have 300 mm length for a total shell length of 600 mm
- Designed for fabrication on an M-40 DT (diamond-turning) or similar precision diamond-turning machine
- Multilayer reflective coating: Pt/C
- Energy band coverage: 0.1 keV to 79 keV
- Includes thermal baffling for thermal stability
  - Must maintain 20 deg C +/- 1 deg
  - Maintained with zonal heating elements

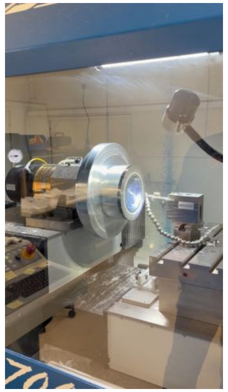


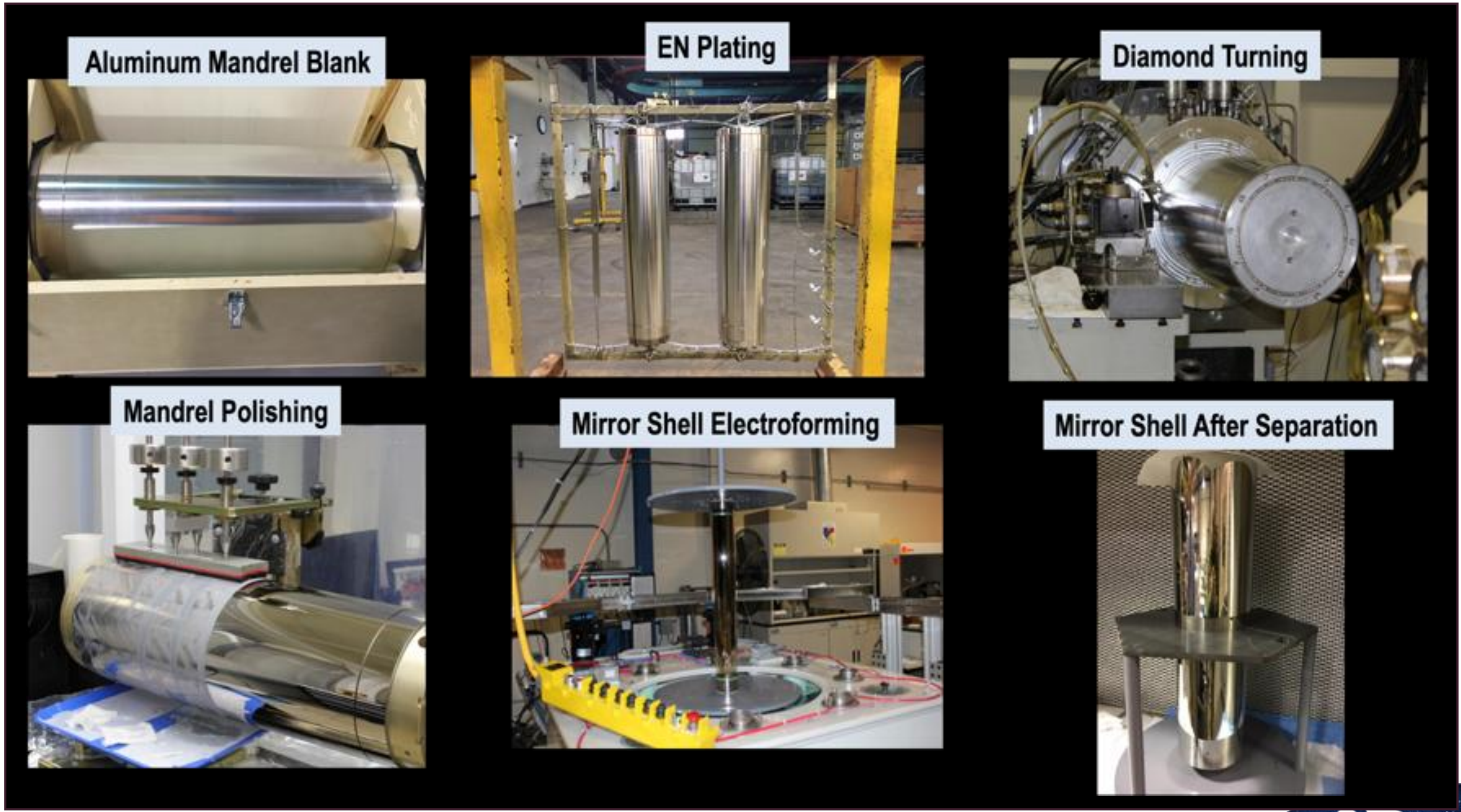




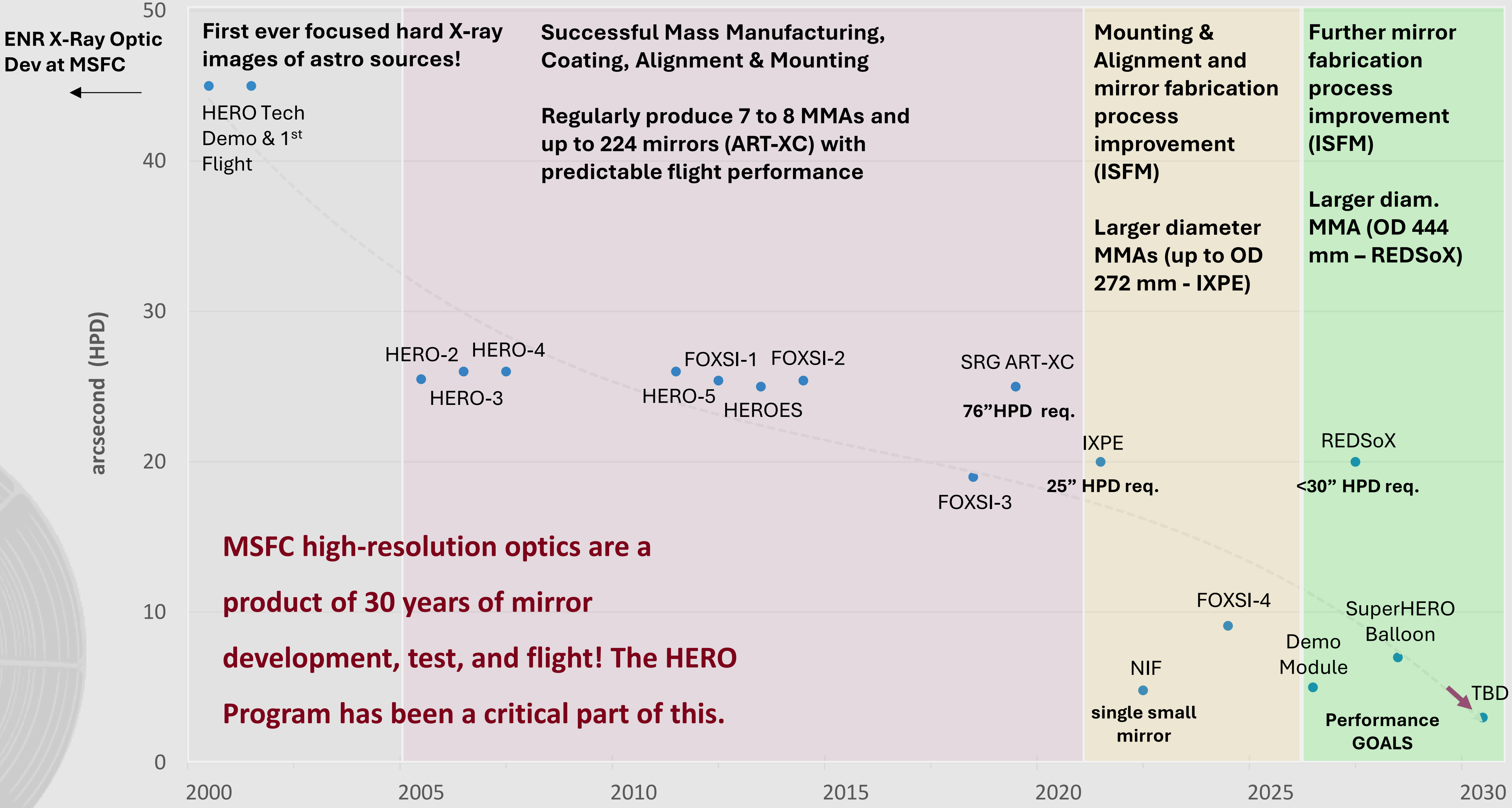
Electroformed Nickel-Cobalt Replicated Optics
Full Shell X-ray Optics

- *IXPE* size mandrels requiring the use of the Moore M-40 Diamond Turning Machine
  - 600 mm ling (300 mm P / 300 mm H)
- Axial figure error greatly reduced with reduced deterministic polishing using the Zeeko IRP600X



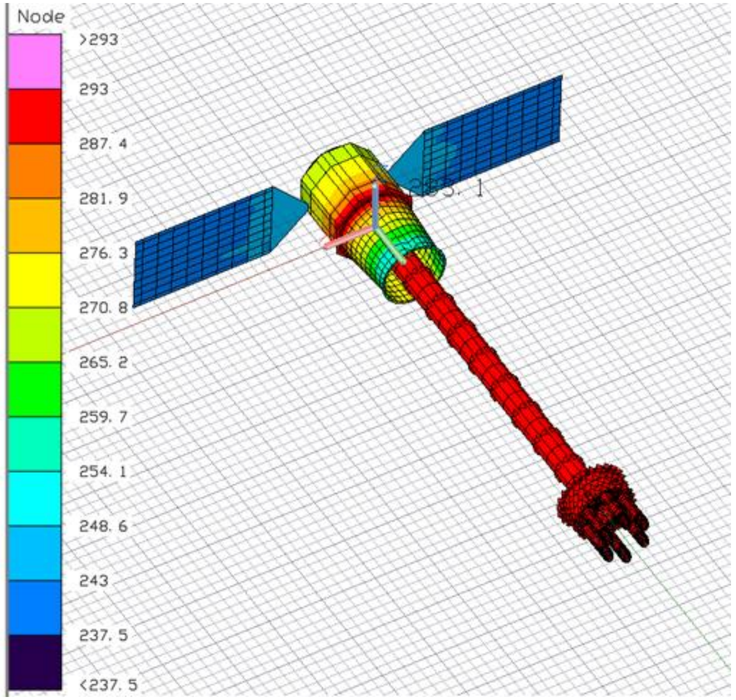


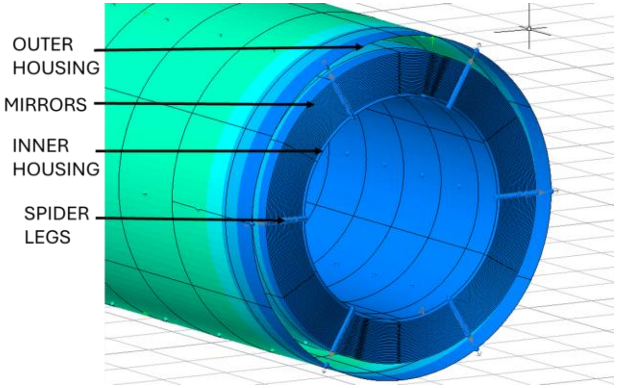
MSFC X-Ray Mirror Module Performance

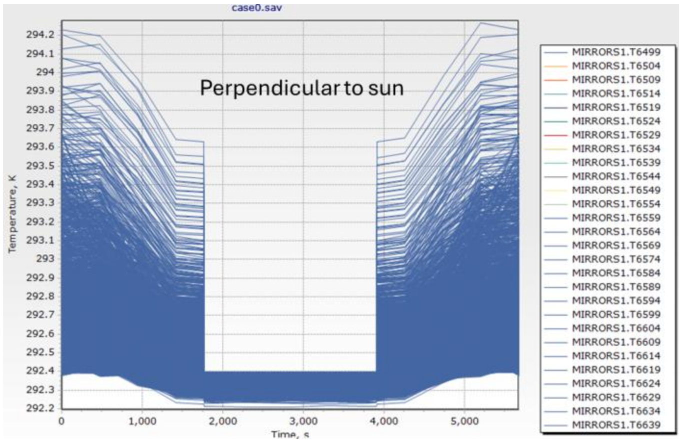


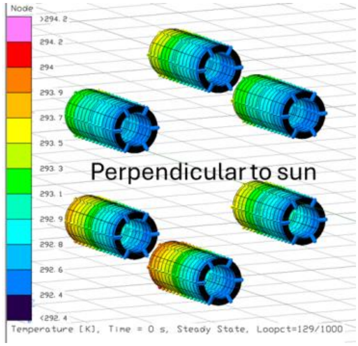
*All values are for Mirror Module Assemblies (MMAs), with the exception of the NIF optic.
*All values reflect X-ray test measurements or in-flight performance. Not all values are gravity subtracted.

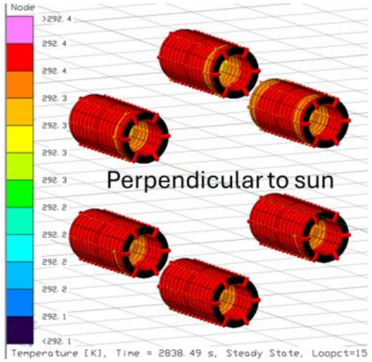
MMA Thermal Model









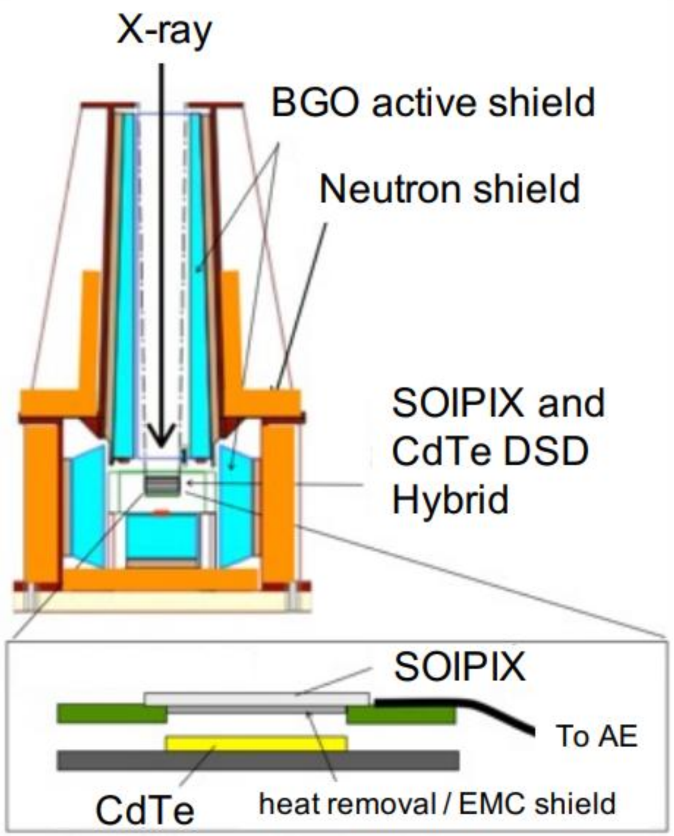


Heating power required is reasonable

Anti-Sun Case Power (W)	Perpendicular-to-Sun (W)	Sun-facing 45° (W)
20.84	24.83	26.91

- Performed a thermal analysis of the *HEROIX* observatory using Thermal Desktop, focusing on the quasi-steady-state behavior of the six MMAs in operational orbital environment.
- MMA thermal requirements applied: 20 ± 1 °C (292.15–294.15 K).
- Developed high-fidelity thermal model of each MMA, including nested shells (30) and supporting structures.
- Evaluated thermal performance across key observatory orientations: anti-sun, perpendicular-to-sun, and 45° sun-facing.
- Dual-layer zonal heater control network (internal and external to the shells) is required for stable thermal regulation.
- Verified that *HEROIX* maintains safe thermal compliance across standard orbital conditions while using minimal heating power.

Hybrid Focal Plane Detector Assembly



Mori et al, 2022

- Mass per unit: 45 kg (2 cm BGO)
- Power per unit: 24 W @ -25 C
- Temp Req: Detector plane: -25 C
- Survival Temp: -30 to 40 C
- Avoid SAA

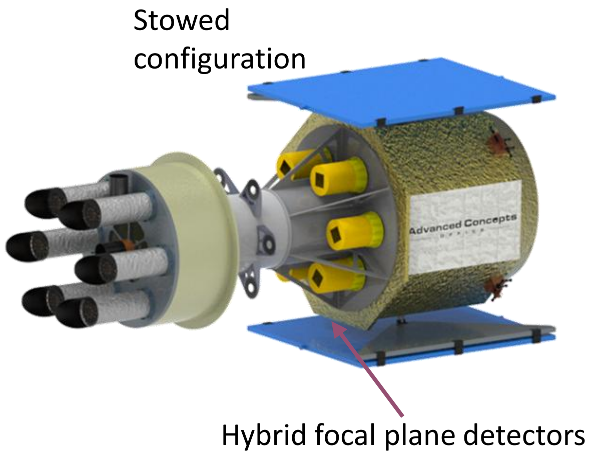
- Staged design with the soft X-ray focal plane positioned directly in front of the hard X-ray focal plane
- Developed for *FORCE* (Nakazawa et al, 2018)
- Soft X-ray detector: SOIPIX (SOI-CMOS)
  - Energy coverage: 1 to 25 keV
  - Silicon thickness: 0.3 mm
  - Pixel size: 36 µm
  - Energy resolution: 250 eV at 6 keV
  - Focal-plane size: 44×44 mm^2 (≈12.6 arcmin FoV)
  - Time resolution: 10 µs

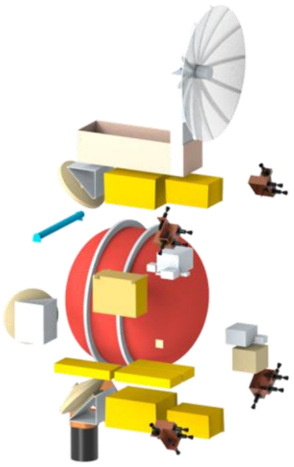
- Hard X-ray detector: CdTe-DSD
  - Double-sided Strip Detector (CdTe-DSD)
  - Energy coverage: 20 keV to 79 keV (up to ~200 keV capability)
  - Detector thickness: 1 mm
  - Strip size: 250 µm
  - Energy resolution: 1 keV at 60 keV
  - Detector tile: 32 mm^2 (≈9.1 arcmin FoV)
  - Time resolution: 25.6 µs per array

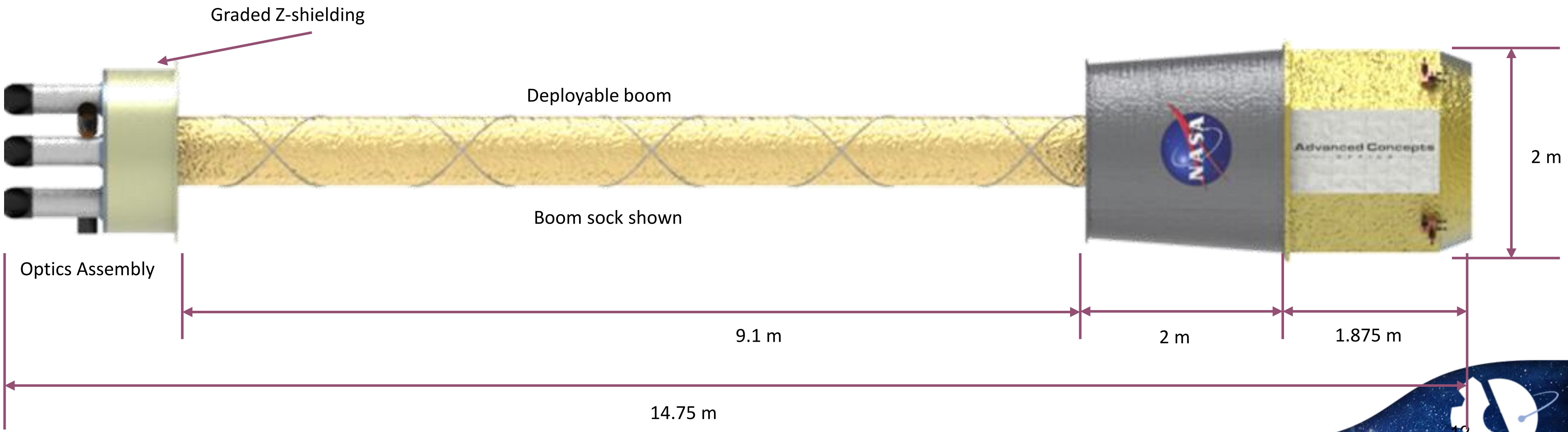
- Assembly encased in BGO (Bismuth Germanate) anticoincidence shield

HEROIX Flight Configuration

- *HEROIX* utilizes a commercially available spacecraft bus and boom system with integrated avionics, RCS thrusters, fuel tank, attitude-control sensors, reaction wheels, and magnetorquer rods.
- The star camera and gyroscopes are mounted on the optical table, aligned with the tip/tilt/rotation system.

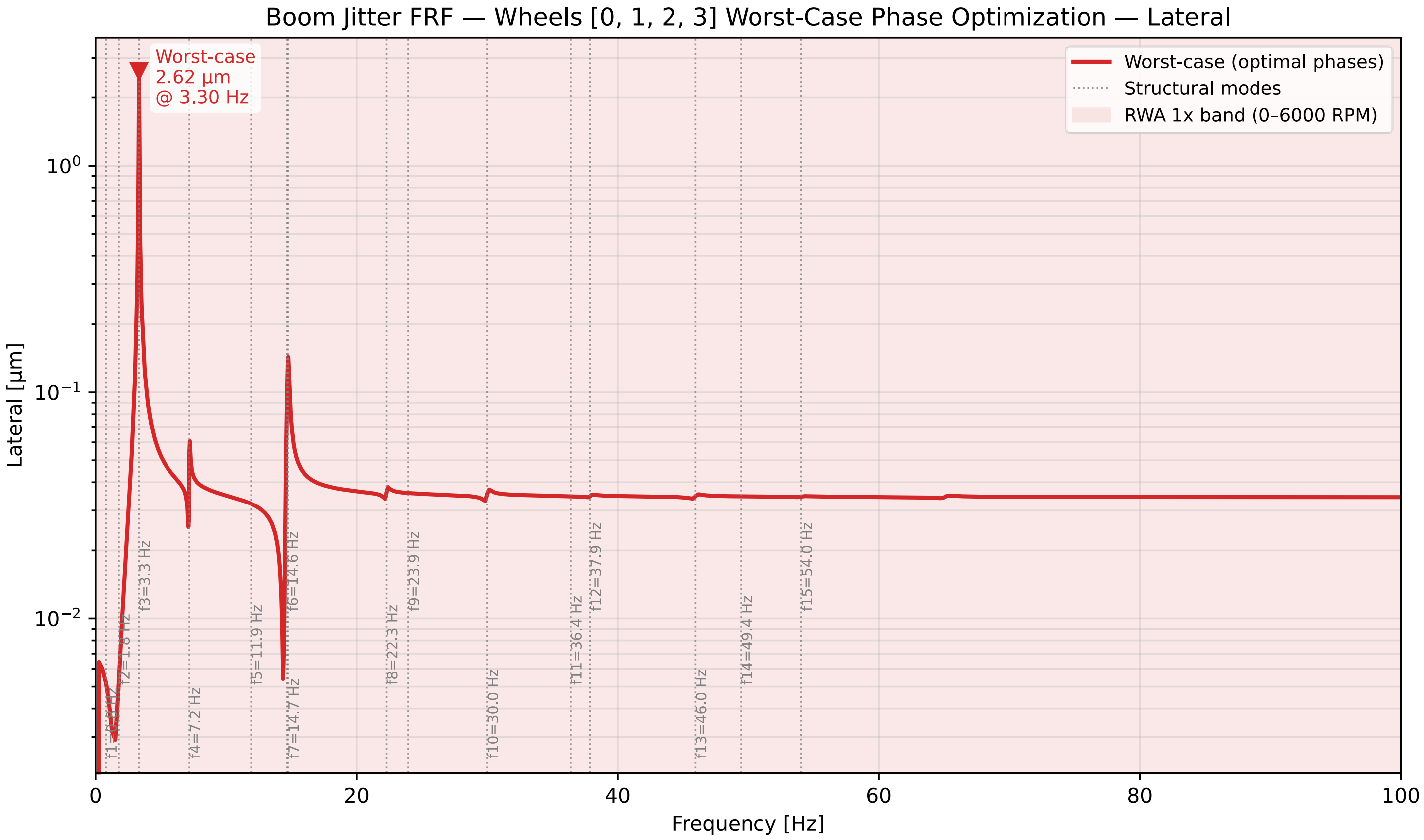


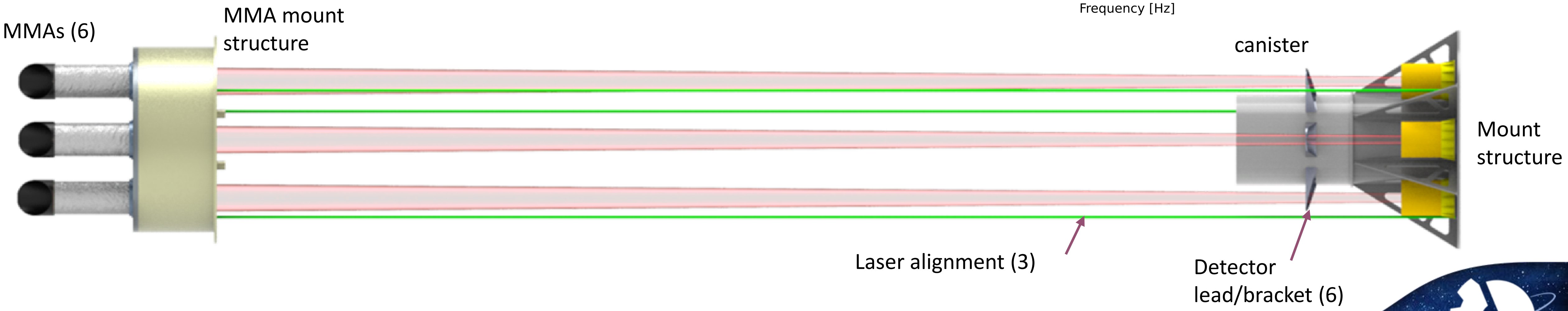




Boom Stability

- The MMA-to-hybrid-detector relative aspect must be known to within 35 μm relative shear (0.6 arcsec)
- NASTRAN model constructed using a candidate commercially available extendable boom and reaction wheels
  - Lateral misalignment displacement: 2.6 μm
- Three laser boom-alignment trackers allow monitoring of lateral misalignment and relative angular misalignment.

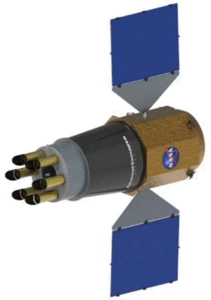


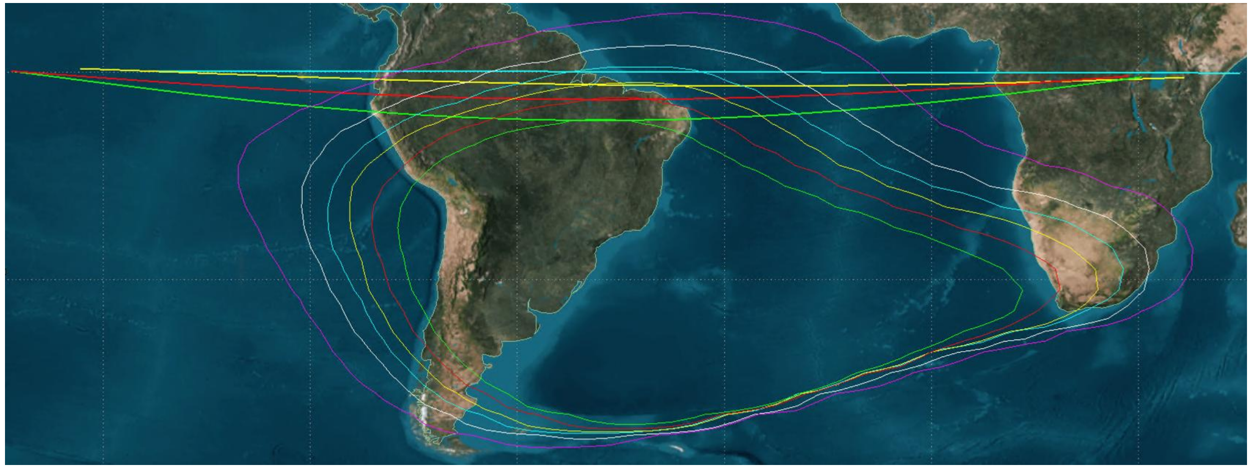


HEROIX Launch Configuration & Orbit

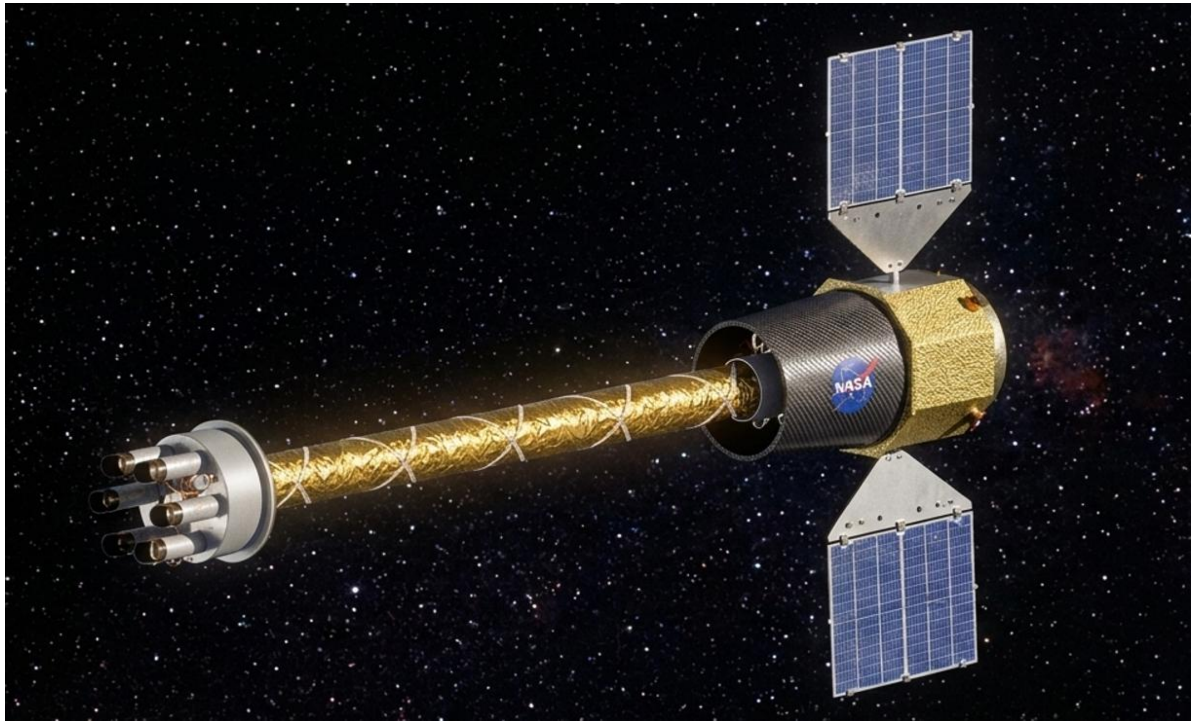
- *HEROIX* incorporates an extendable boom that allows launch in a stowed configuration, enabling compatibility with many launch fairings
- Low-inclination LEO orbit requirement
  - NA launch site
  - 500 km, 1.5 deg inclination
  - Requirements met by NASA's Launch Services Program fleet
- ACS propulsion system added to maintain orbit beneath much of the SAA (428 kg)
- Orbit available

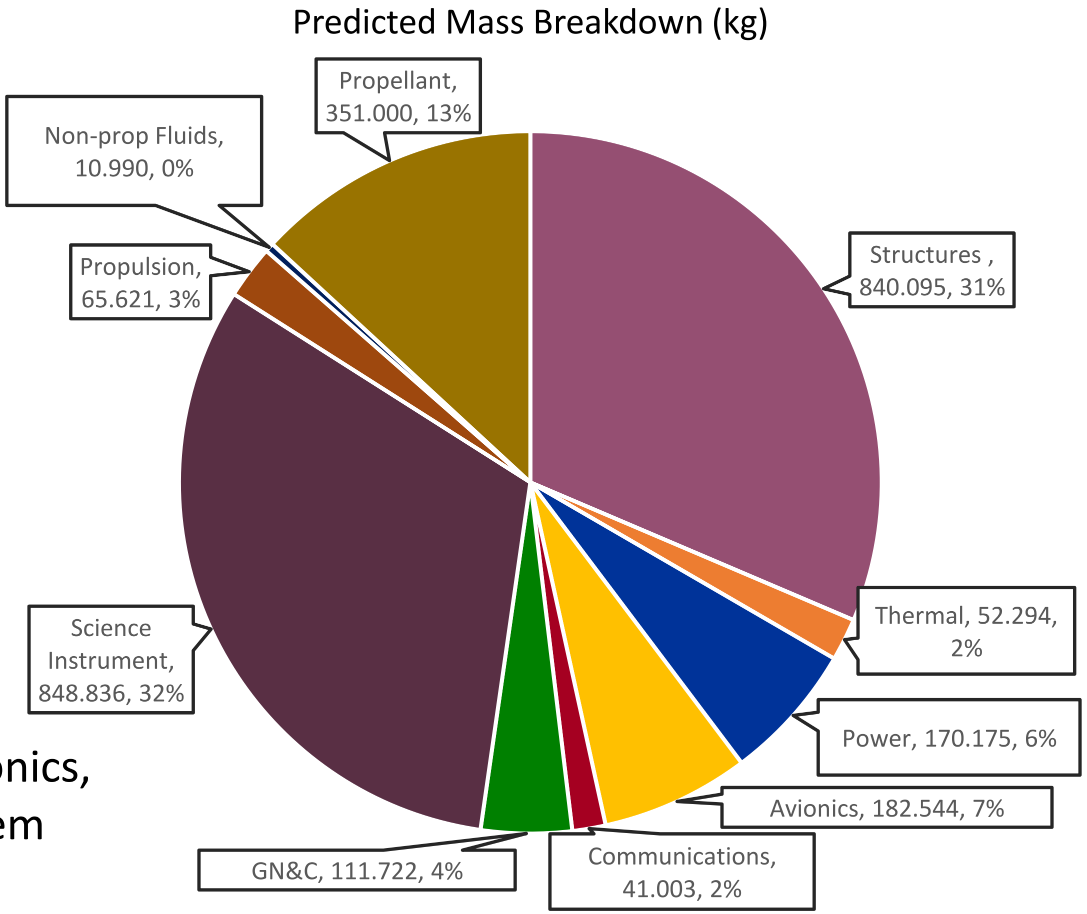
Launch support bypasses launch loads on boom





HEROIX Mass Breakdown





- The MSFC ACO study incorporated power, communications, avionics, GN&C, propulsion, the science payload, and the bus/boom system (structure) to generate a comprehensive equipment list
- *HEROIX* mass estimate: 2968 kg*

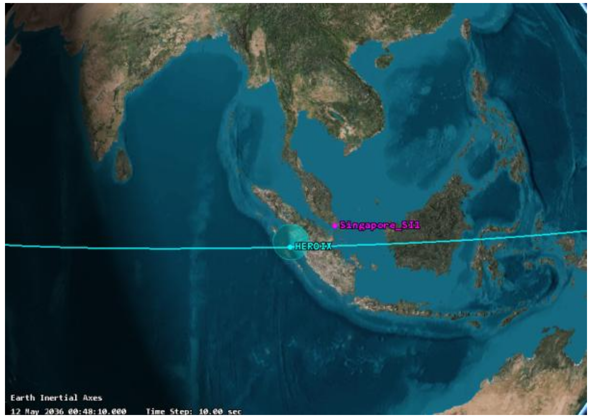
Well matched for an Astro MIDEX

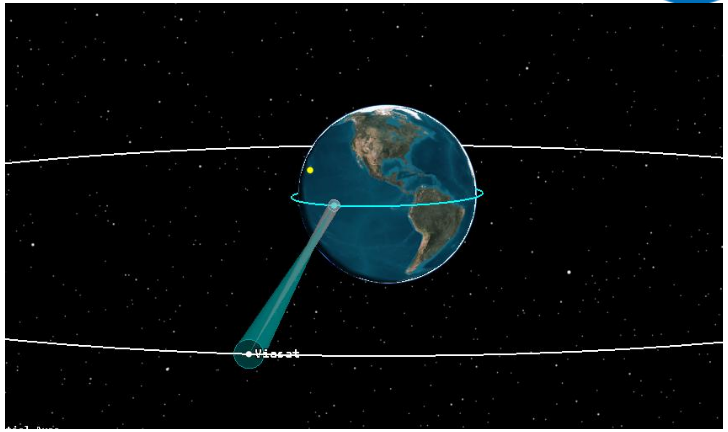
- Mass Growth Allowances based on AIAA Standard Mass Growth Allowance Table (ANSI/AIAA S-120A-2015)
- Detailed Mass Estimate List (MEL) and AIAA Mass Growth Allowance table provided in a separate file.

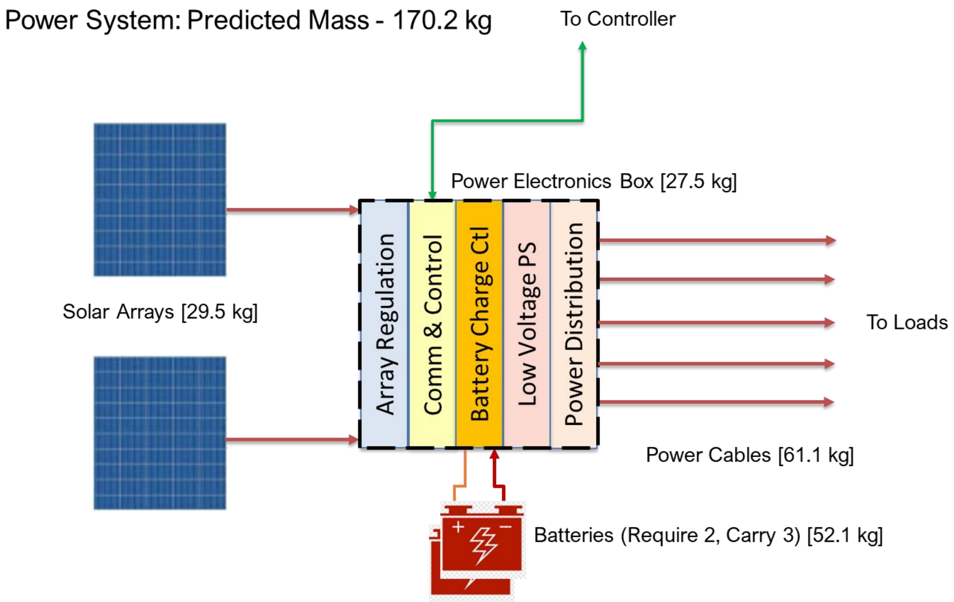
Comms & Power

Communication
- Direct-to-Earth via Near Space Network; Singapore (SI-1) is only available station adding operational risk
- NASA transitioning from TDRSS to commercial satcom
- Commercial satellite-to-satellite relay expected to be available in the 2030s

Power System
- Unregulated articulated solar-array / battery system supplying payload and bus for 10-year mission
- Total power requirement: 1236 W
- Predicted mass: 170.2 kg

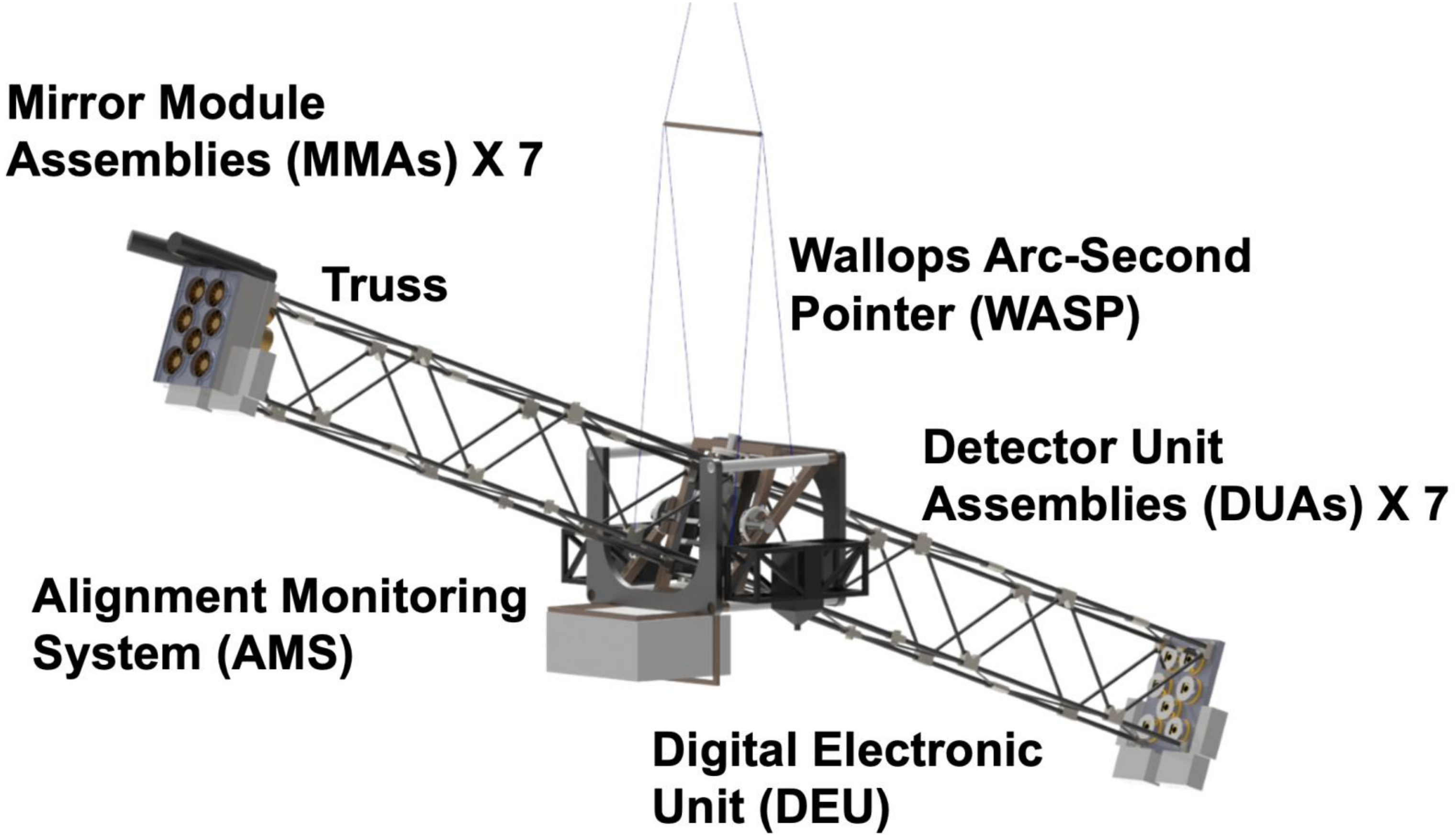






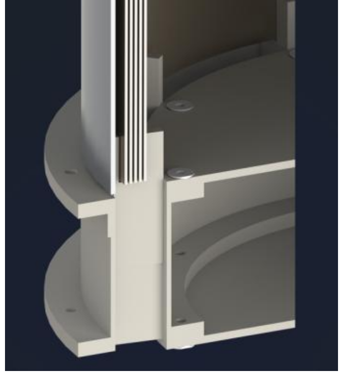
The *SuperHERO* Hard -X-ray Balloon-Borne Telescope

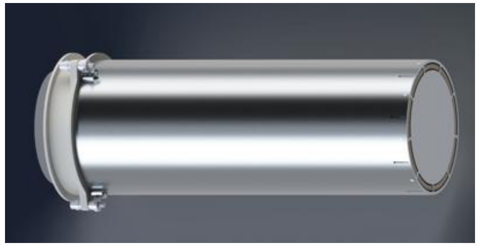
- Successor to the successful *HERO/HEROES* missions
- Incorporates cutting-edge MSFC's NiCo shell x-ray optics
- Takes advantage of proven technologies from collaborating institutions (WashU, UNH, WFF, Kavli IPMU, & iMAGINE-X)
- Mission's technical goal: 10 arcsec Half Power Diameter (HPD) in the hard-x-ray band

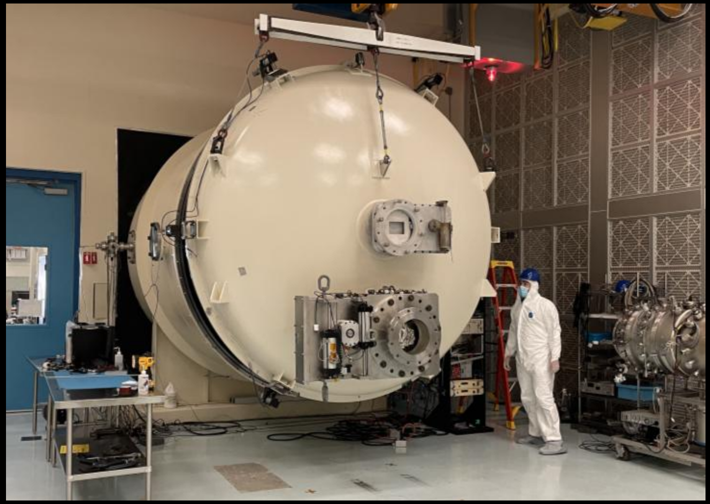


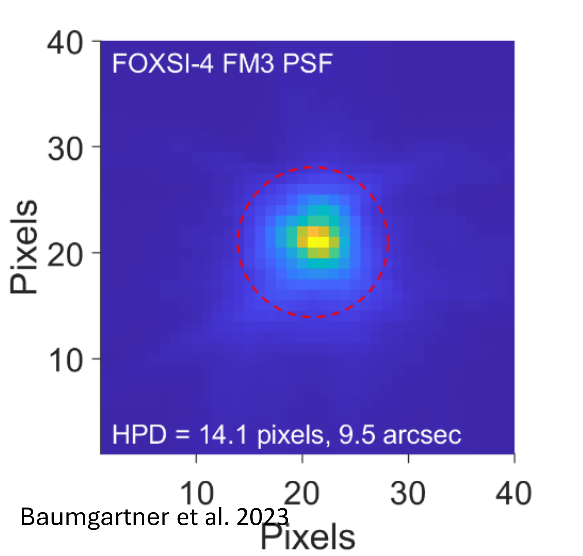
SuperHERO Mirror Module Assembly(MMA)

- Seven MMAs, requiring seven replications off of the two super polished mandrels.
- MMAs to be enhanced for future missions. Designed to accommodate a total of 5 shells each (100 kg to 200 kg)
- Calibration at Marshall 100-meter X-ray Beamline.





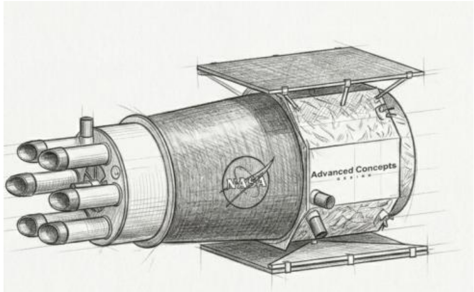




Baumgartner et al. 2023

Summary

- Broadband X-ray observations reveal key physics behind galaxy evolution, the origin of high-energy cosmic rays, and the behavior of matter in extreme accretion environments.
- X-ray NiCo replicated-shell optics and next-generation broadband X-ray detectors are maturing rapidly and make a MIDEX-class NASA mission feasible in the 2030s.
- The *HEROIX* broadband X-ray telescope mission concept is designed to leverage these advances, enabling groundbreaking observations for the astrophysics community in the coming decade.



Please contact me or Science PI Chien-Ting Chen to discuss HEROIX!

Pictures of team
Kazu’s team photo where I look stupid

Chien-Ting’s Head meeting

Student’s hard at work-
Gen, Adrianah, and Iroha working at Beamline