The Rocket Experiment Demonstration of a Soft X-ray Polarimeter — REDSoX*

Herman L. Marshall, Sarah Heine, Alan Garner, Rebecca Masterson, Moritz Günther, Ralf Heilmann (MIT), Steve Bongiorno (MSFC), Eric Gullikson (LBNL)

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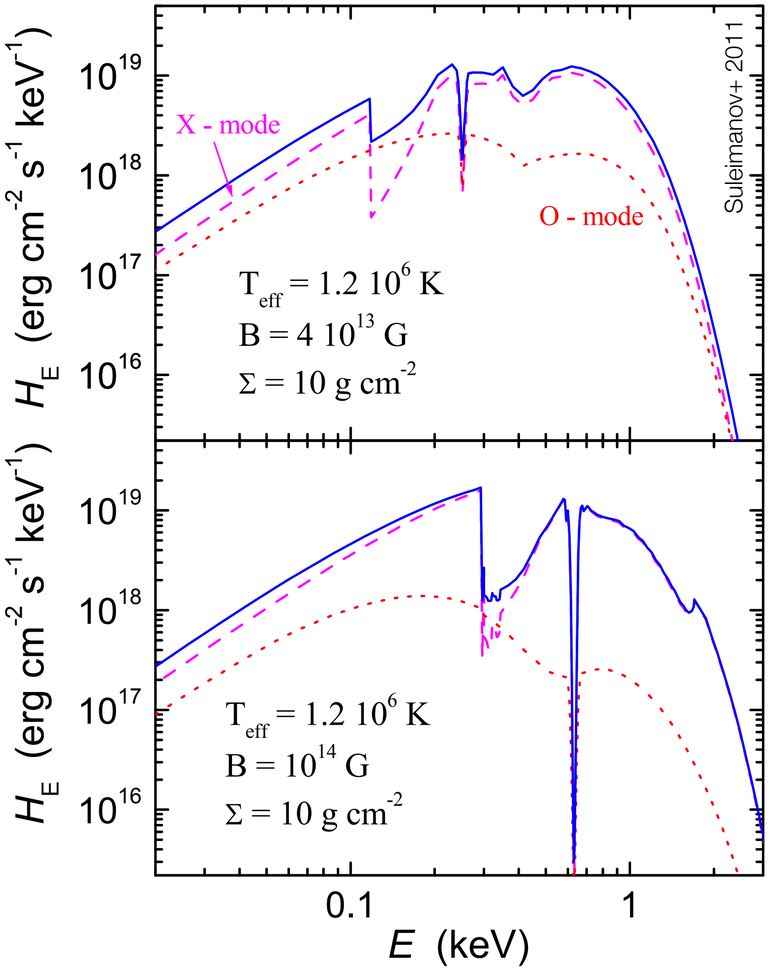
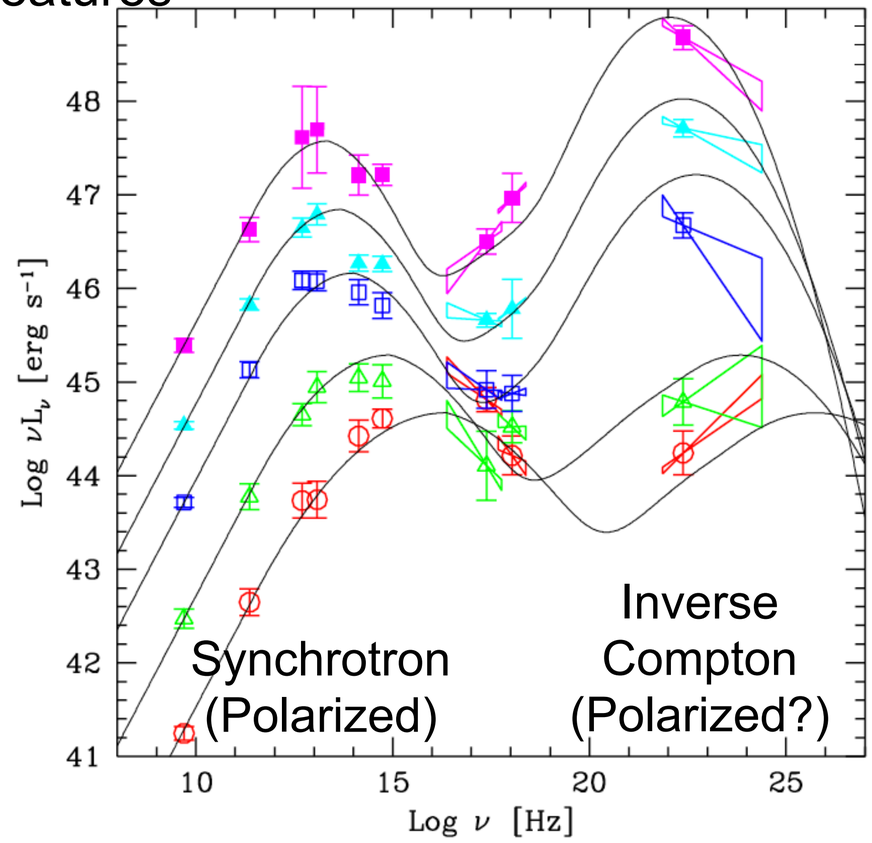
Soft X-ray Polarimetry Science Goals
Neutron Star Atmospheres & Active Galaxies

- Isolated neutron stars with magnetized atmospheres
- Atmosphere is polarized if gaseous, unpolarized if condensed
  - Explore range of surface melting points, nature of absorbed lines
  - Complementary to IXPE (2-8 keV)
- **Spectropolarimetry** of absorption features



- AGN with relativistic jets (blazars): B-field uniformity, switchover to iC emission
- AGN soft excesses: disk or jet?
- Tidal disruption events with jets



☑ Observe 5-10 sources of each type with an orbital mission (REDSoX: 1 blazar)

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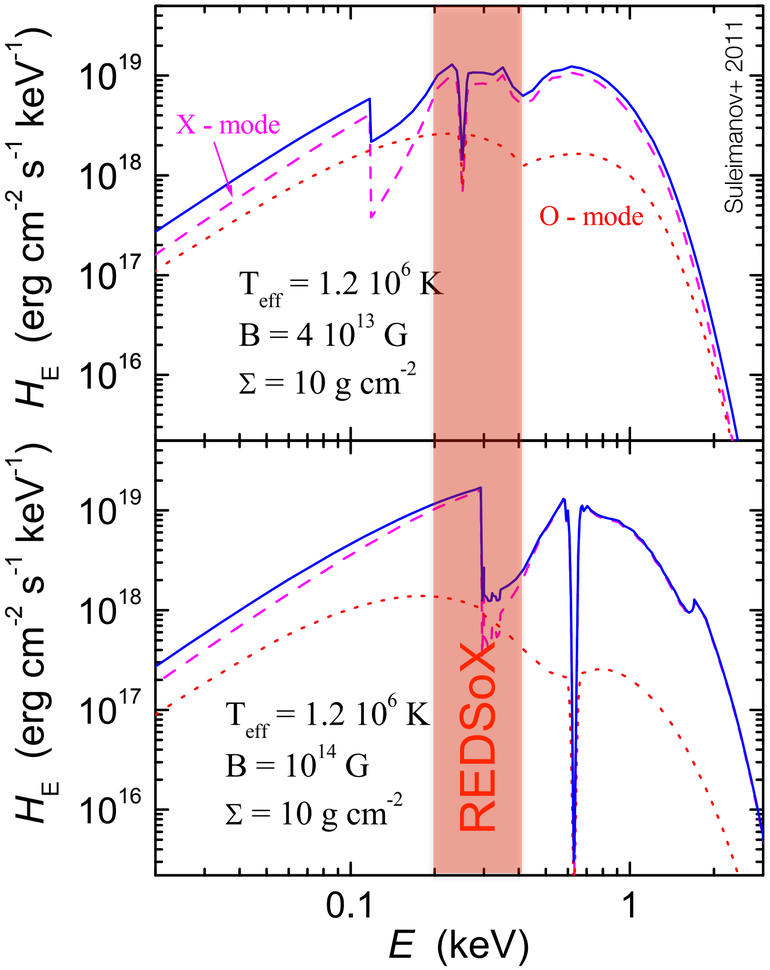

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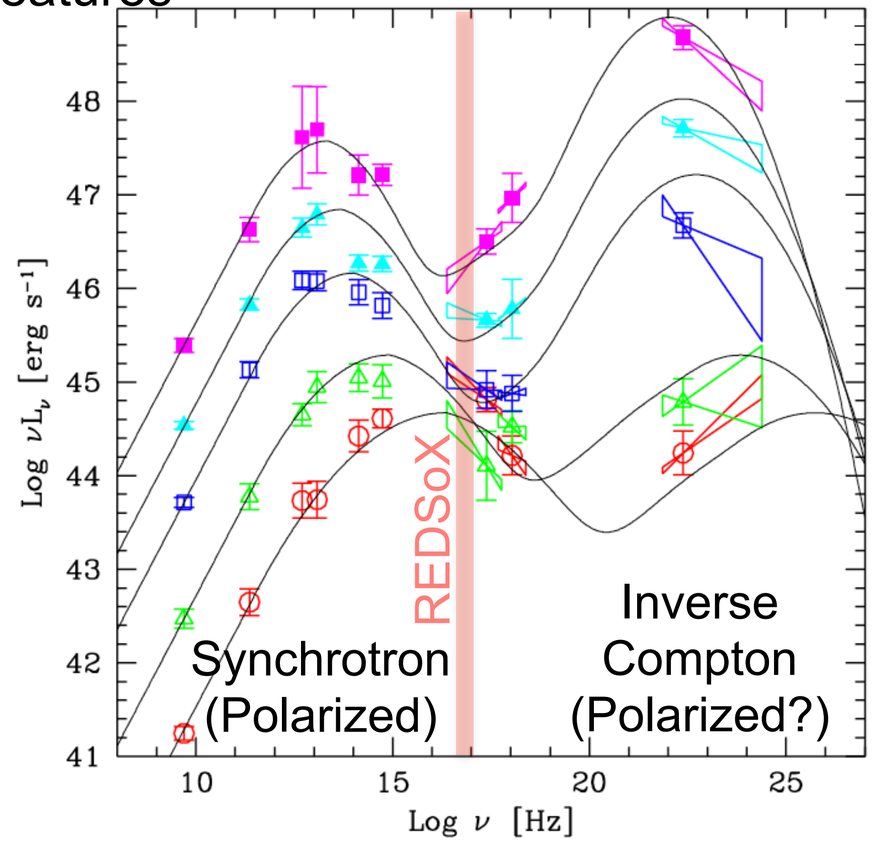

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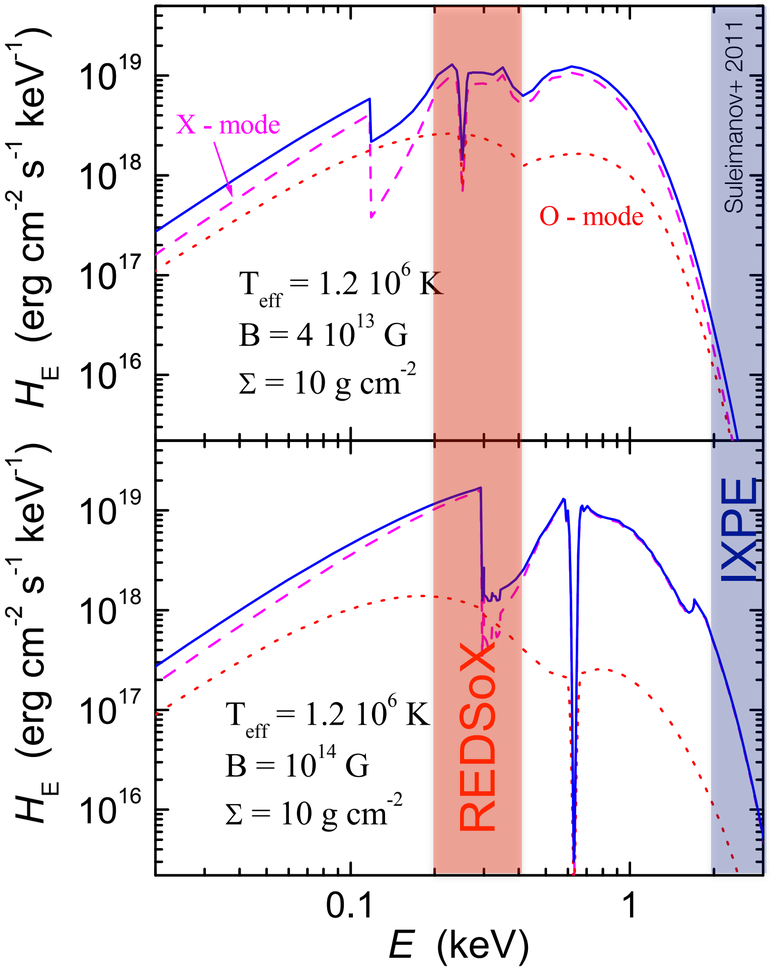

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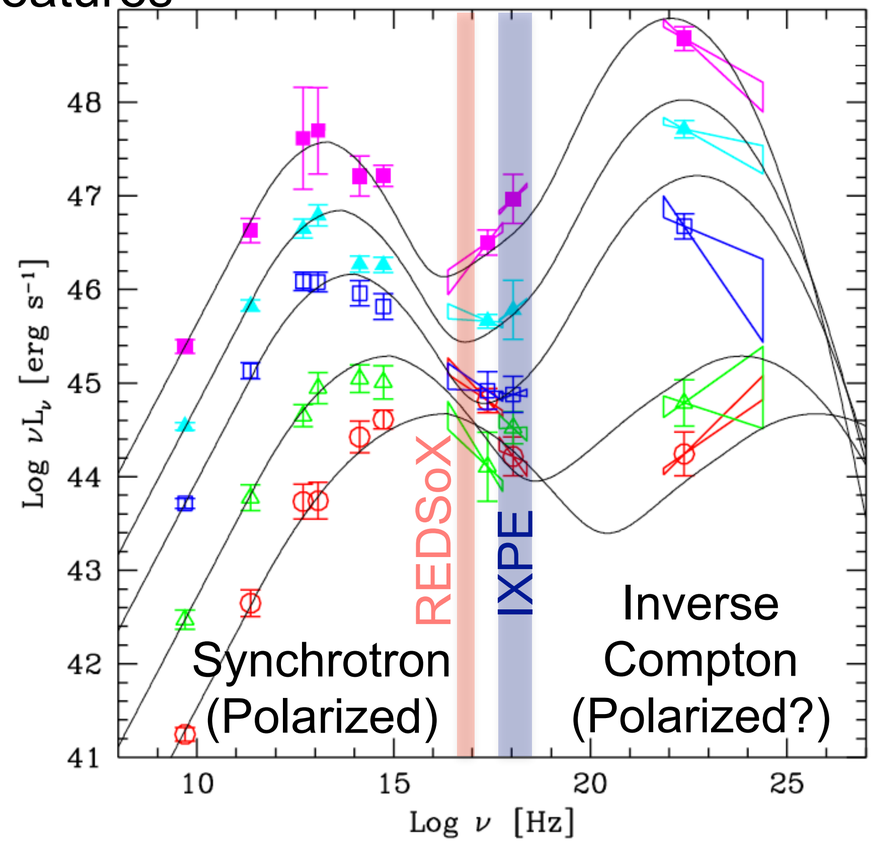

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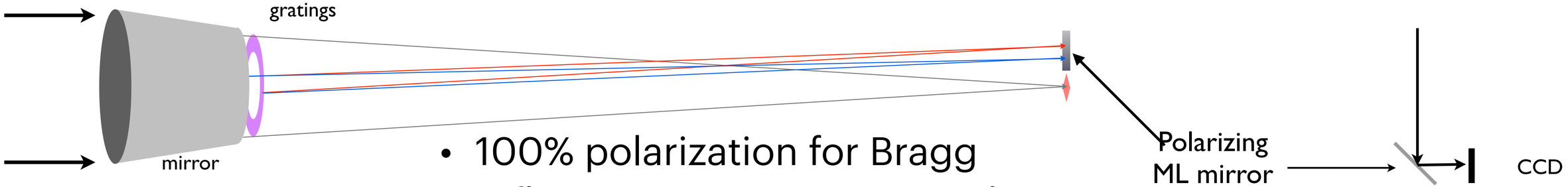
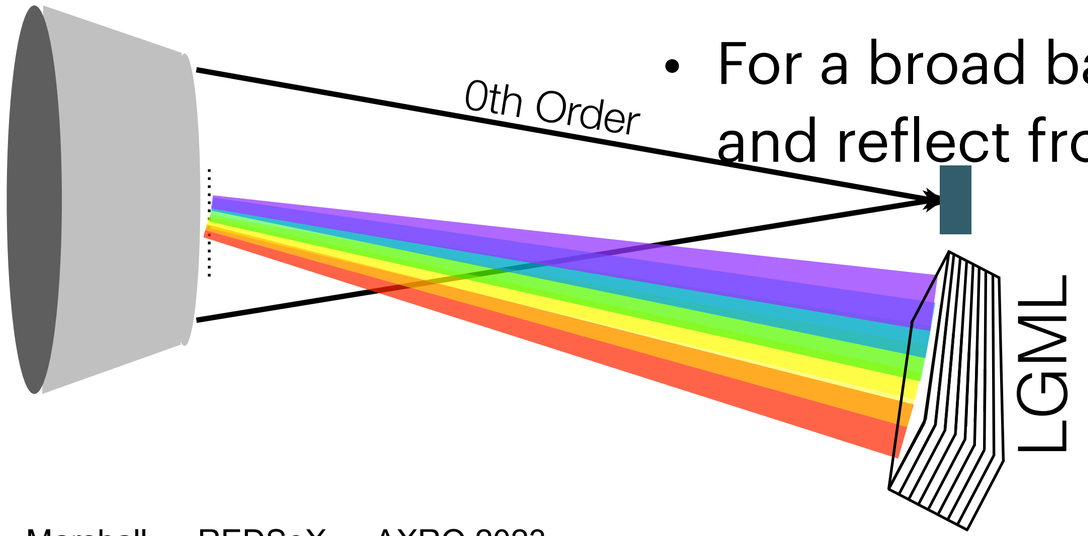
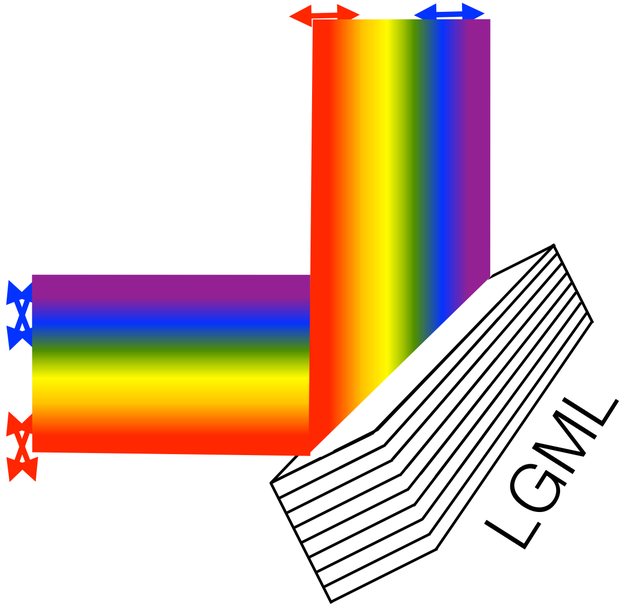
Multilayer Polarimeter Schematic Layout



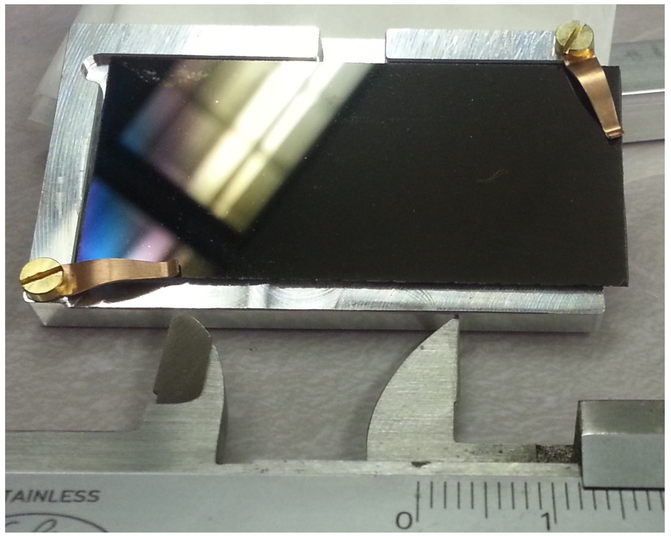
- 100% polarization for Bragg reflections at Brewster's angle
- Brewster's angle is 45° for X-rays
- Reflecting X-rays at 45° requires multilayer coatings
- For a broad band, disperse X-rays and reflect from an LGML

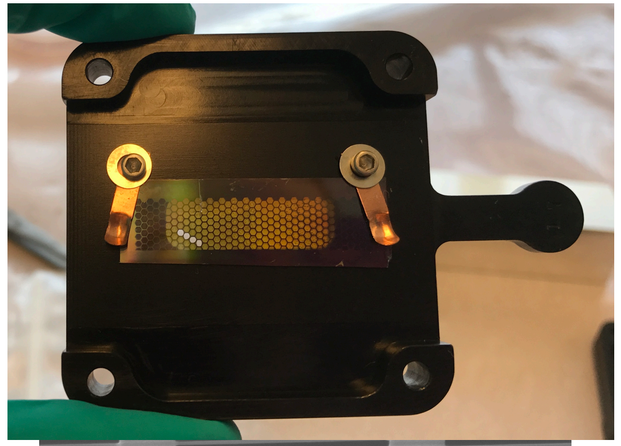


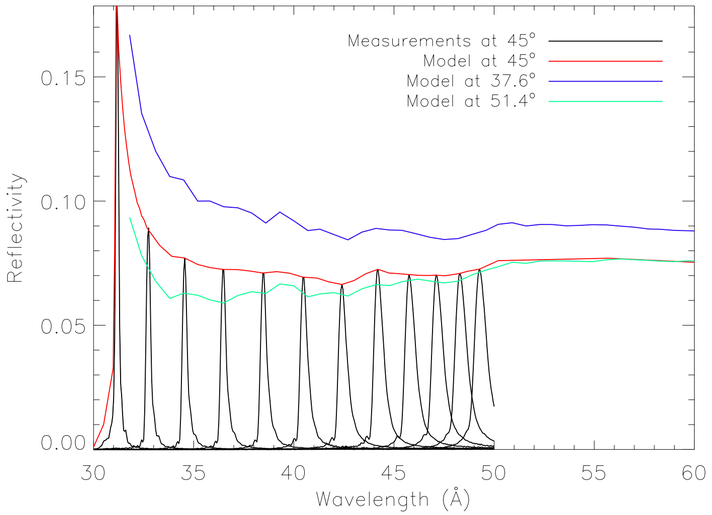


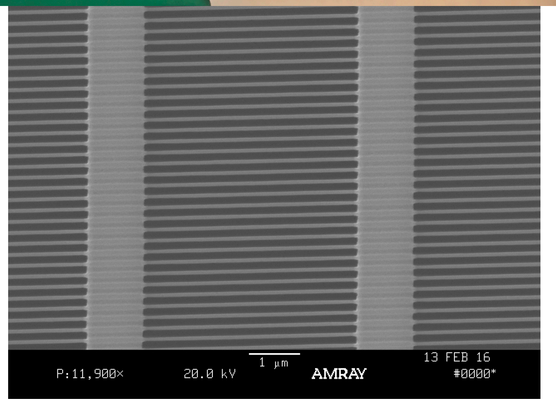
Polarimeter Components

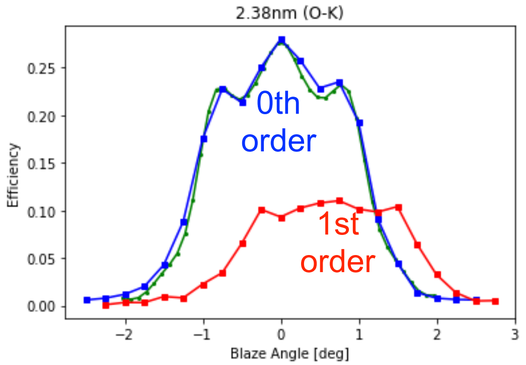
- MSFC mirrors like those of IXPE (25” HPD) but simpler
- Gratings like Arcus prototypes (but smaller)
  - made at MIT
  - measured at MIT
- Cr/Sc multilayer mirrors like
  - previously made and measured at LBNL
  - verified at MIT
- Testing CCD detectors







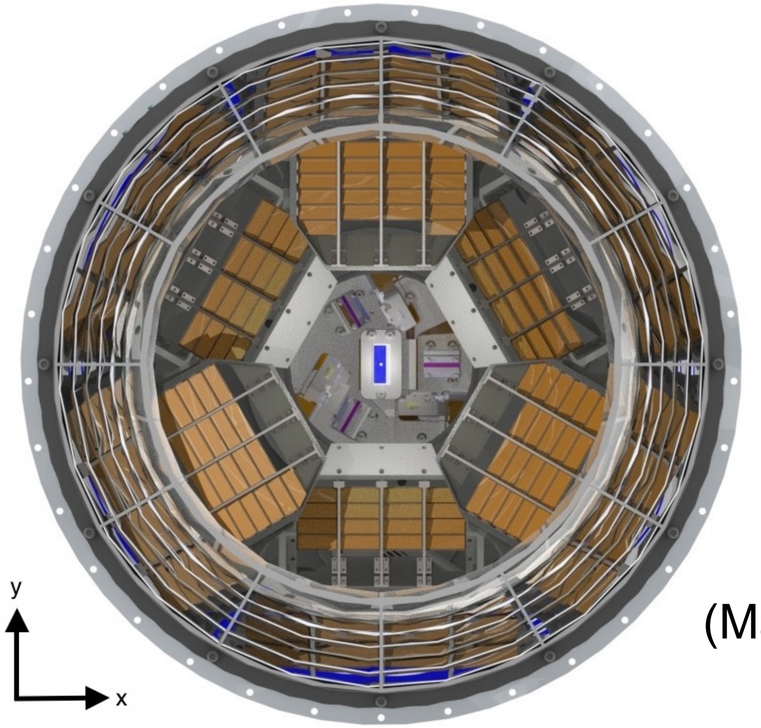


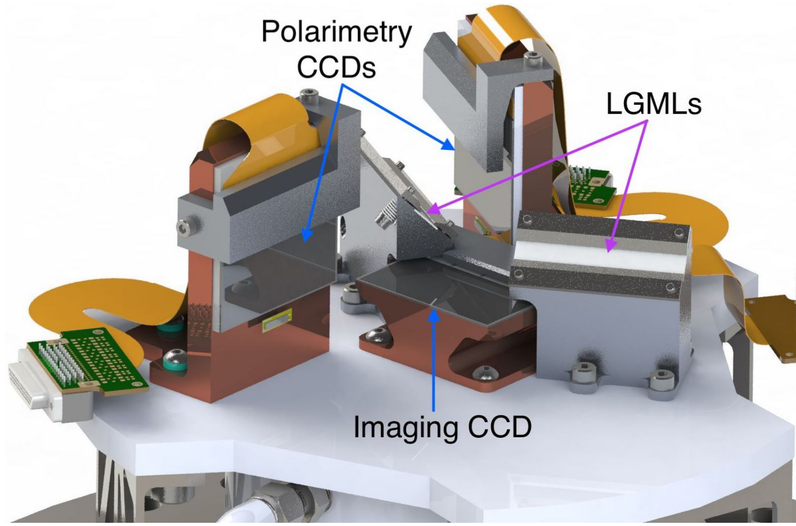


REDSoX Polarimeter (In Development)

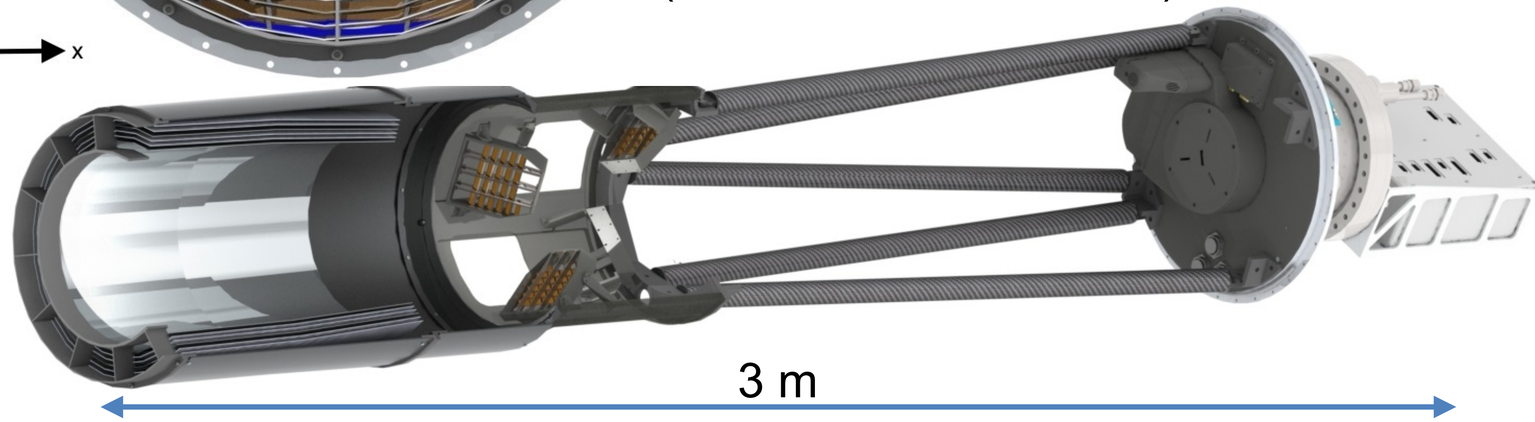
Launch in 2027

- Sounding rocket ($5M)
  - ✦ 5 min exposure
  - ✦ MDP = 17% for Mk 421 or Her X-1
- Wolter-I Ni optics (MSFC)
  - ✦ Using 5 existing mandrels
  - ✦ 2.5 m focal length
  - ✦ <25” HPD
- CAT gratings (MIT)
- 4 LN_2 cooled CCDs
- 3 multilayers (LBNL) — for Stokes IQU





(Marshall+ 2018, JATIS)



Progress and Status — Overview

- Management
- Structural design: modifying 7-yr-old design (JATIS paper)
- Optics (MSFC) in detailed design phase
- Gratings (MIT SNL) in prototyping phase
- LGMLs (LBNL) ready for flight fab
- Detector evaluation (Raptor, XCAM, Sydor or Princeton Instr/Teledyne)
- Electronics requirements driven by detector choice

Progress and Status — 1

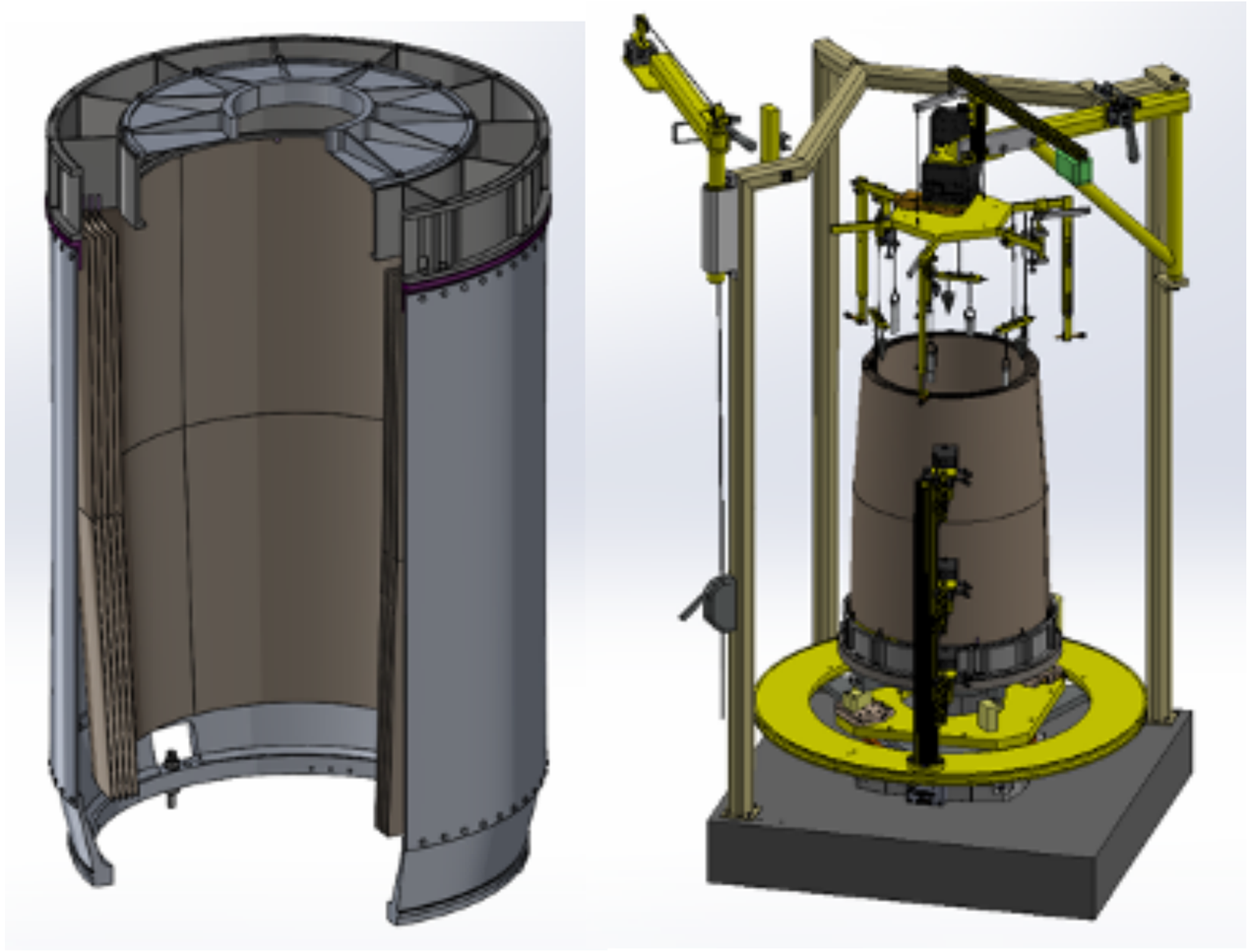
- Management
  - ✦ Received NASA award, 1st year funding
  - ✦ Hired Deputy PI (100%)
  - ✦ Hired Systems Engineer (25%), was also PM for 1st year
  - ✦ Hired Deputy PM, now PM (100%)
  - ✦ Hired electrical engineer (20%)
  - ✦ Hired mechanical engineer (50%)
  - ✦ Established L1 and L2 requirements, finishing L3 (for vendor SOWs)
  - ✦ Holding internal MKI management reviews, planning internal PDR for February 2024
  - ✦ Held Mission Initiation Conference with WFF
    - requirements on rocket (Black Brant IX), ACS, t/m, power, etc are OK
    - established communications with subsystem leads

Progress and Status — 2

- Structural Design underway
  - ✦ Started with 7-yr-old CAD
  - ✦ Modifying due to requirements flowdown
  - ✦ Changing LN2 “bucket” to flowthrough cold plate
  - ✦ Using vacuum-tight telescope door, no detector vacuum box
- Optics (MSFC) detailed design nearly done
  - ✦ Based on existing mandrels
  - ✦ Added structure for ACS camera
  - ✦ Clarified interfaces
  - ✦ Settled on SOW for fab, test, and cal

REDSoX Mirror Module Assembly

- Design and fab based on IXPE equipment and procedures
- Initial MMA design is done (left)
- Design of initial shell alignment station (right) is done
- Now modeling MMA dynamics
- Have designed mounting gantry for SLTF X-ray tests

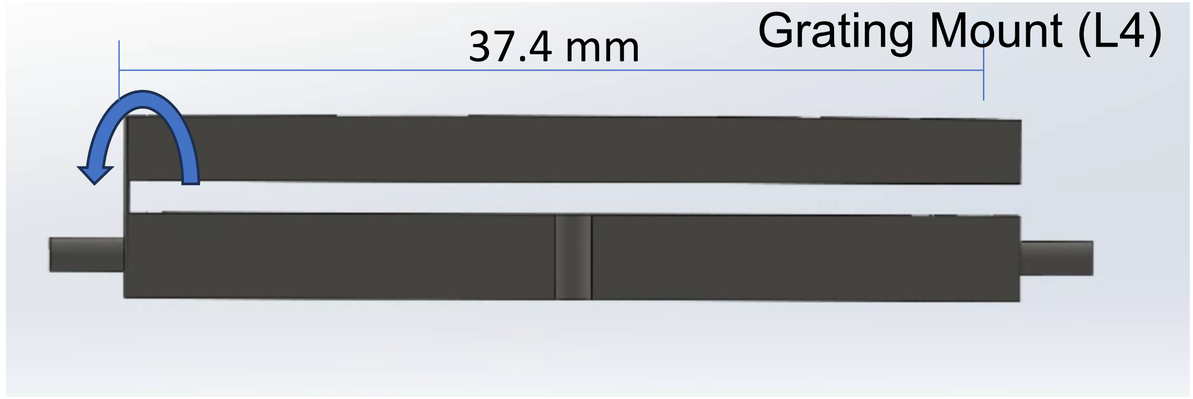


Progress and Status — 3

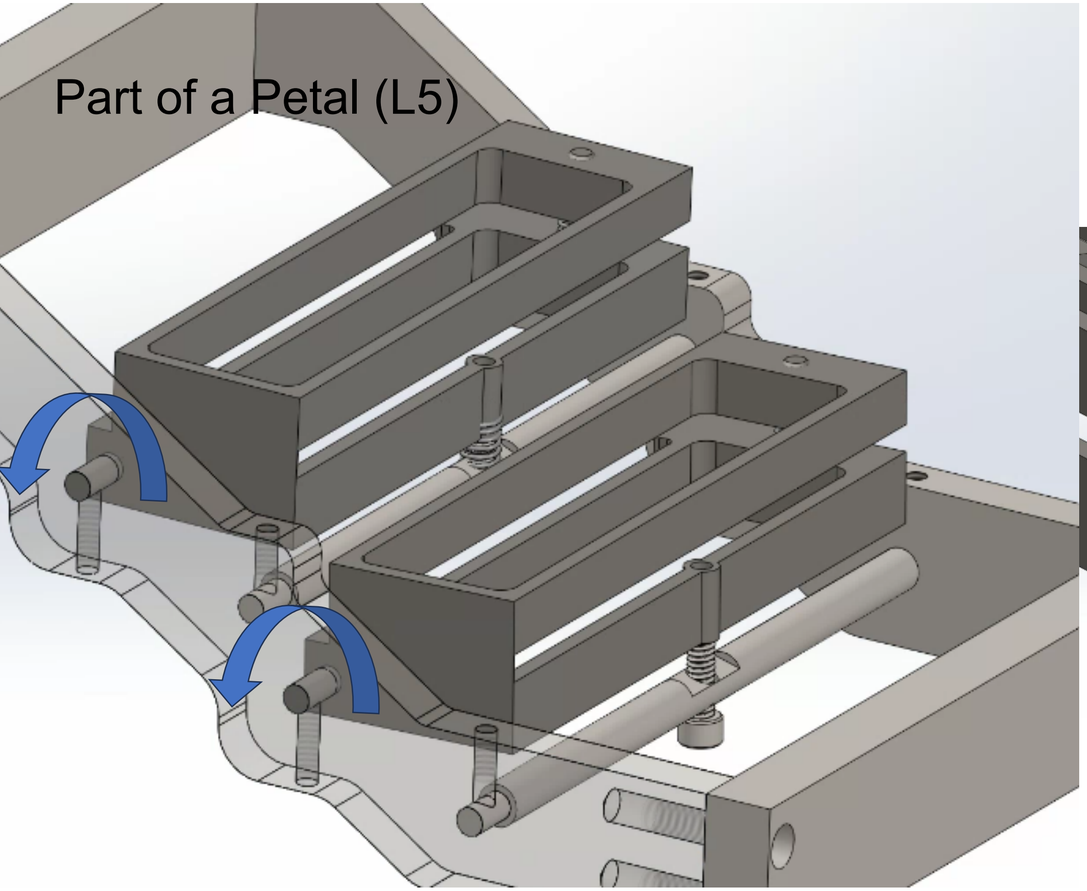
- Gratings (MIT SNL) in prototyping phase
  - ✦ Settled on grating dimensions
  - ✦ Received frame prototypes (L2 & L3 structure)
  - ✦ Prototype grating mounts being fabricated
  - ✦ Developed grating and mount test plan
    - Shake to GEVS level at MIT, to flight level at WFF
    - Test in X-ray beamline before and after shake
- LGMLs (LBNL)
  - ✦ Settled on SOW with design and test requirements — affects structure detail
  - ✦ Ready to order flight versions for delivery by early 2024

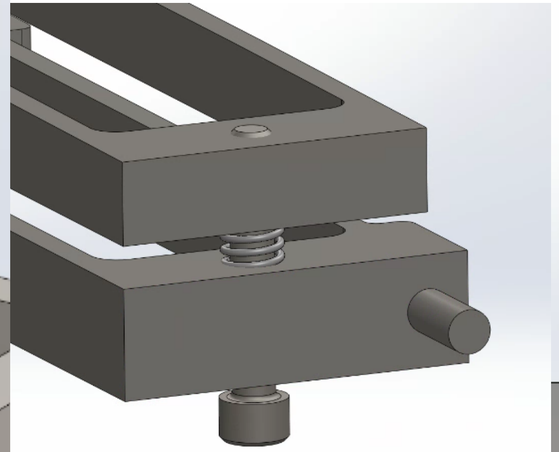
Grating Support Structure Design

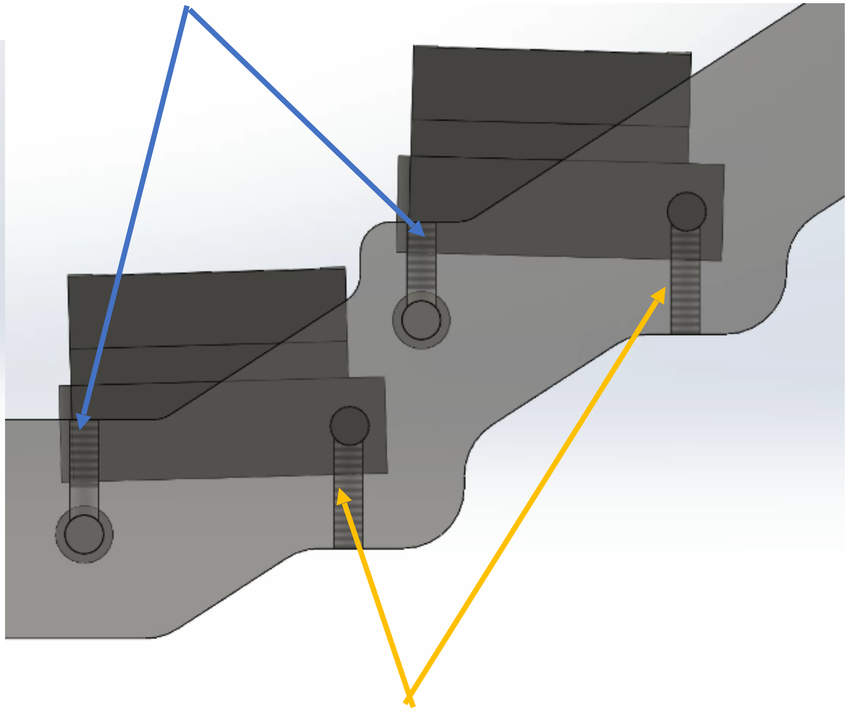
- New designs being prototyped
- Details allow for alignment on “petal”



Set Screws for cross bars



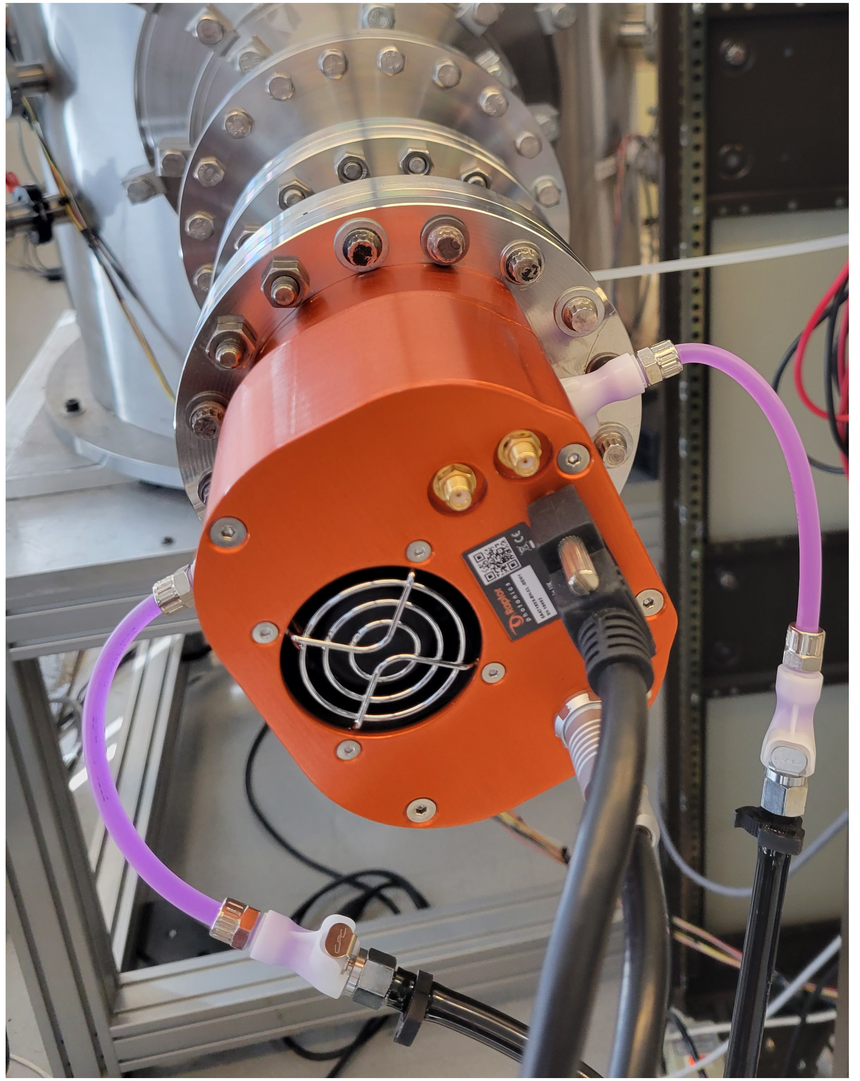




Set Screws for grating mount pins

Progress and Status — 4

- Detector X-ray evaluation for vendor selection
  - ✦ Initially decided against Sydor Wraith
    - significant charge loss/spreading due to wrong Gpixel chip
    - poor QE due to chip but can be used w/o OBF
  - ✦ Raptor Eagle demo unit with e2v 4710 CCD
    - good QE
    - low noise at 75 kHz clocking rate
    - long read time (15 s) for 1.1 Mpix at full resolution
      - use higher clocking rate for imager (tolerating low E sensitivity)
      - use 2x2 (4x4) binning on imager (polarimetry detectors)
  - ✦ Sent RFQs to Raptor, XCAM, and Princeton Instr./Teledyne for custom in vacuum cameras
- Electronics design
  - ✦ Drafted interface with rocket power/command subsystems
  - ✦ Evaluating on-board processing options
  - ✦ Evaluating e-box unit from a comparable flight project



Raptor demo camera on X-ray beam line

Detector Electronics

- Looking at on-chip binning
  - ✦ can decrease frame time
  - ✦ windowing not helpful in polarimetry channel
- REXIS e-box prototype (below)

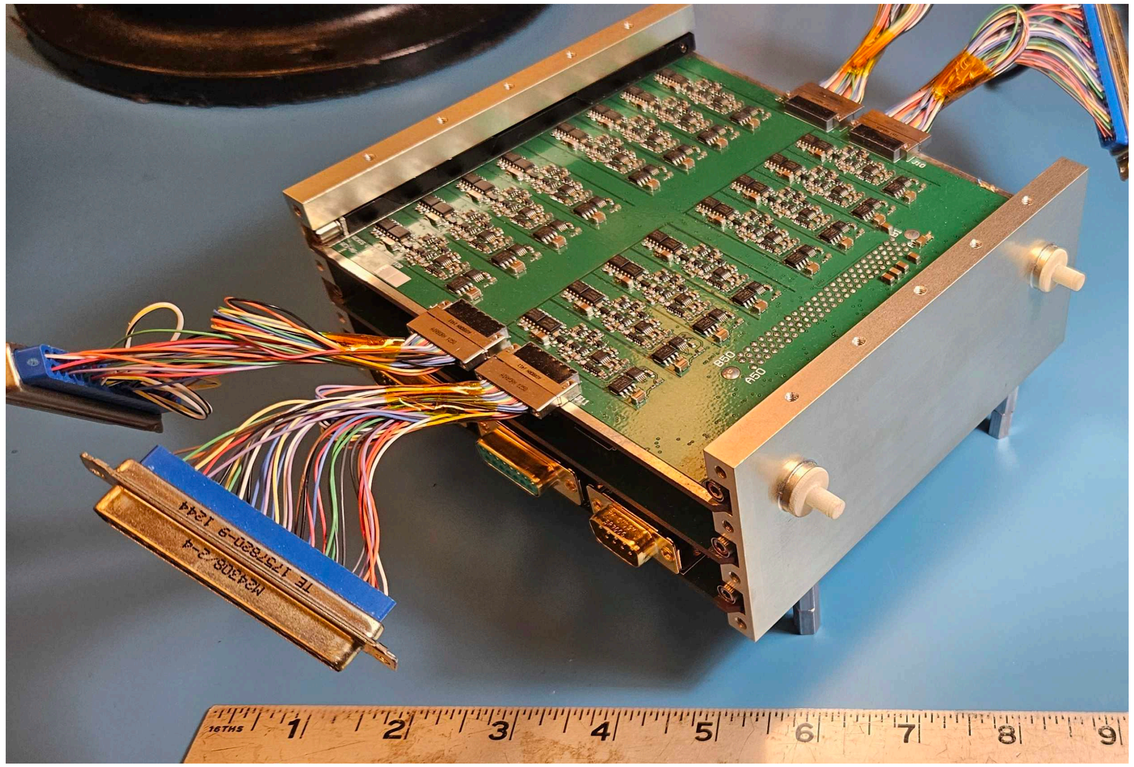
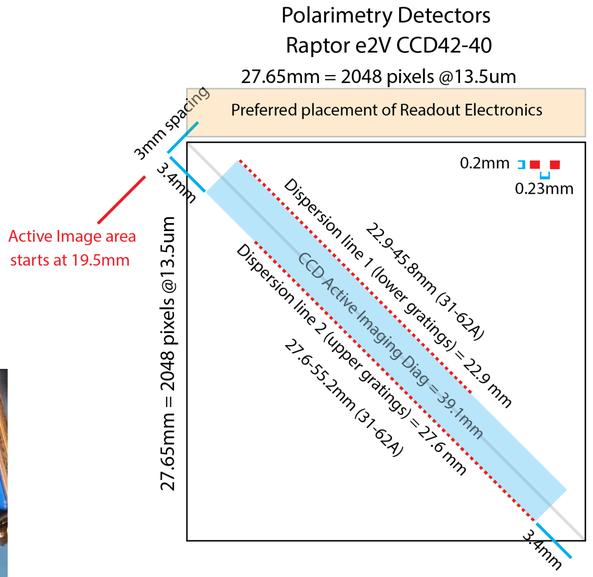
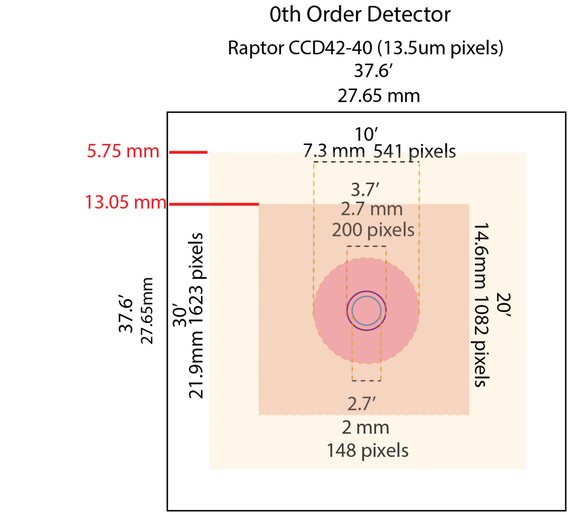


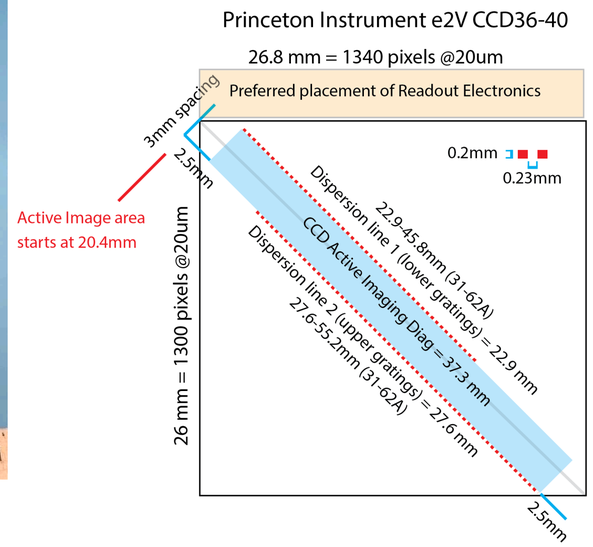
Figure 6
REDSoX Mechanical requirements for placement of CCD active image and LGML

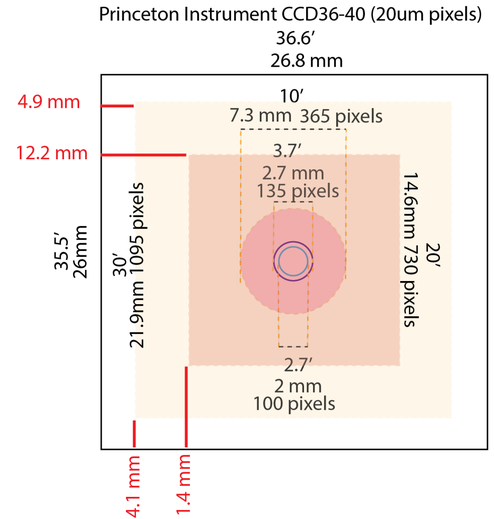


The CCD diagonal for the active image area should start at 19.5mm from the 0th order point



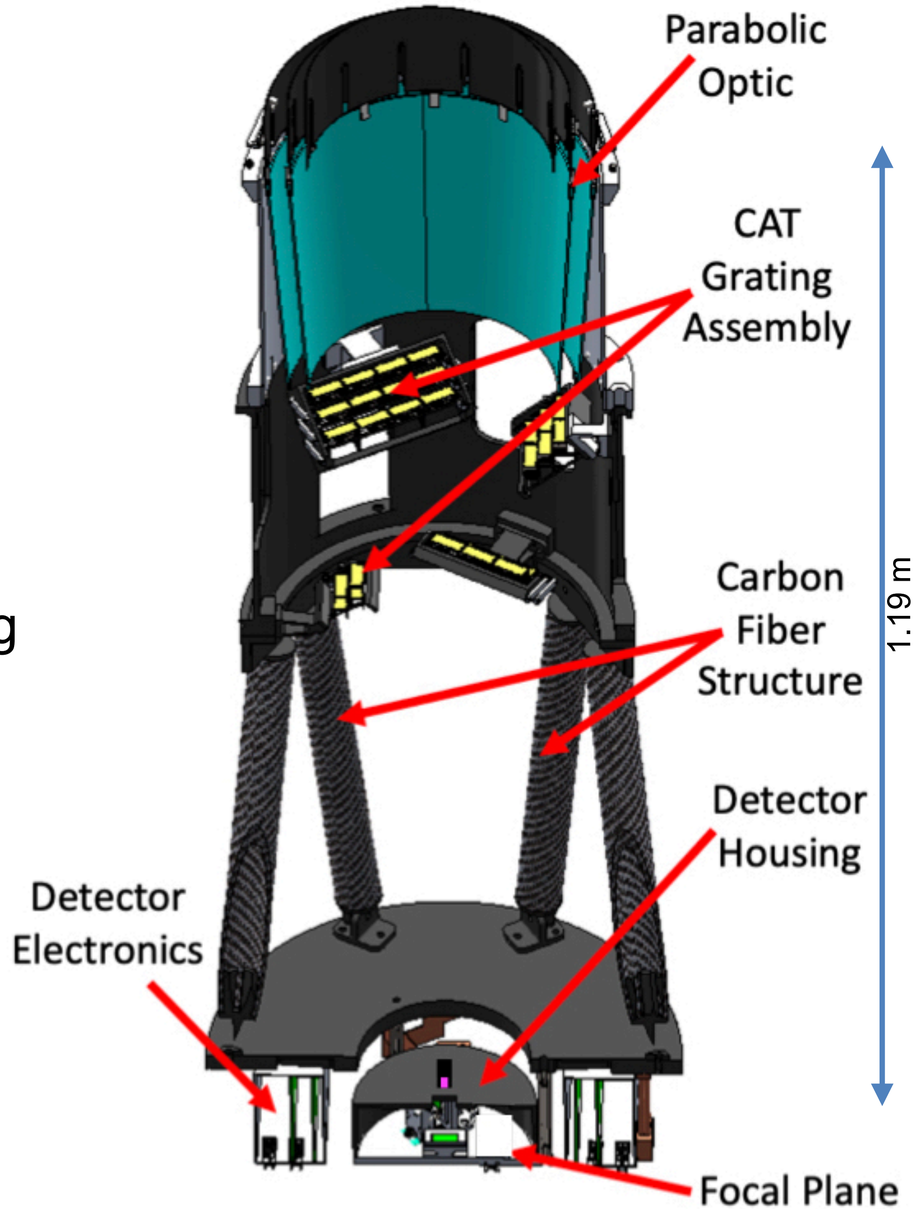
LGML preferred overlap should not exceed beyond 5.75 mm from the edge of the active area
LGML overlap cannot not exceed beyond 13.05 mm from the edge of the active area
The center of the active image area must be at the location of the telescope focus point. For the Raptor, this location is 13.825 mm from the active image area edge.

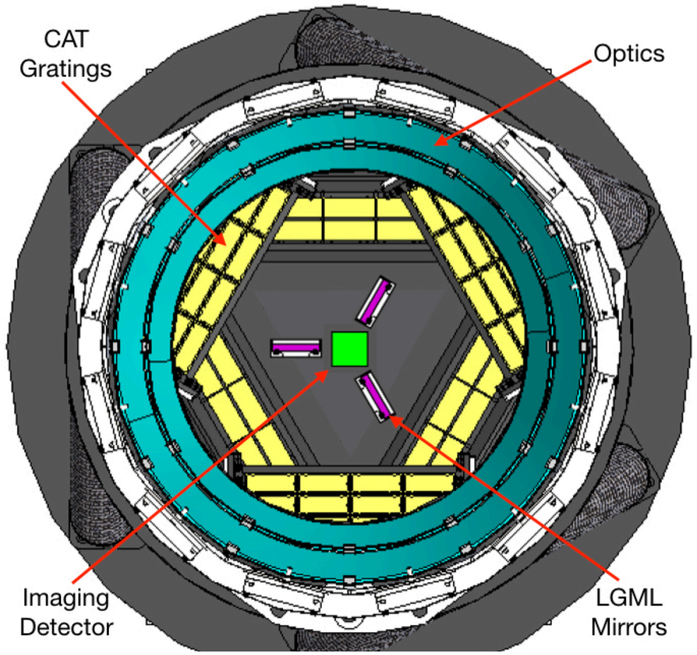


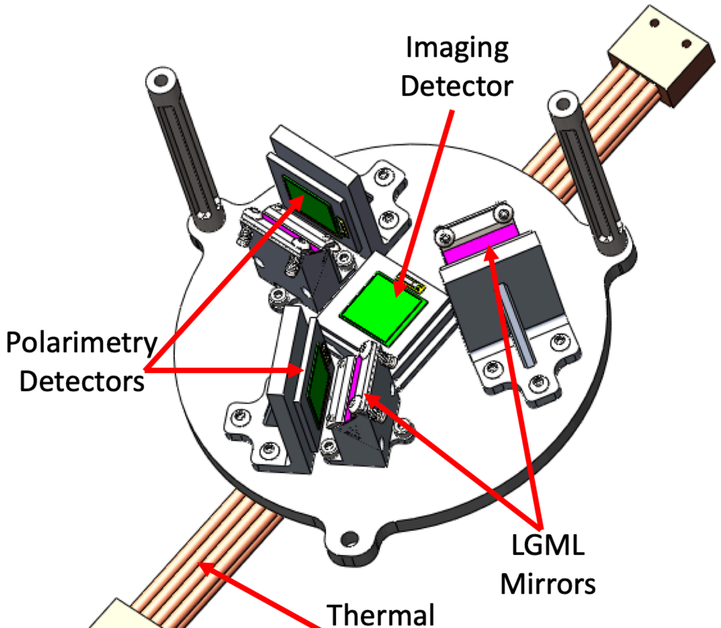


Astrophysics Pioneer (GOSoX Polarimeter)

- Same principles as REDSoX
- Differences:
  - 4 year development, $20M
  - Shorter, less area
  - 2 paraboloidal shells — 15 kg
  - 4 sCMOS, not CCDs, thermoelectrically cooled
  - Orbital: exposures of 0.1-3 Ms (3-100 d)

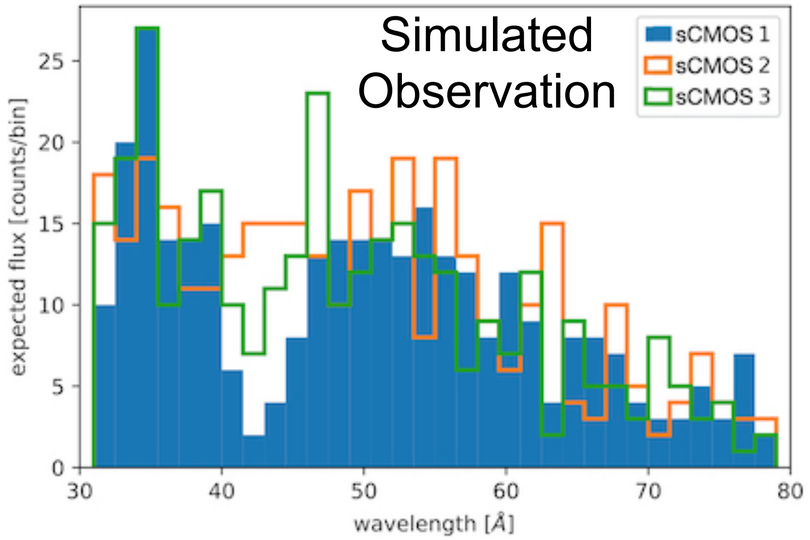


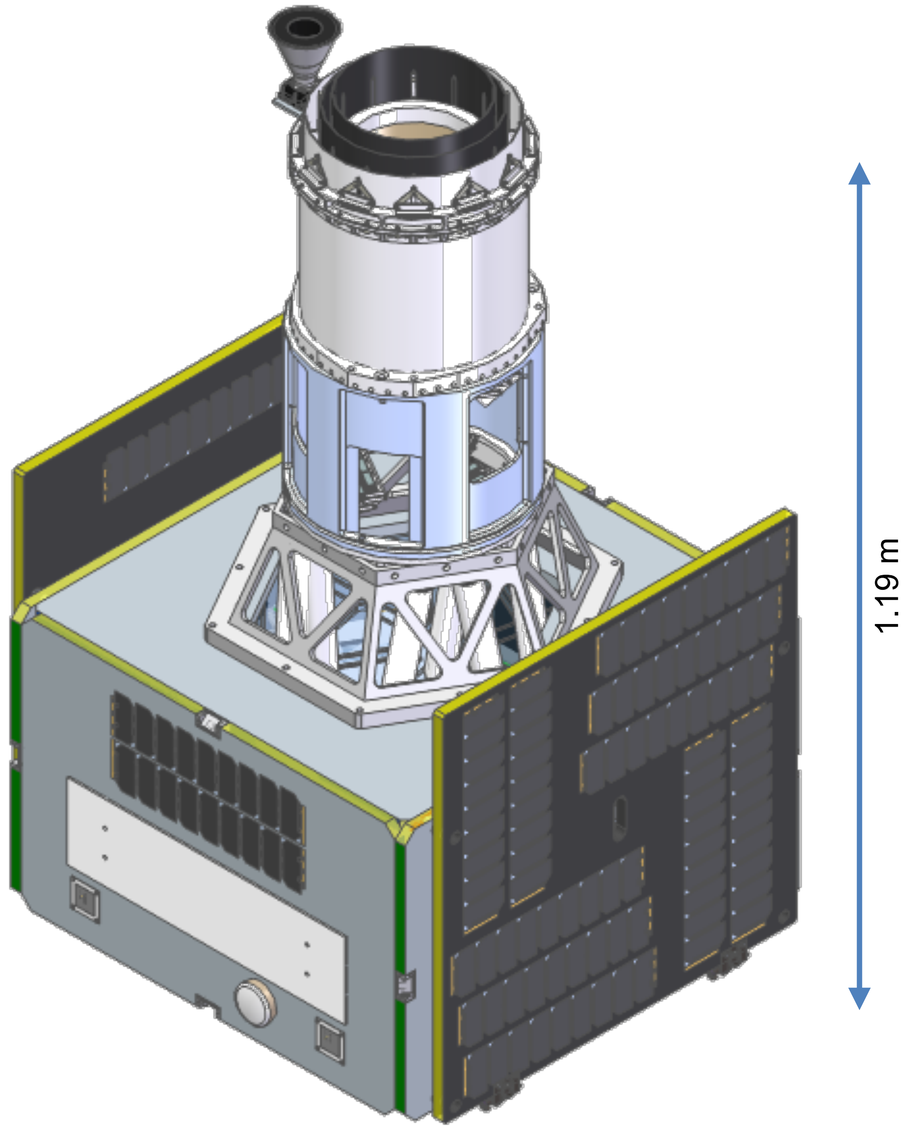




Globe Orbiting Soft X-ray Polarimeter (GOSoX)

Category	Name	T_{min} (Ms)	1 Yr Plan Time (Ms)	1 Yr Plan MDP (%)	Notes
NSs	RX J1856.5−3754		1.0	4.4	Brightest isolated neutron star
	RX J0720.4−3125[T]	0.40	1.3	4.9	Absorption line at 293 eV [15, 14]
	RX J1605.3+3249		1.5	4.8	Abs'n line at 403 eV [14]
	RX J1308.6+2127		1.0	5.8	Abs'n varies: 107-256 eV [14, 17]
	Her X-1[T]	0.10	0.4	3.2[b]	Magnetosphere-disk interaction
	PSR B0656+14[T]	0.15	1.0	3.8	Magnetospheric emission
AGN	Mk 421[T]	0.10	0.2	1.9[b]	High spectral peak (HSP) blazar
	PKS 2155−304		0.2	5.0[b]	HSP blazar
	3C 273[T]	0.75	3.0	4.8	Low spectral peak blazar
	RE J1034+396[T]	0.25	1.0	4.8	Narrow Line Sy 1 (NLS1)
	Ark 564		1.0	5.0	NLS1
Null	Capella	0.25	1.0	2.5	Null polarization target





Rocket Experiment Demonstration of a Soft X-ray Polarimeter

REDSoX*, A Sounding Rocket Payload in Development

- **PI**: Herman L. Marshall (MIT Kavli Institute)
- **Co-Is**
  - MIT: Sarah Heine (DPI), Sean MacNeil (PE), Alan Garner (PM), Moritz Günther
  - MSFC: Steve Bongiorno
  - LBNL: Eric Gullikson
- **Goals**:
  - 1- Prototype a soft X-ray polarimeter for an orbital mission (GOSoX)
  - 2- Train early career researchers

Key Facts of the REDSoX* Polarimeter:

- **Science**: 0.18-0.40 keV polarimetry of a BL Lac object, isolated neutron star or pulsar, to determine magnetic fields where X-rays are produced, and observe the effects of vacuum birefringence
- **Status**:
  - Developed a rotatable, polarized X-ray source (0.15-0.7 keV)
  - Demonstrated workable components
  - **Funded for launch in 2027**
  - Design work in progress, PDR in Feb. 2024

(Marshall et al. 2018, JATIS, 4,011005)

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