Imaging X-ray Polarimetry Explorer (IXPE) Mission Overview

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on behalf of the IXPE Team

General Observer Program

GO Cycle 1 Proposals were due on October 18, 2023

- 135 proposals - 121 regular, 14 theory, 6 large
- 103 Ms of IXPE time requested, oversubscription > 6
- Over 1400 co-Is (174 institutions, 30 countries)
- 48 proposals part of student theses

- 99 distinct targets, includes source classes beyond prime mission:
  tidal disruption events, white dwarfs, galaxy clusters, recurrent nova

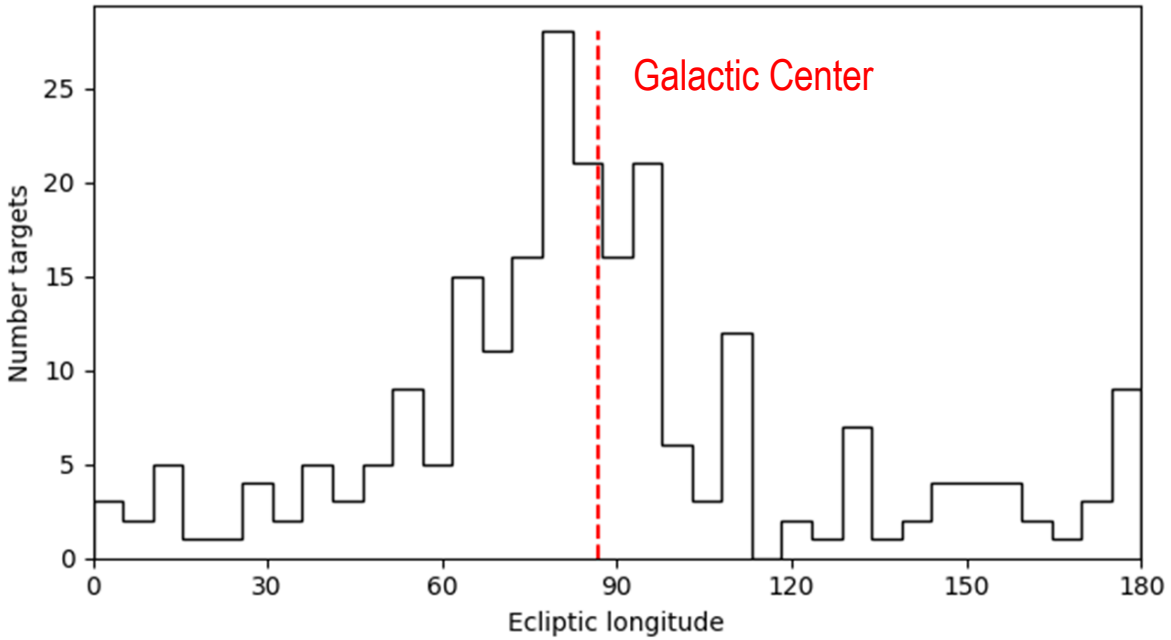
- Approved 39 proposals: 31 regular, 1 large, 7 theory
- Regular in categories A (13), ToO (8), and C (10)
- ToO were very highly oversubscribed, by a factor of 14
- GO observations started on 2024-02-03T12 UTC
- Will conduct 15 Ms of GO observations, including one large program for 2 Ms

IXPE GO Cycle 2

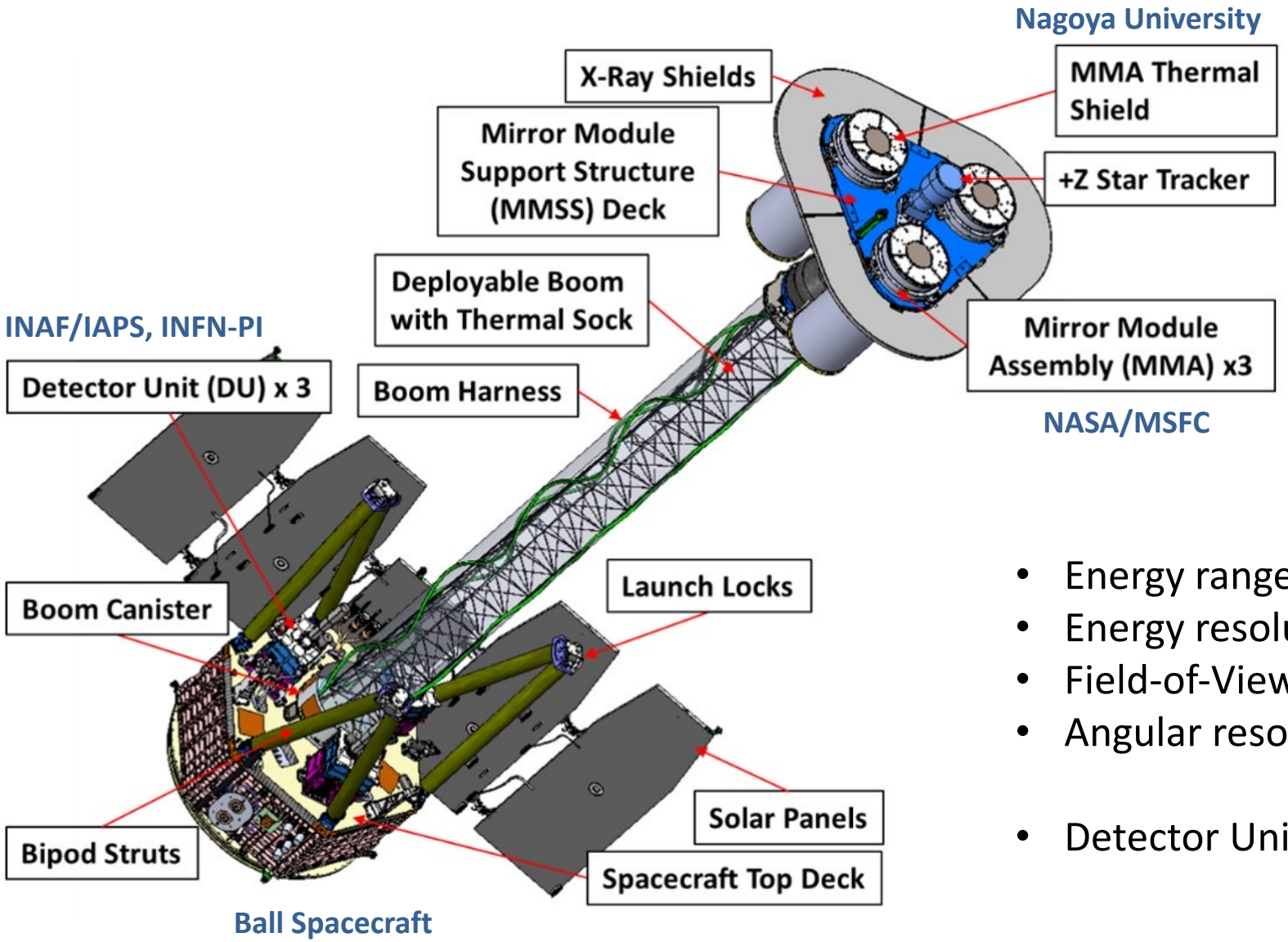
- **Deadline for IXPE GO cycle 2 is August 29, 2024.**
- Notice of Intent is **not** requested for this cycle.
- Continuing joint program with NICER, adding joint programs with NuSTAR and Swift.
- Swift GO cycle 21, due on 9/26/2024, will award IXPE time (200 ks, one medium ToO).
- Plan to allow ToOs with unspecified coordinates.

- IXPE targets cluster towards the Galactic center.
- Please propose targets away from GC.
- Best are targets within 34° of an ecliptic pole.

- Can observe 1 Crab source for ~75 ksec.
- Then need ~7 days to get data to ground.



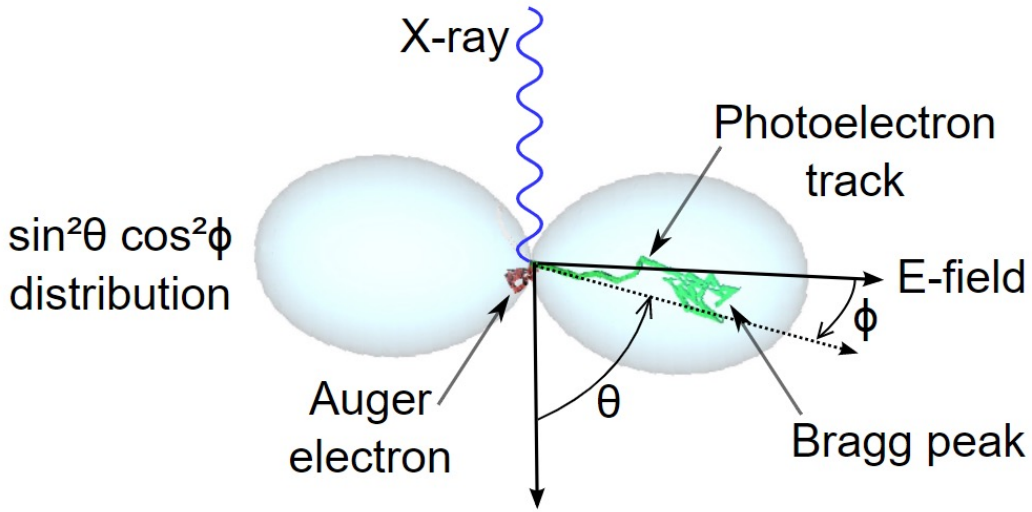
Imaging X-ray Polarimetry Explorer

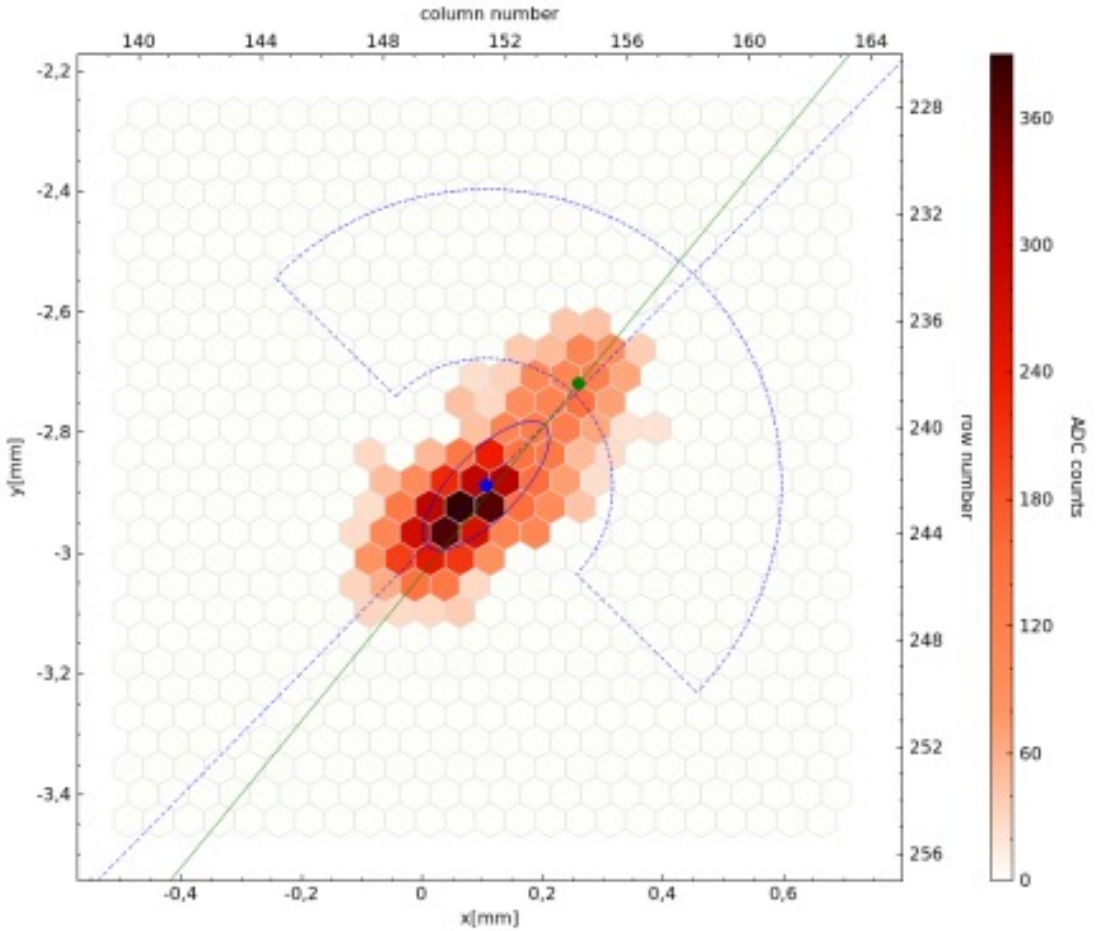


- Energy range: 2–8 keV
- Energy resolution: 0.57 keV FWHM @ 2 keV ($\propto \sqrt{E}$)
- Field-of-View: 12.9′ diameter, useful 10′
- Angular resolution: 30″ HPD

- Detector Unit = DU, numbered DU1, DU2, DU3

X-ray polarization via the photoelectric effect

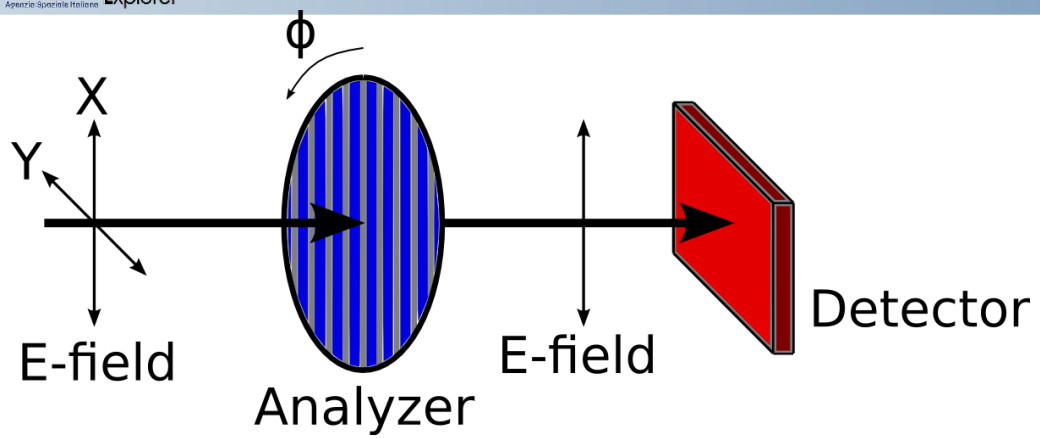




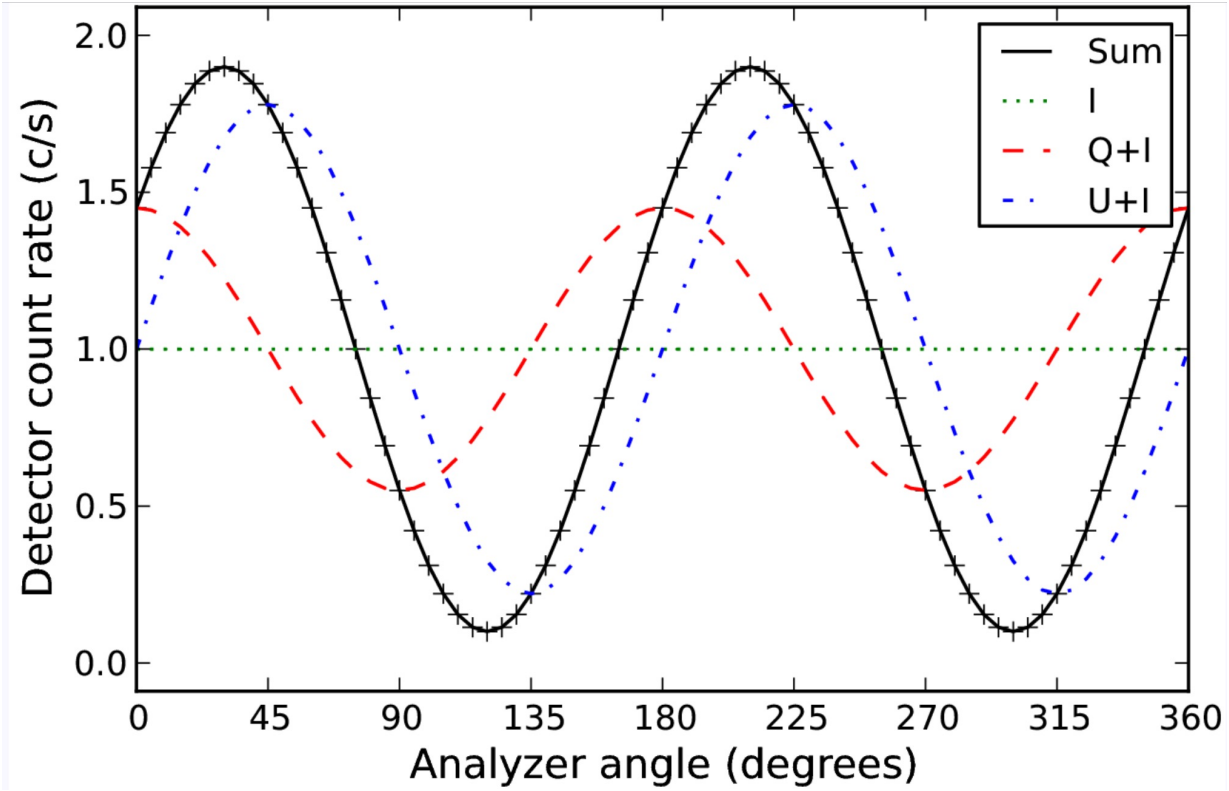
- IXPE uses the photoelectric effect to measure *linear* polarization, no sensitivity to circular polarization.
- Photoelectron ejected along photon E field.
- Key is to find photoelectron direction at interaction point.

Photoelectron track from Cas A for 2.7-keV photon in DU1.

Measuring polarization using Stokes parameters



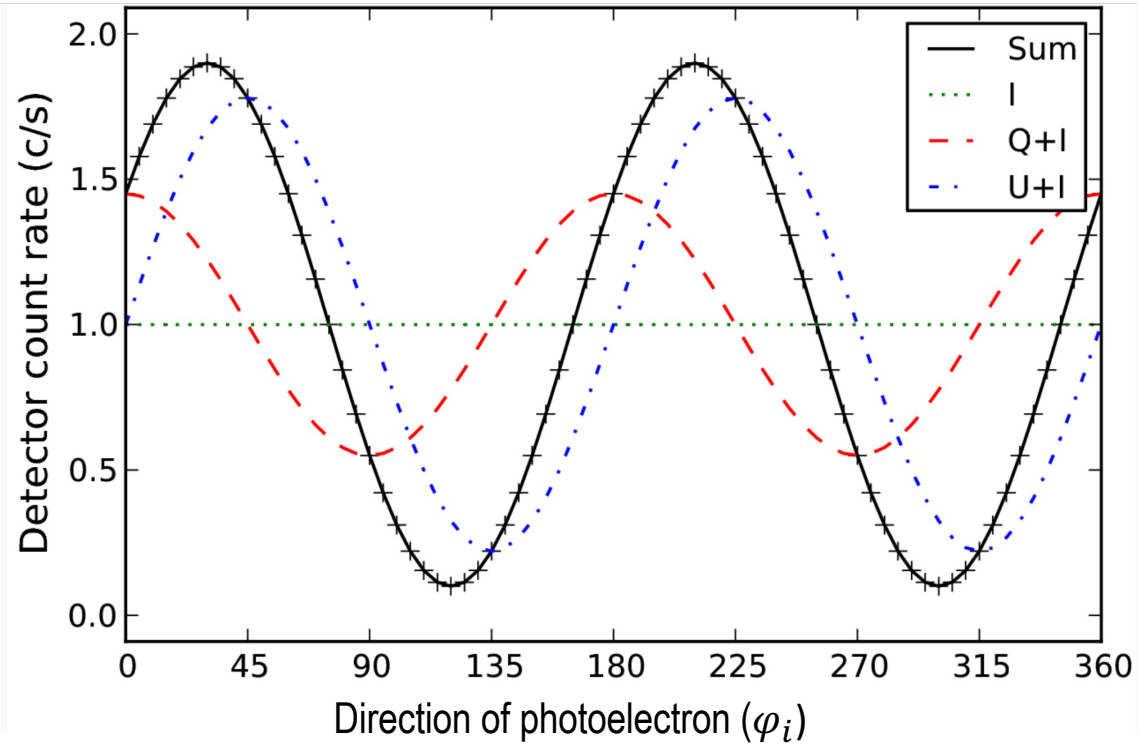
- Measure polarization by rotating analyzer and finding rate versus angle.
- Angle of peak rate gives polarization angle.
- Amplitude of modulation gives polarization degree (PD).
- Need to take into account polarization sensitivity.
- Use “modulation factor” = μ = modulation for 100% polarized beam.
- PD = modulation/μ
- **For IXPE, measure ϕ instead of rotating analyzer.**



Direction of photoelectron (φ_i)

- Stokes parameters are the amplitudes of the constant (I), cosine (Q), and sine (U) components.

Measuring polarization using Stokes parameters



- Work in Stokes parameters
  - Independent, gaussian errors
  - Simply additive
- Compute Stokes parameters (q_i, u_i) from initial direction of photoelectron (φ_i) for each event i

$$q_i = 2\cos(\varphi_i) \quad u_i = 2\sin(\varphi_i)$$

- Make sums of q_i, u_i, intensity (Q, U, I)
- Find polarization degree (PD) and position angle (PA)

$$\mathrm{PD} = \sqrt{(Q/I)^2 + (U/I)^2}$$
$$\mathrm{PA} = (1/2)\tan^{-1}(U/Q)$$

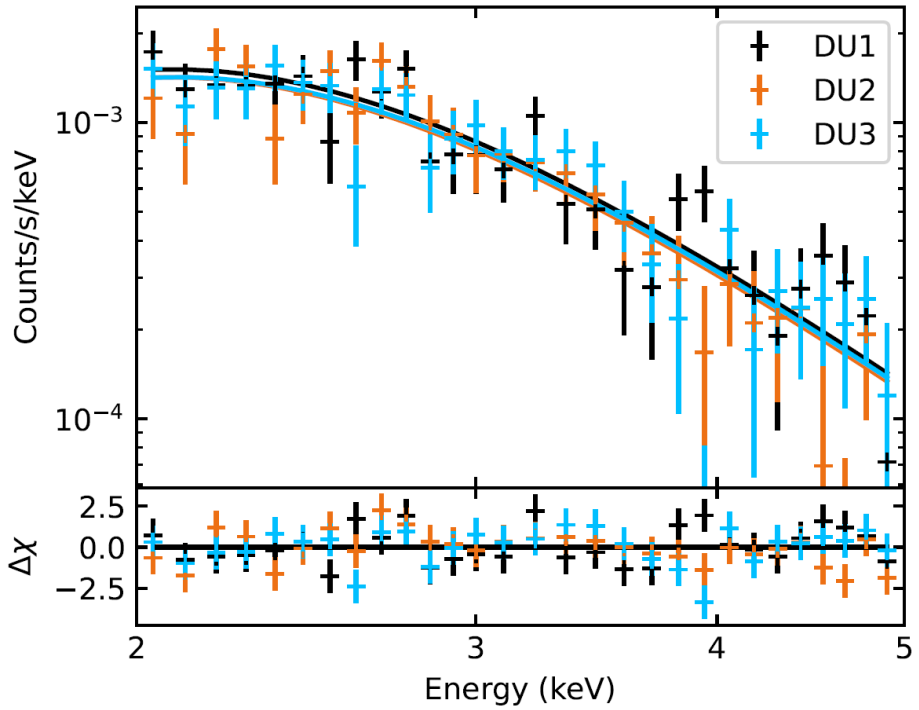
- Can do this in bins (energy, time, phase, …)

Measuring polarization using Stokes parameters

Spectrum = counts in energy bins.

For each X-ray find: 1

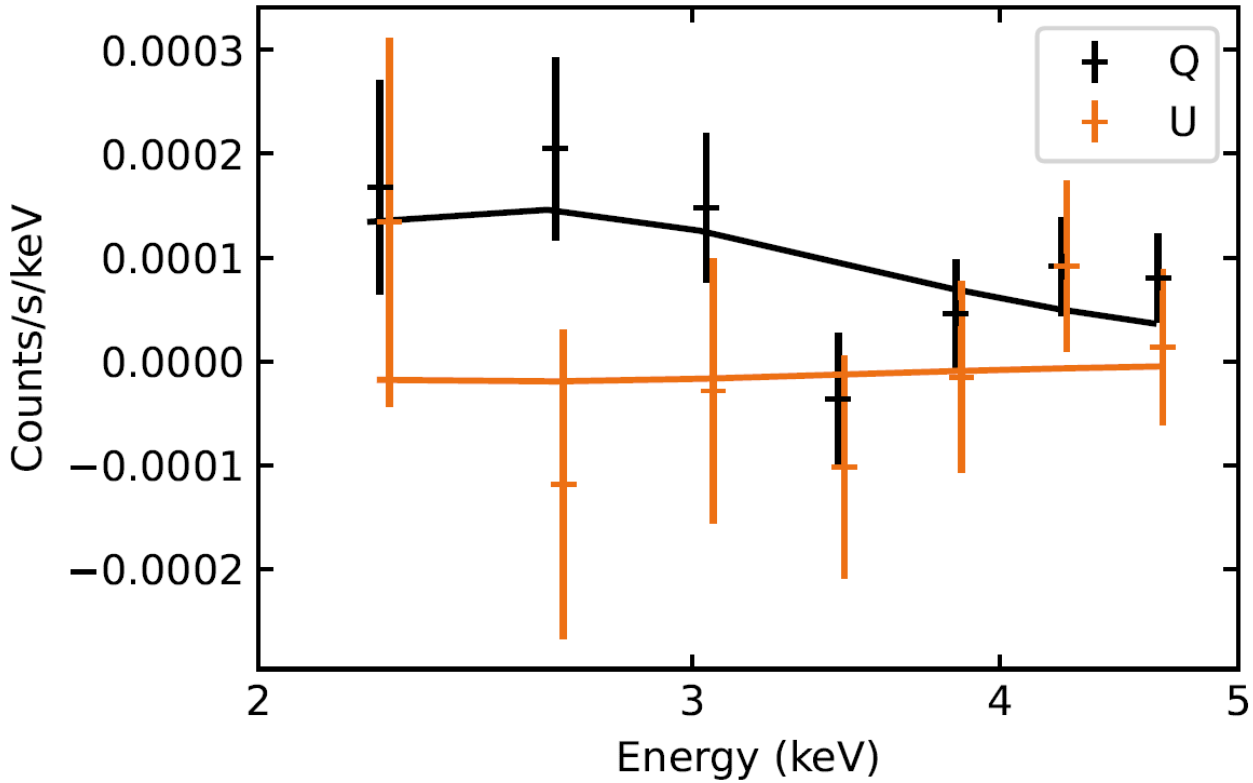
Make sums in energy bins:



Spectropolarimetry uses sums of q_i, u_i in energy bins.

For each X-ray find: $q_i = 2\cos(\varphi_i)$ and $u_i = 2\sin(\varphi_i)$

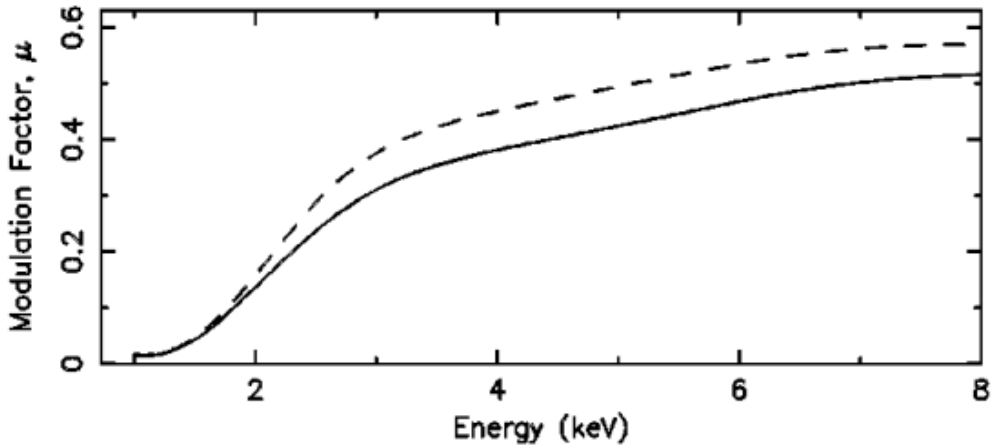
Make sums in energy bins:

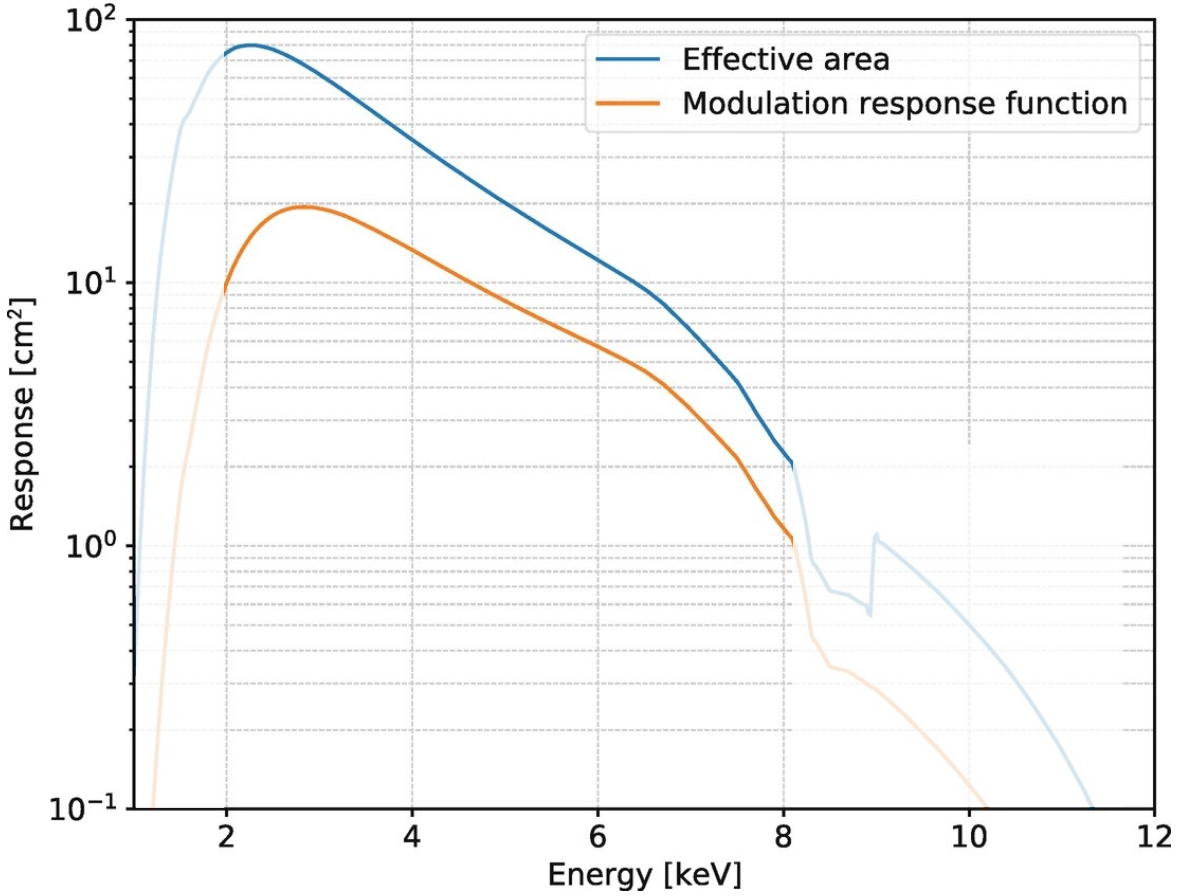


Have three spectra: I, Q, U.

Measuring polarization using Stokes parameters

- To do spectral fitting, one uses the response matrix and auxiliary response file, which is the effective area versus energy.
- Need to take into account the polarization response (μ).
- Use the 'modulation response'.





- Can do all this in Xspec
- See talk by Doug Swartz

Minimum Detectable Polarization

Minimum Detectable Polarization 99% (MDP99) is the Polarization Degree that has only a 1% probability of being produced by random fluctuations from an unpolarized source.

$$MDP99 = \frac{4.29}{\mu\, s}\sqrt{\frac{s+b}{T}}$$

where μ = modulation factor, *s* = source rate, *b* = background rate, *T* = exposure time.

For MDP = 2% with μ = 0.4 and *b* = 0, need 3×10^5 X-rays.

Can use PIMMS to calculate MDP

Can use ixpeobssim to simulate observation and find MDP, see talk by Niccolo' di Lalla.

For extended sources and background mitigation, see talk by Stefano Silvestri.

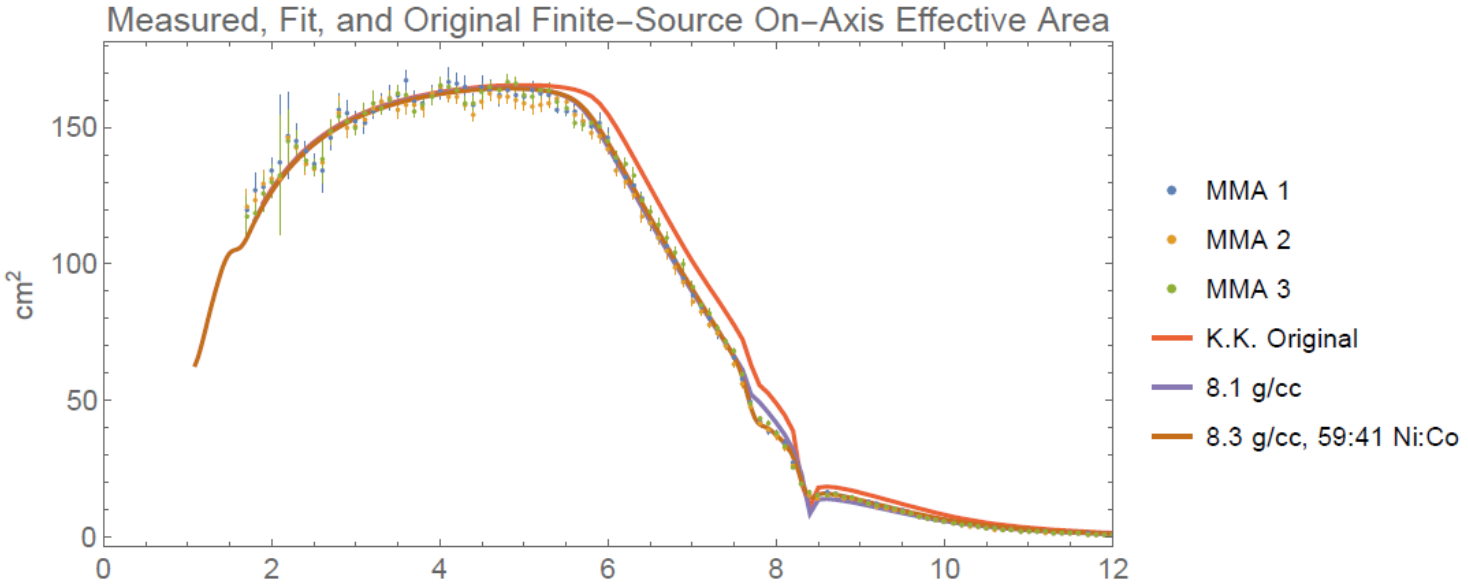
Calibration Updates

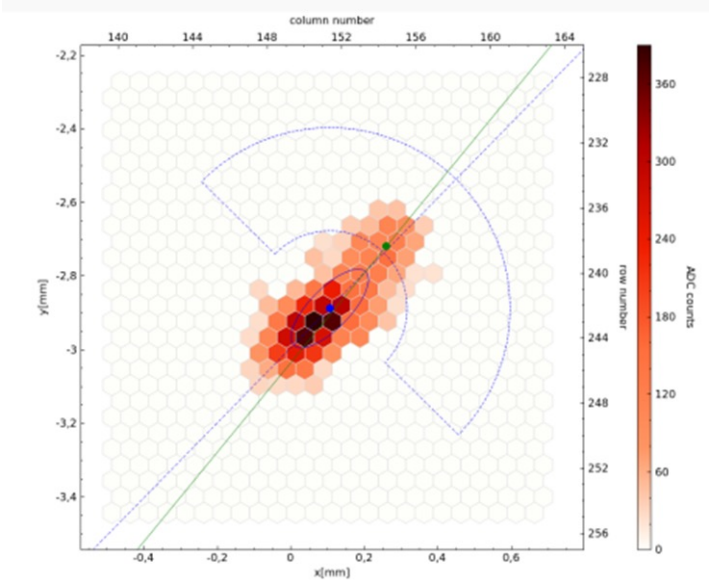
- IXPE calibration had issue in 6-8 keV band, now solved with adjustment of mirror surface density and Ni:Co ratio in fits to ground calibration data.

- Now include time-dependence of gas pressure in DUs
- Reduces difference in normalization of DUs.
- See talk by Doug on ixpecalcarf

- Working on correction for charging of gas electron multipliers that affects spectra for bright sources.

- Neural network approaches to X-ray image analysis can improve polarization sensitivity. Currently manpower limited for implementation.





IXPE Science at HEAD 2024

Recent advances in X-ray polarimetric and spectroscopic studies of accreting stellar-mass black holes,
April 9 at 5:20 pm

Probing Blazar Jets with Multi-wavelength Polarization,
April 11 at 1:40 pm

Posters/individual talks:
IXPE sources: a quick-look database and high-level data analysis toolkit, 105.14
X-ray Polarization of the Eastern Lobe of SS 433, 107.02
Polarization of pulsar wind nebulae and millisecond pulsars, 107.15
An IXPE-Led Campaign on the Soft State of Cygnus X-1, 107.65
Two years of supernova remnants with IXPE, 300.01

IXPE is making exciting discoveries that are reshaping our understanding of the energetic universe.