XL-Calibur
The Balloon-Borne Hard X-ray Polarimeter

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Introduction

XL-Calibur is a second-generation balloon-borne hard X-ray polarimety mission that we plan to fly in both the Northern and Southern hemispheres in the coming years. It on the success of X-Calibur, which flew from McMurdo in the 2018-19 austral summer and placed limits on the polarization properties of the accreting pulsar GX 301-2 in the 20-50 keV range.

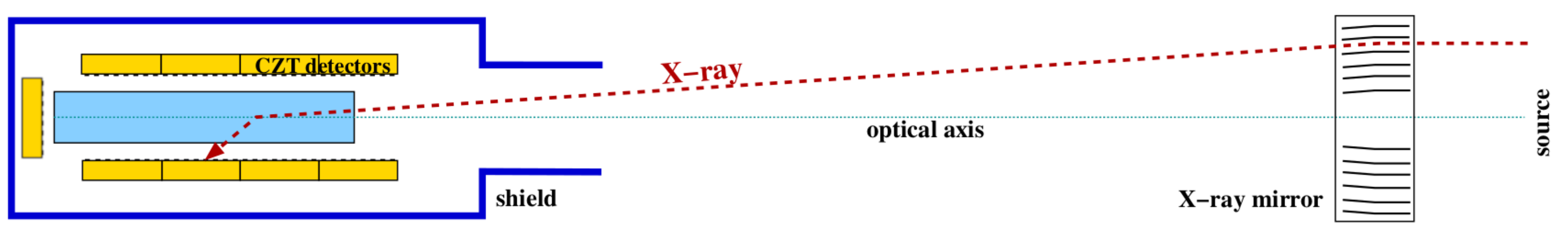
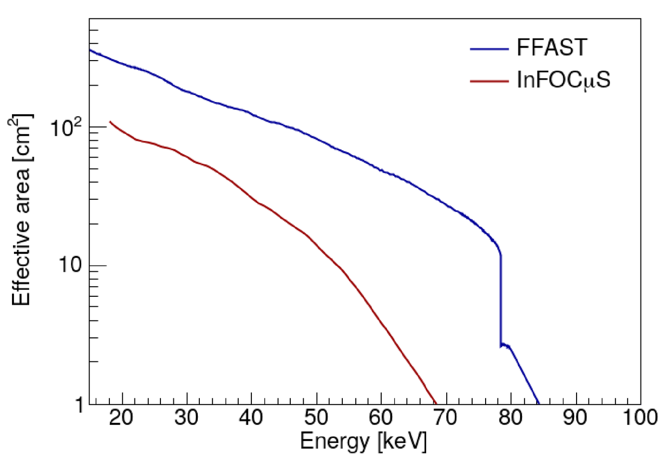


Figure 1: X-rays from the source are focused through a grazing incidence mirror onto a beryllium element, in which the photons are preferentially scattered with respect to their polarization. The beryllium stick is surrounded on four sides by sixteen CZT detectors, each read out by two ASICs. At the rear of the polarimeter is a seventeeth detector used for imaging. The entire detector is set within a CsI shield to suppress background.

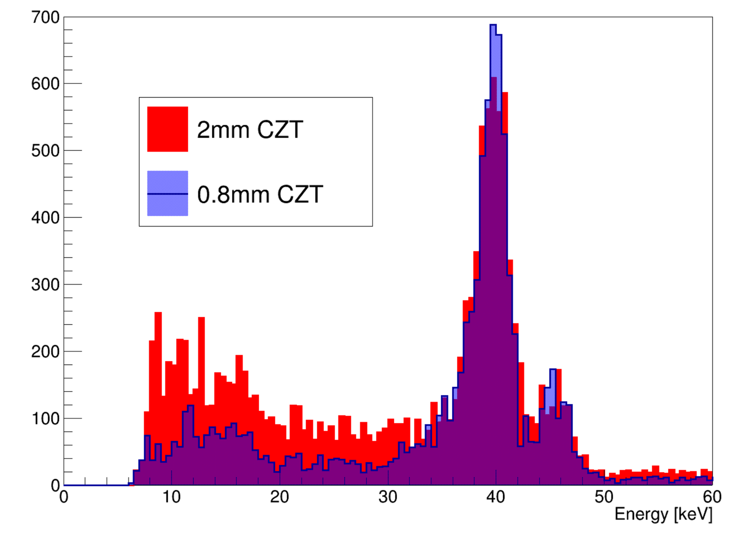
FFAST Mirror



- Supplied by Osaka University; originally built for the Formation Flying All Sky Telescope
- 3 – 10× **better effective area** than the Infocμs mirror used on X-Calibur
- Calibration expected to give the mirror a Half Power Diameter of 1.7 arcmin by flight
- FFAST mirror has 12 m focal length; WUSTL team is building a truss for this focal length
  - Focal spot must deflect by <3 mm
  - Truss must withstand 16 g – forces (the potential force during parachute deployment)

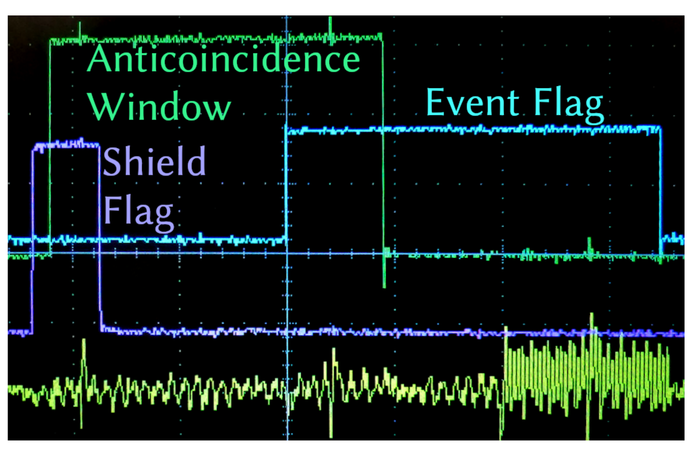
Upgraded Polarimeter

By using thinner CZT detectors and more effective shielding, we can lower the background by a factor of 6 – 14



- CZT thickness decreases from 2 mm to 0.8 mm. This loses 1 % of 15-50 keV photons and 5 % of photons above 60 keV, but background scales with Volume$^{2/5}$.
- Thin CZT doesn't see the "low energy tail" present in the 2 mm.
- Thin CZT detects comparitively more events in the photopeak.

- Shorter anticoincidence window (6 μs ⟶ 2 μs)
- Lower active shield thresholds due to the shorter window (X-Calibur flew with body shield at 1.1 MeV and the top at 200 keV)
- Quicker electronics will have less deadtime caused by large shield pulses
- Solar cycle is leaving minimum, which will further reduce background



References

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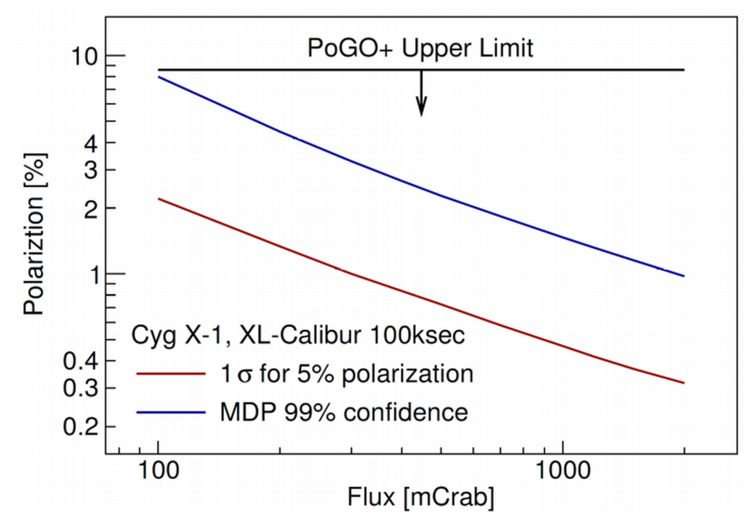
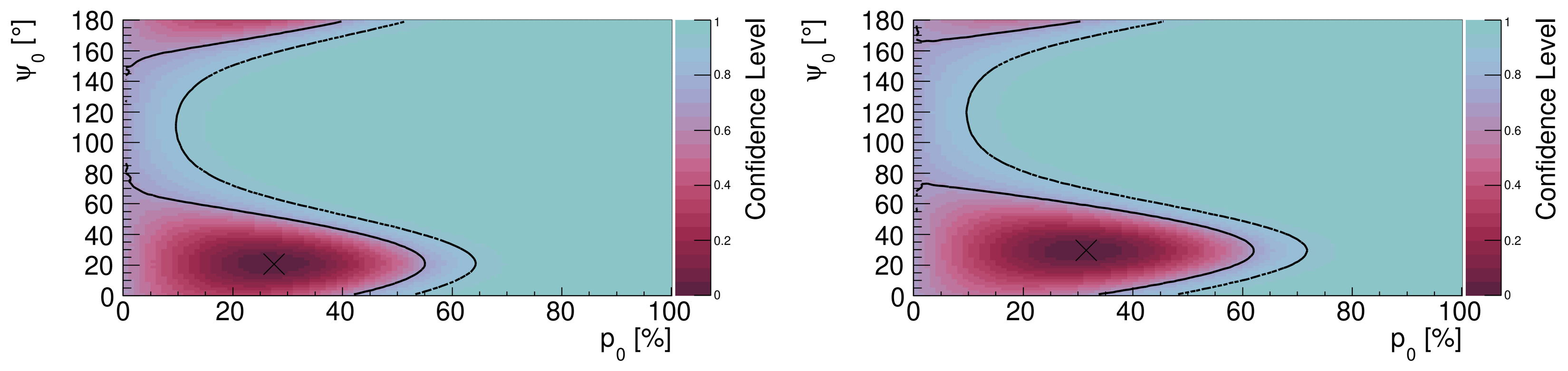
X-ray Corona of Accreting Stellar Mass Black Holes

- Observe Cygnus X-1 during Kiruna flight
- PoGO+ placed an upper limit on the polarization of Cygnus X-1 in the low/hard stateupper at 8.6 %[1]
- Lamp post corona predicts polarization of 15 %, so extended corona is favored [2], [4]
- For 100 ks observation at 700 mCrab, XL-Calibur has MDP of 2 %



Pulsed X-rays from Accreting Pulsars

- Possible targets: GX 301-2, Vela X-1, Her X-1
- Polarization depends on x-ray beam shape: fan or pencil beam [3]
- Polarization also depends on birefringence of the magnetized QED vacuum and plasma in the accretion column [3]
- XL-Calibur is well suited to study these through the cyclotron absorption features that fall within its energy range



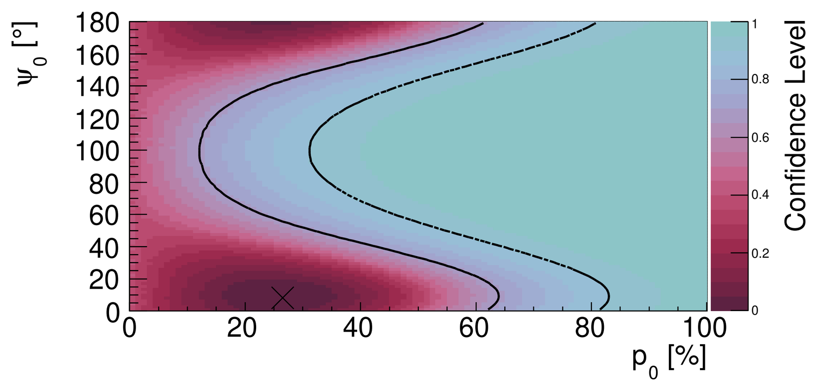
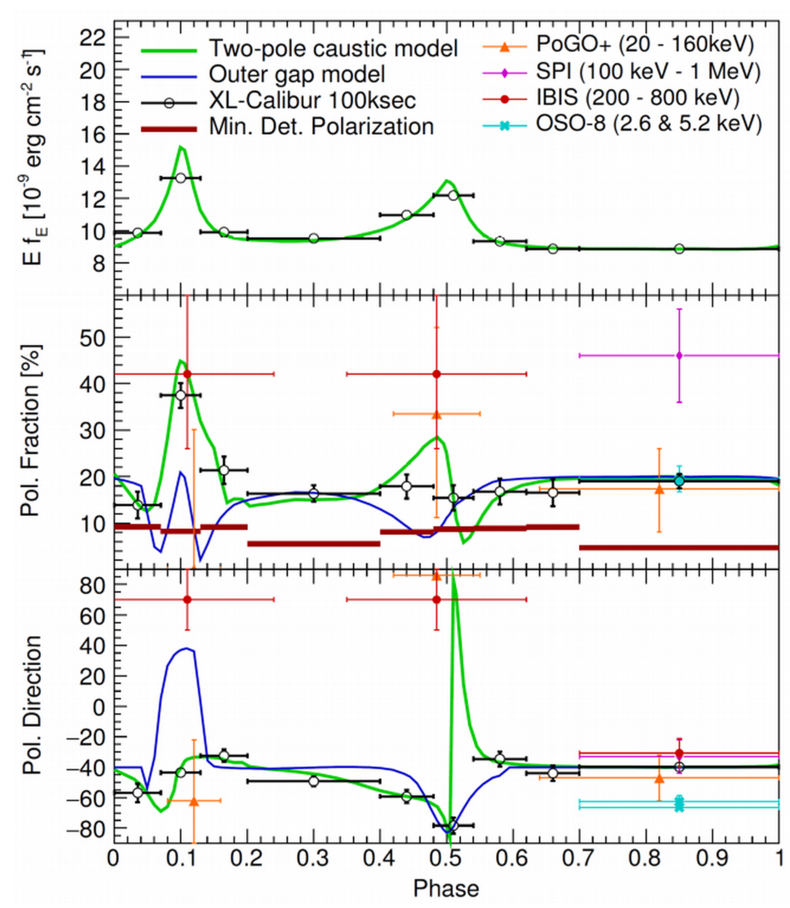


Figure 2: Polarization from the X-Calibur observations of GX 301-2 for the entire pulse (top left), main pulse (phase 0.8 to 1.14, top right), and bridge and secondary pulse (phase 0.14 to 0.8, bottom left). The cross indicates the most likely polarization fraction p_0 and angle Ψ_0.

Crab Nebula and Pulsar

- Crab is behind the sun during June, so may be observed depending on Kiruna launch opportunities
- X-rays are likely synchrotron emission from gaps in the magnetosphere; polarization could help distinguish where these gaps might be
- Shown at right is a simulated 100 ks ON observation of XL-Calibur, showing how it could differentiate between emission models
- With phase-resolved polarimetry XL-Calibur would seperate the contributions of the pulsar and the nebula



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