The Stellar X-Ray Polarimeter

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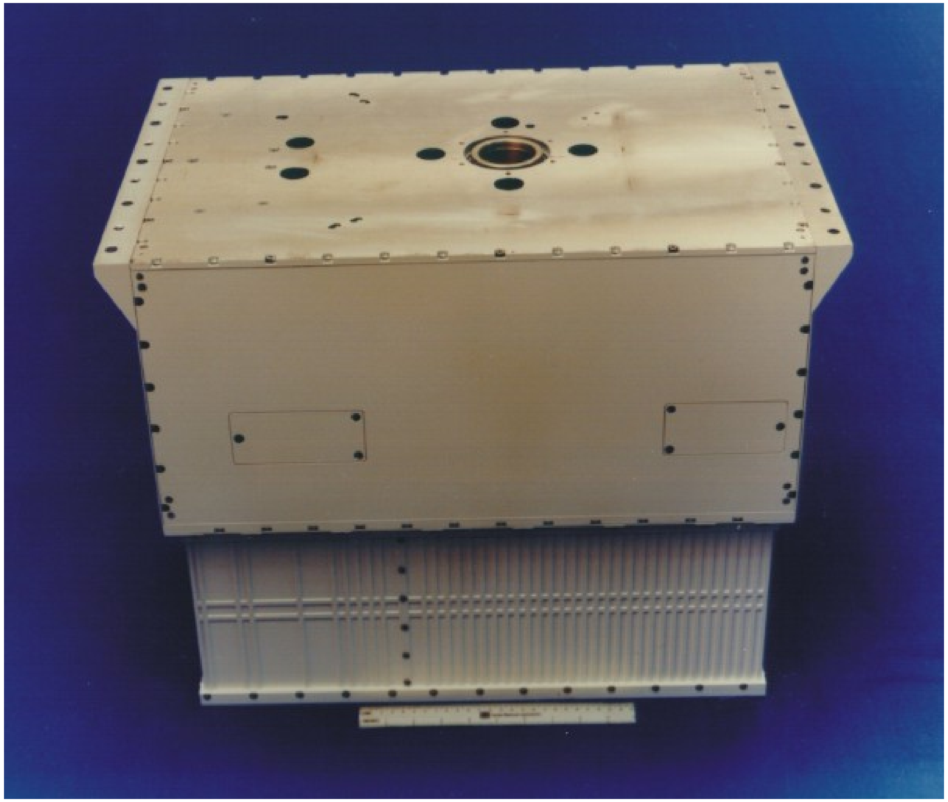
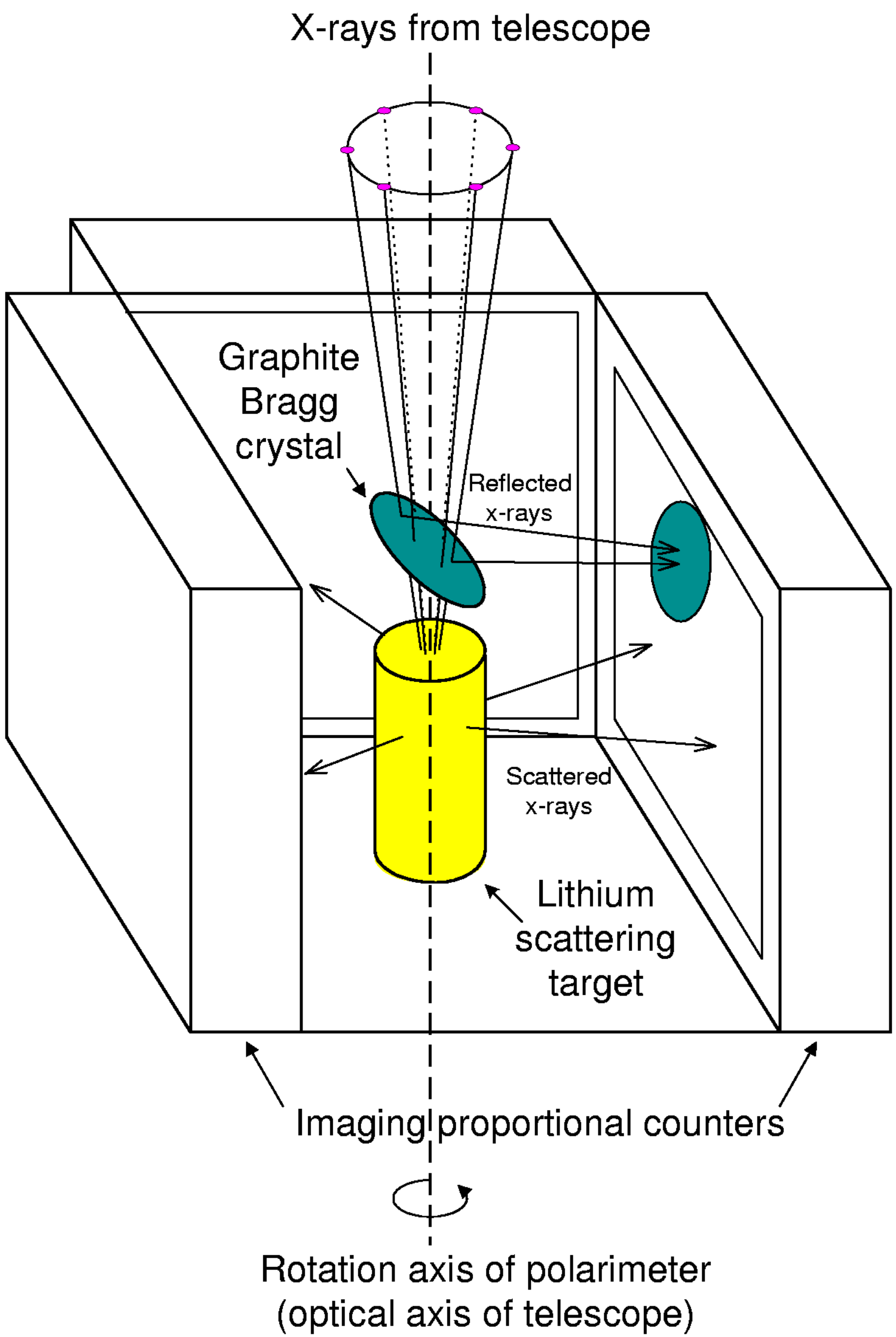
Robert Novick, Eric Silver, Martin Weisskopf, Enrico Costa, John Tomsick, Paolo Soffitta, Klaus Ziock, Joseph Dwyer, Igor Lapshov, Ron Elsner, Eric Ford, Brian Ramsey, Alda Rubini, Giuseppe Manzo, Andrea Santangelo, and many others

SXRP Flight Model



- Most sensitive X-ray polarimeter built to date
- Flight model exists, operates reliably
- Extensively calibrated, well understood
- SXRP-FM and SODART telescopes at SAO

Basic Operation



Polarization Sensitivity

Polarization sensitivity has two aspects:

- Statistics of polarization measurements
- Systematic error for bright sources

Instrumental parameters:

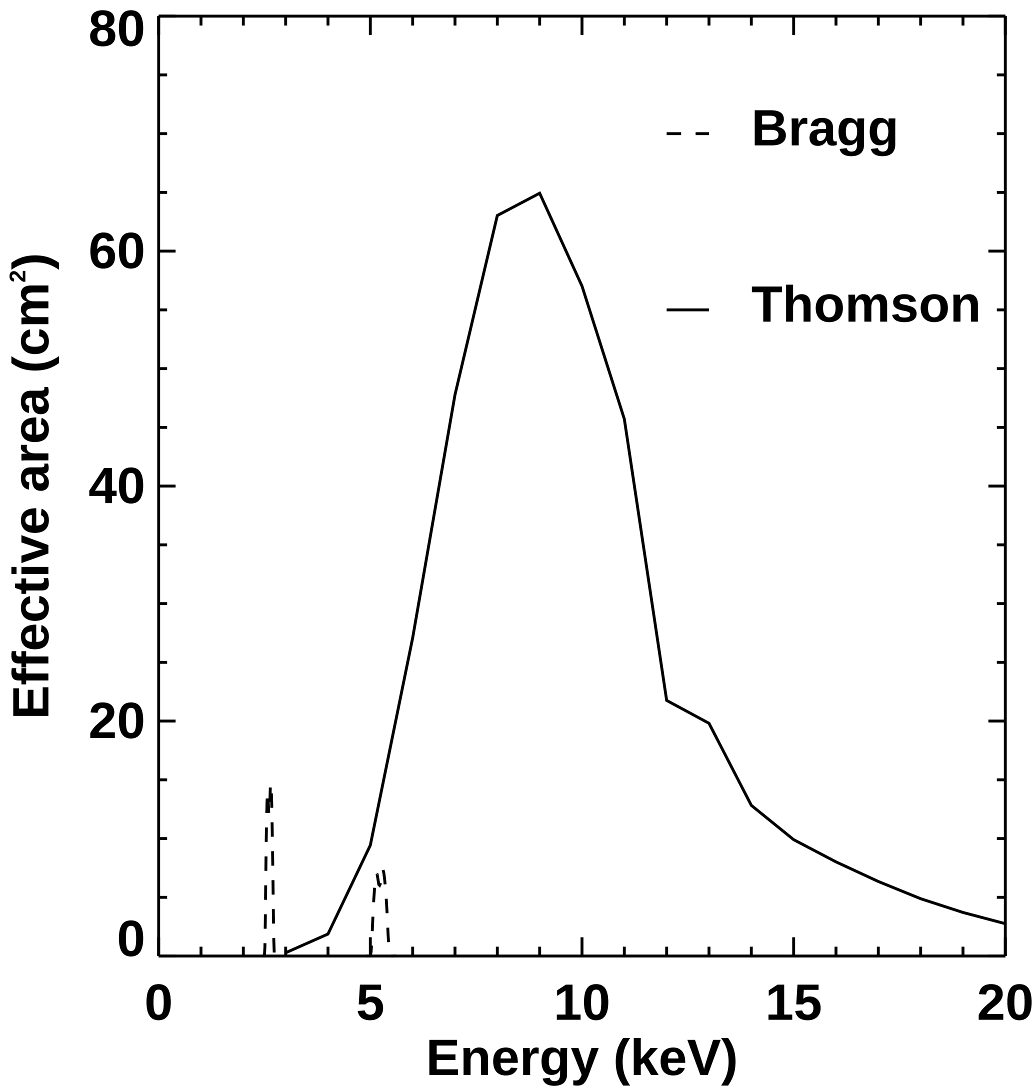
- Effective area or source counting rate, S
- Background rate, B
- Modulation factor, μ

Modulation factor is the fractional count rate modulation for a 100% polarized source and is important for both the statistics of polarization measurements and systematic errors.

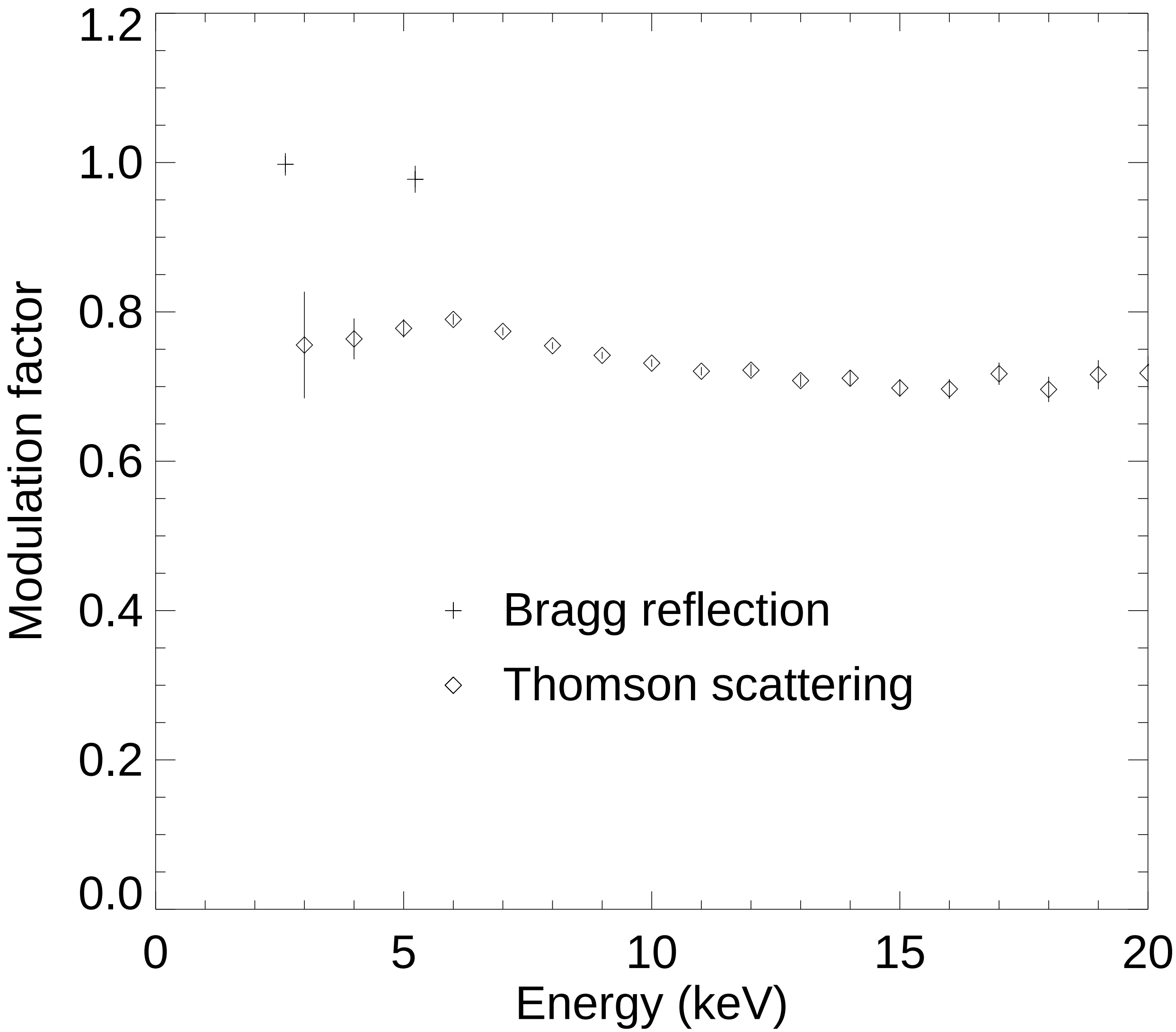
Minimum Detectable Polarization (MDP) =

$$\frac{4.29}{\mu S}\sqrt{\frac{S+B}{T}}$$

Effective Area

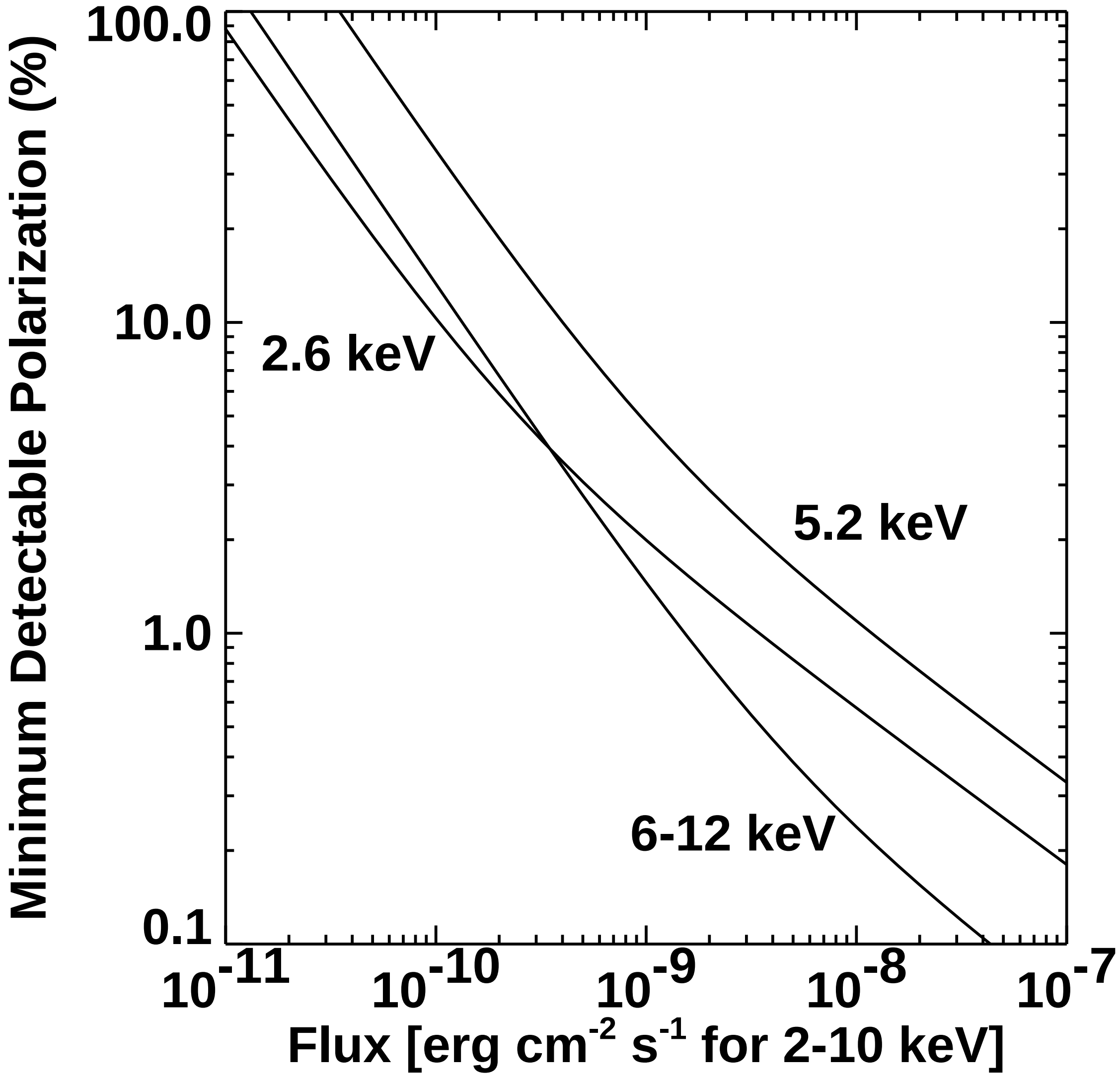


Modulation Factor



High modulation factors are key to achieving good polarization sensitivity

Polarization Sensitivity

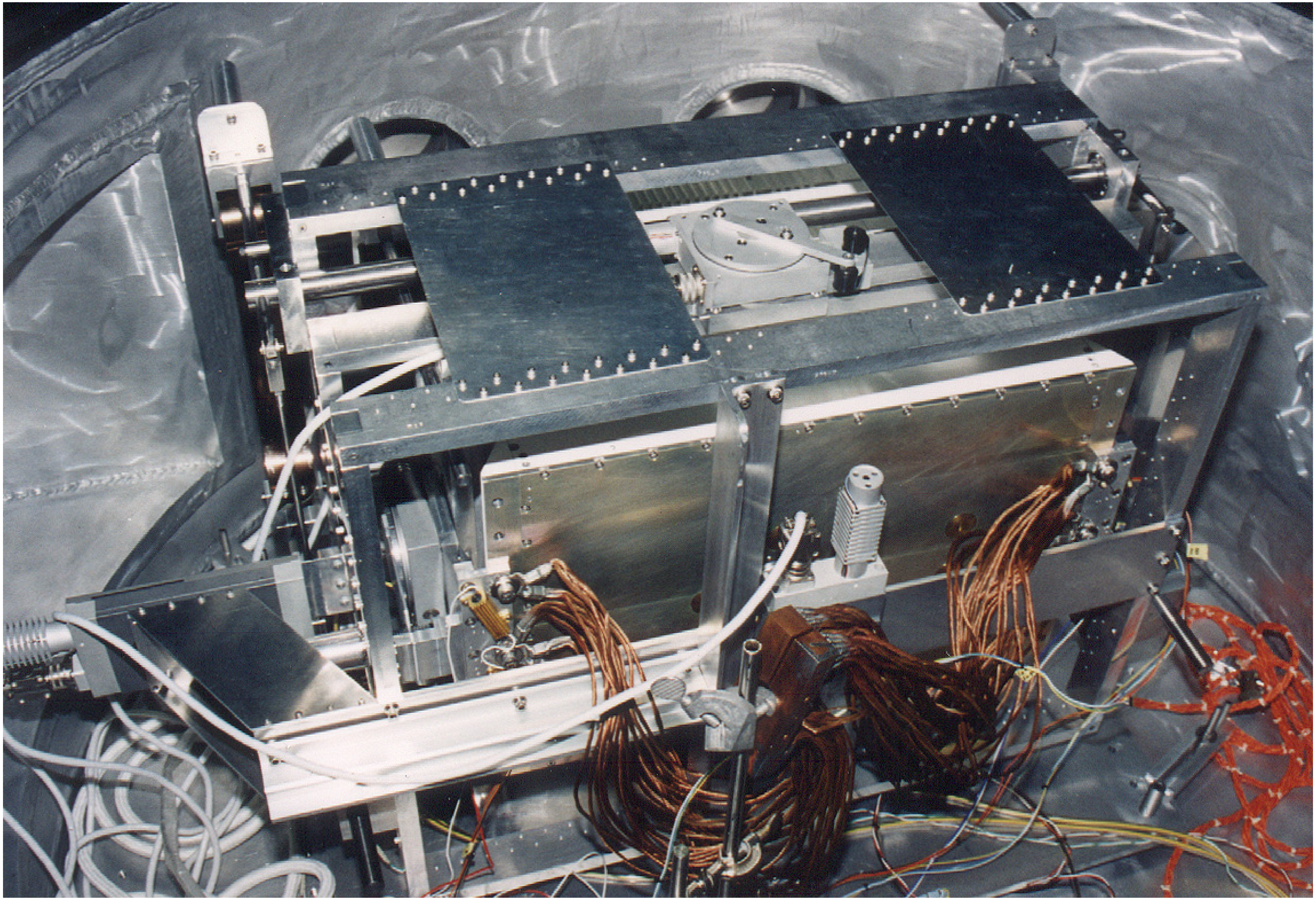


For 500 ks observations

Example Source Sensitivities

Target	MDP 2.6 keV (%)	MDP 5-12 keV (%)
Stellar Mass Compact Objects		
Persistent (Cyg X-1, GRS1915+105)	< 1	< 1
Transient (GX339-4, 4U1630-47)	< 1	< 1
Neutron-star Binaries		
Cen X-3, Vela X-1 (5 pulse bins)	< 1	< 1
Her X-1 High State (5 pulse bins)	3.2	2.0
LMXBs (Sco X-1 GX 5-1, GX 349+2, ...)	< 1	< 1
Isolated Neutron Stars		
Pulsars (Vela, Crab, B1509-58) (5 pulse bins)	1–5	< 1
Magnetars (4U0142+61, RXS1708-40)	4-11	30-70
Supernove Remnants		
Plerions (Vela, G21.5-0.9)	7	18
Shell (Tycho, Cas A, G347.5-05)	4-10	20-40
Supermassive Black Holes		
Seyfert 1 (NGC4151, IC4329A, NGC3783, ...)	3.5-12	1.1-40
Seyfert 2 (NGC4507, MCG-5-23-16, NGC5506)	6-16	2-12
Blazars (Mkn421, PKS2155-304, 3C279...)	2-4	5-12

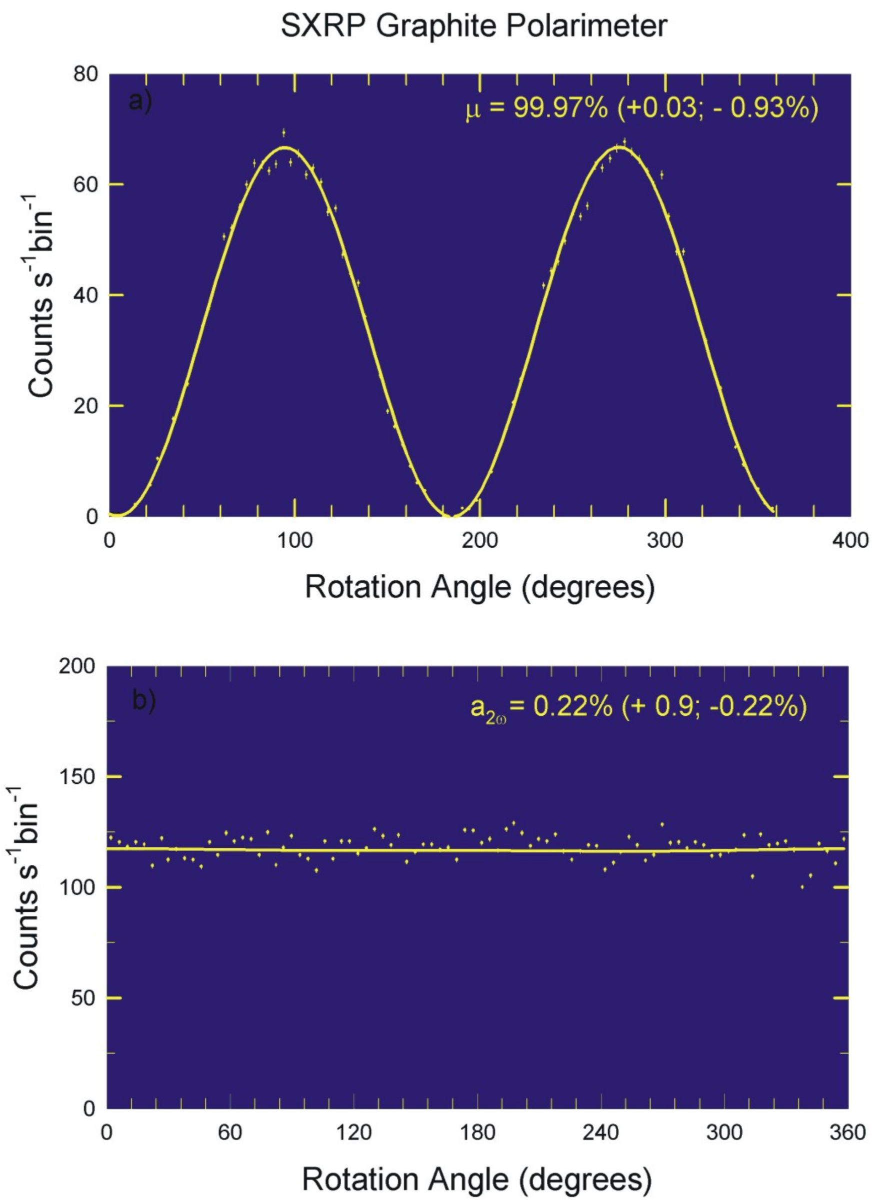
SXRP Calibration



SXRP-FM extensively calibrated in X-ray beam at LLNL

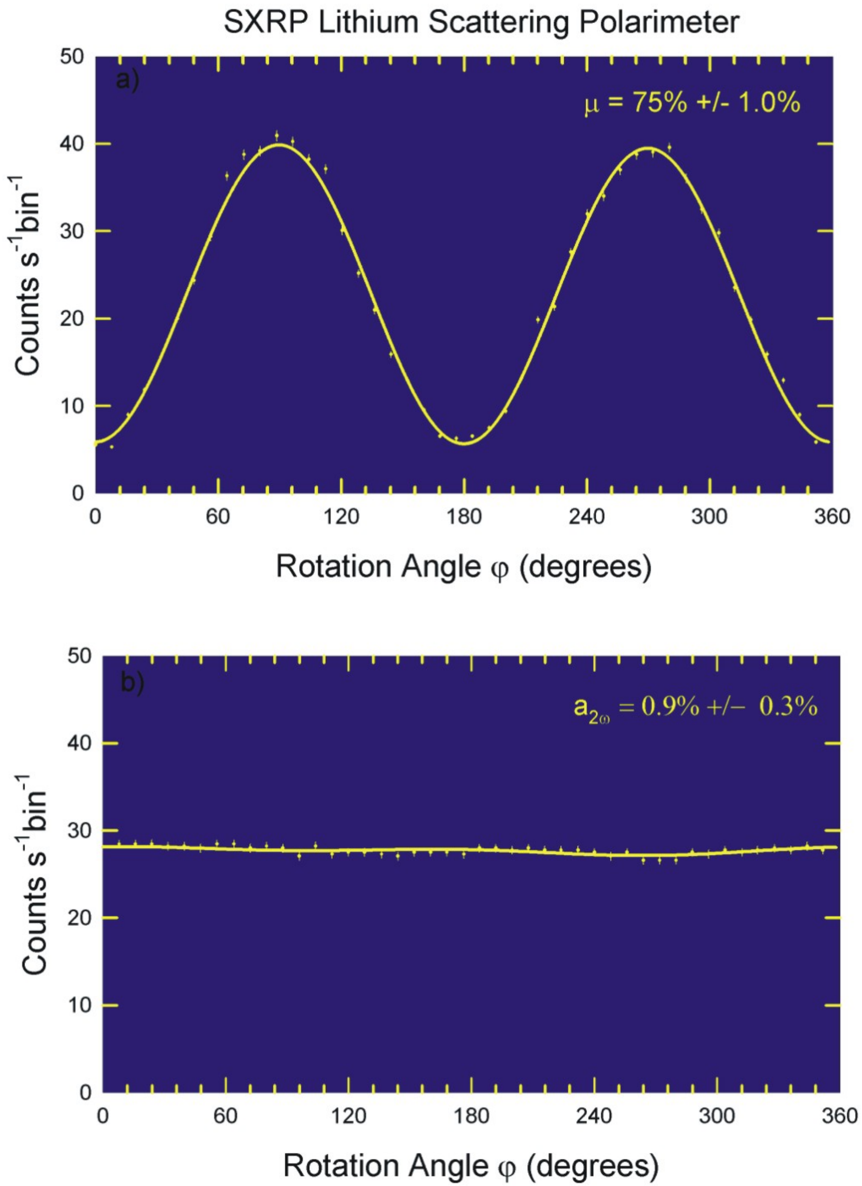
See Poster by Tomsick for details

Bragg Calibration



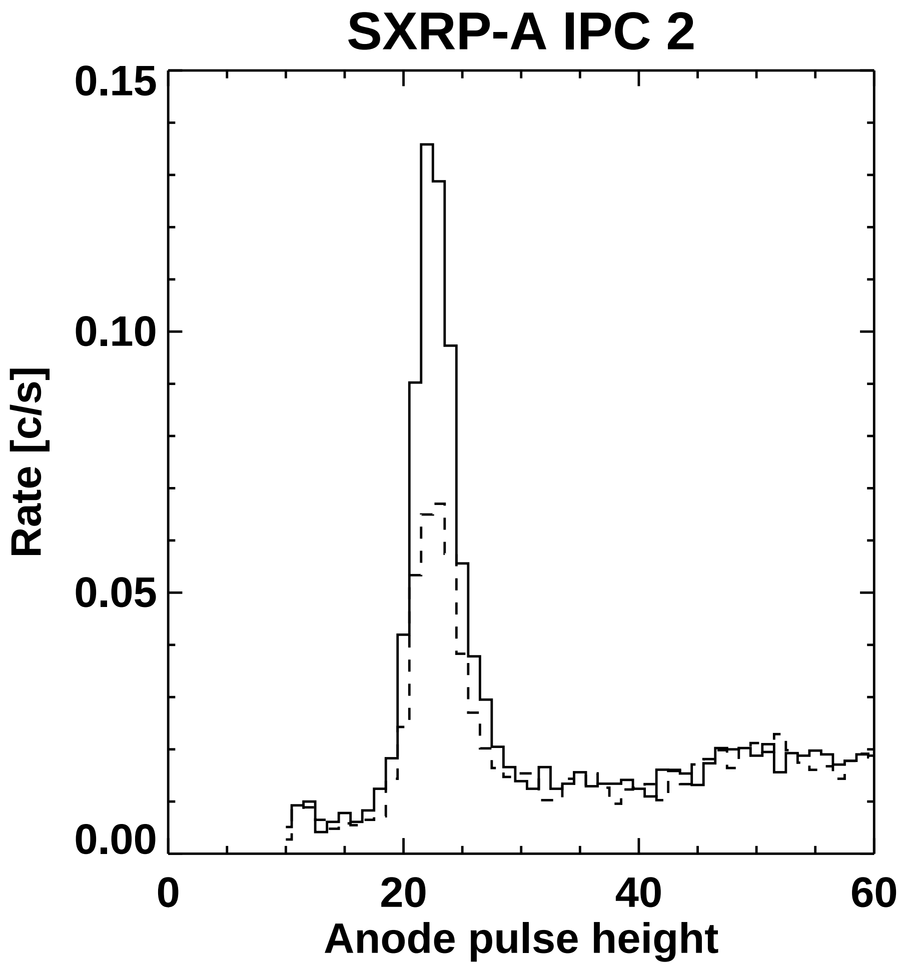
Bragg polarimeter has very high modulation factor and very low instrumental polarization

Lithium Calibration



Thomson scattering polarimeter has moderate modulation factor and low instrumental polarization

Performance Monitoring



Complete functional tests in April 1998, July 1999, April 2000, April 20001, April 2003

Imaging proportional counters and all other systems continue to operate reliably

Conclusions

- SXRP is the most sensitive X-ray built to date
- Flight model exists, operates reliably
- Extensively calibrated, well understood
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X-ray clues to viability of loop quantum gravity

Sir — The unification of quantum mechanics with gravity is the most pressing question in theoretical physics today. However, experimental feedback to the theorists has been sorely lacking. Astrophysicists are now beginning to probe the behaviour of gravity at quantum (microscopic) scales.

For example, Igor G. Mitrofanov (*Nature* **426,** 139; 2003) described a possible constraint on a leading theory, loop quantum gravity, based on the polarization of high-energy radiation from astrophysical sources. The high-energy photons have to travel cosmological distances to reach us, allowing small effects of quantum gravity to reveal themselves. This specific constraint depends on the reported detection of polarization from a γ-ray burst, which has yet to be confirmed, hence Mitrofanov cautioned readers to await confirmation of this measurement before concluding that loop quantum gravity is not viable.

There is no need to wait. The constraint on the polarization of γ-rays applies equally to the polarization of X-rays, for which there are 30-year-old measurements. The X-ray polarization of the Crab nebula, a thousand-year-old remnant of an exploded star, was first measured by Novick and collaborators[1] in 1972 and confirmed by a different instrument four years later[2]. The observed X-ray polarization from the Crab nebula is in strong conflict ($\chi < 10^{-4}$) with the predictions of loop quantum gravity, if the effects of quantum gravity depend linearly on photon energy.

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1. Novick, R. *et al. Astrophys. J.* **174,** L1–L8 (1972).
2. Weisskopf, M. C. *et al. Astrophys. J.* **208,** L125–L128 (1976).

Loop Quantum Gravity

Rotation of polarization in linear case

$$\Delta\phi(E) = 4\pi^2 \chi l_P D (E/hc)^2$$

(Gambini & Pullin 1999, Phys. Rev. D 59, 124021)

Constraint

$$\chi < 10^{-4} \Delta\phi(E) (E/\mathrm{keV})^{-2} (D/\mathrm{kpc})^{-1}$$

For Crab nebula at 2.2 kpc, $\Delta\phi < 0.3$ between optical and 2.6 keV implies $\chi < 10^{-4}$