# Polarization properties with INTEGRAL/IBIS

## Swift J1727.8 -1613 and others


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# Polarization with INTEGRAL/IBIS

1. The IBIS/Compton mode and Crab nebula
2. Microquasars polarization with Swift J1727.8-1613
3. Interpretation and outlook

# 1. Principle of IBIS/Compton mode

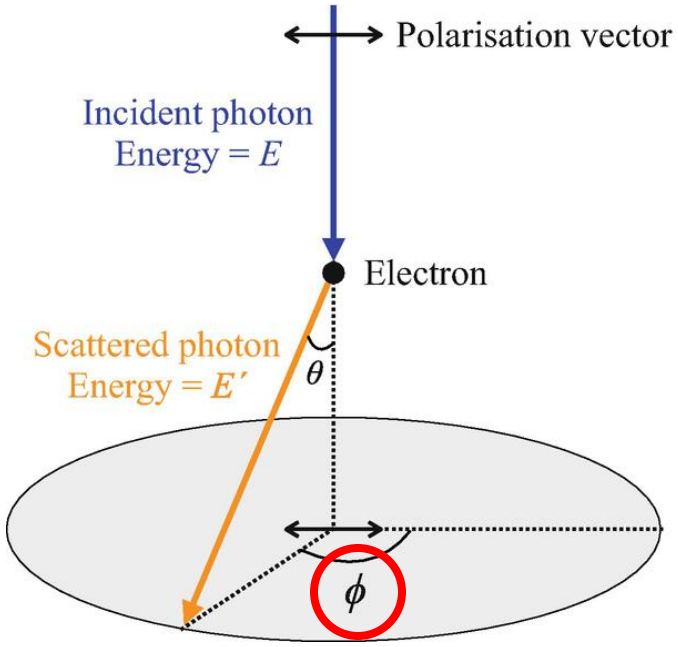
# Polarization of gamma-rays

- Compton scattering depends on polarization of incoming light (Klein-Nishina formula)

$$\frac{\mathrm{d}\sigma_C}{\mathrm{d}\Omega} = \frac{r_e^2}{2}\left(\frac{E'}{E}\right)^2\left[\frac{E'}{E} + \frac{E}{E'} - 2\sin^2\theta\cos^2\phi\right]$$

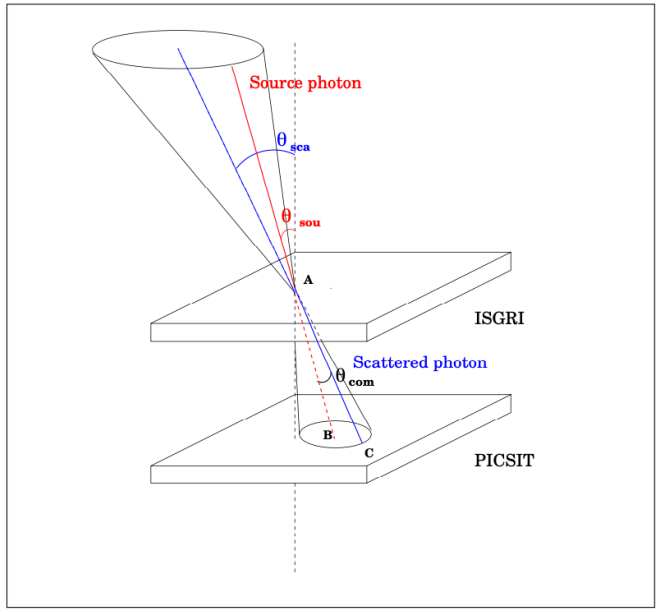
- Distribution for large number of photons (**polarigram**):

$$N(\phi) = C\,(1 + a\cos(2(\phi - \phi_0))),$$

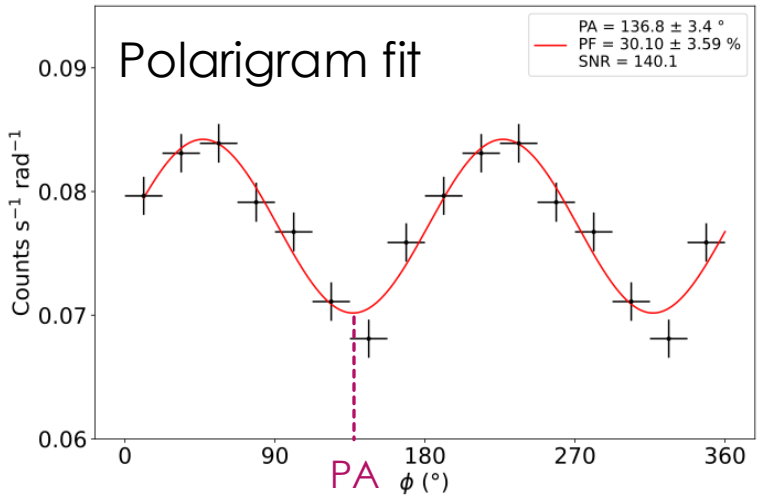


# Polarization of gamma-rays

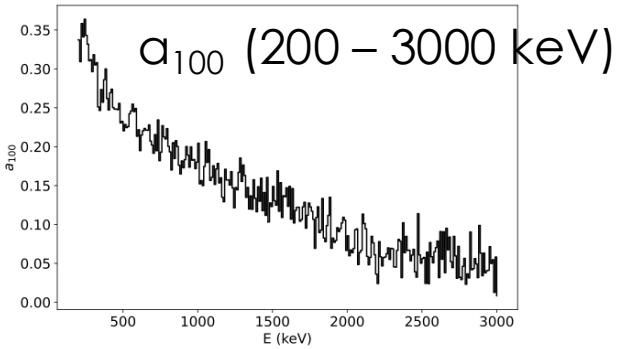
- IBIS telescope: ISGRI (30 - 500 keV) + PICsIT (170 - 3000 keV)
- **Polarization Angle (PA) and Fraction (PF)** from polarigram fit and MCMC simulations for $a_{100}$ value




$$N(\phi) = C\,(1 + a\cos(2(\phi - \phi_0))),$$



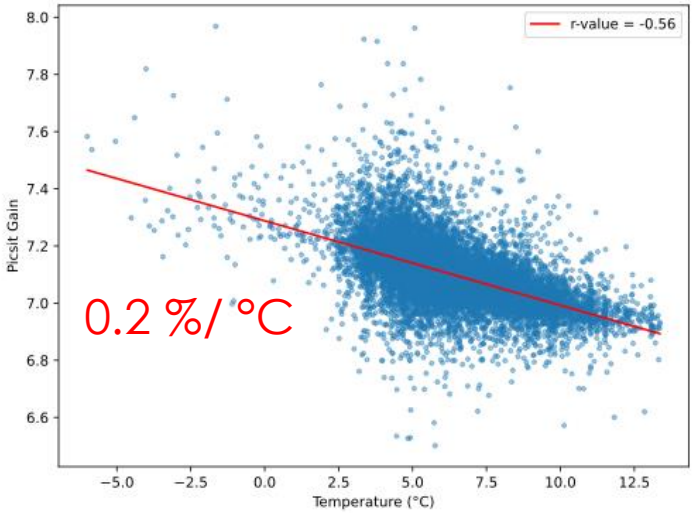

- **PA = $\phi_0$ + 90°**
- **PF = a/$a_{100}$**



# Latest changes

- PICsIT calibration without $^{22}$Na source:
- Gain/temperature correlation → PICsIT gain
- Compton 511 keV background line → PICsIT offset

Gain/temperature correlation




- OSA11.2 code implementation for ISGRI

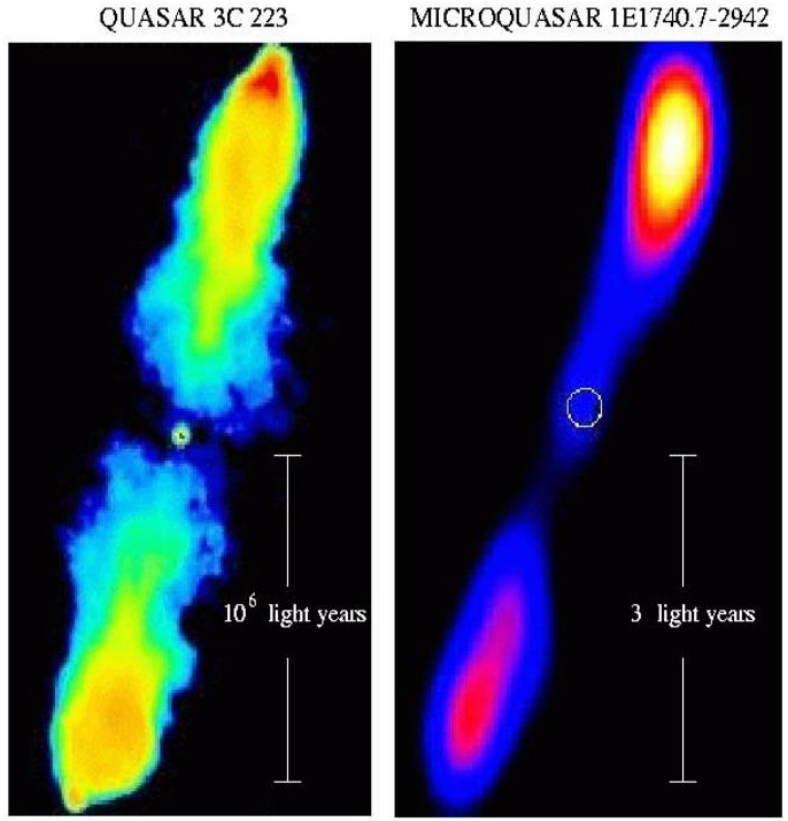
- Extension to lower energy band (200 - 300 keV)

- Crab nebula polarization compatible with other mission: **PA = 141 ± 4°** and **PF = 22 ± 7 %**

| Instrument | Energy (keV) | Method | Material | Optics | PA (°) | PF (%) |
|---|---|---|---|---|---|---|
| INTEGRAL/SPI | 130–436 | Compton | Ge | Coded mask | 120 ± 6 | 24 ± 4 |
| Hitomi/SGD | 60–160 | Compton | Si, CdTe | Collimator | 110 ± 13 | 22.1±10.6 |
| AstroSat/CZTI | 100–380 | Compton | CdZTe | Collimator | 143.5 ± 2.8 | 39 ± 10 |
| PoGo+ | 18–160 | Compton | BGO | None | 131.3 ± 6.8 | 20.9 ± 5.0 |
| IXPE | 2–8 | electron tracks in gas | GPD | Wolter I | 145.5 ± 0.29 | 19.0 ± 0.19 |
| INTEGRAL/IBIS | 210–450 | Compton | CdTe, CsI(Tl) | Coded mask | 141 ± 4 | 22 ± 7 |

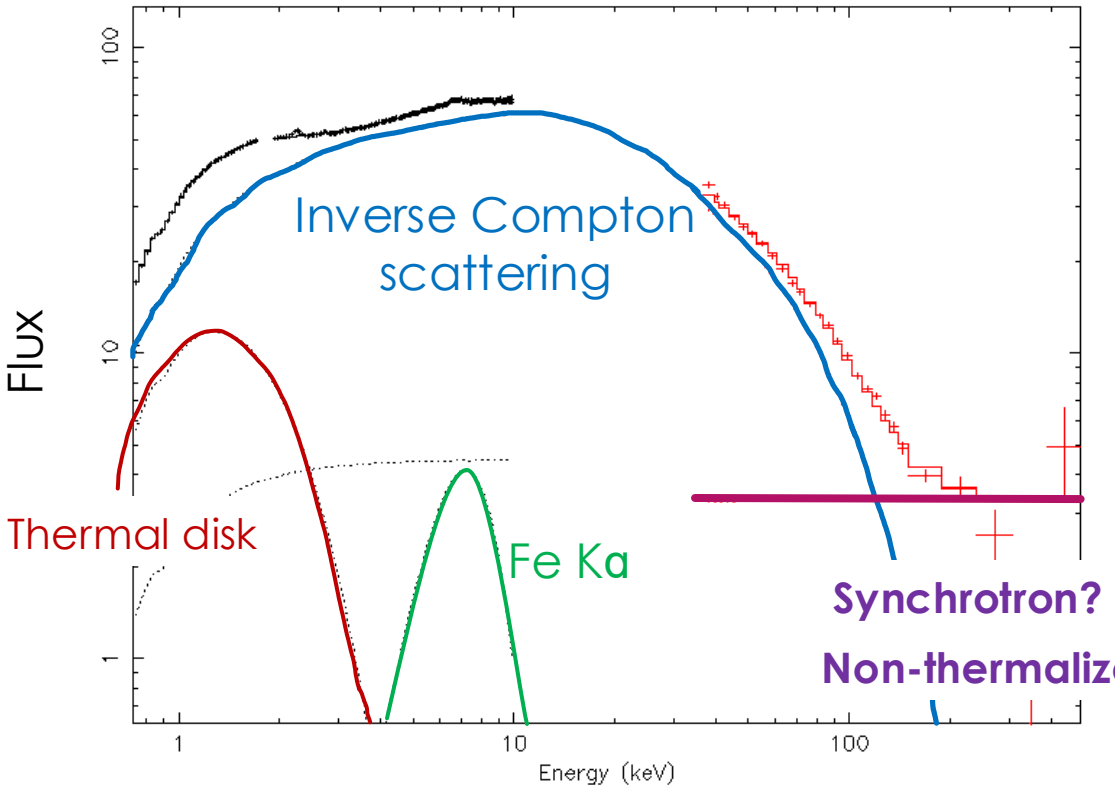
Other mission polarization measurements

# 2. Microquasar polarization




Radio imaging of BH ejection

# Black Hole X-ray Binaries




- What process above few ~100 keV?

→ **Polarization**

- Synchrotron:

For an electron distribution of index p: $\Pi = \frac{p+1}{p+\frac{7}{3}}$

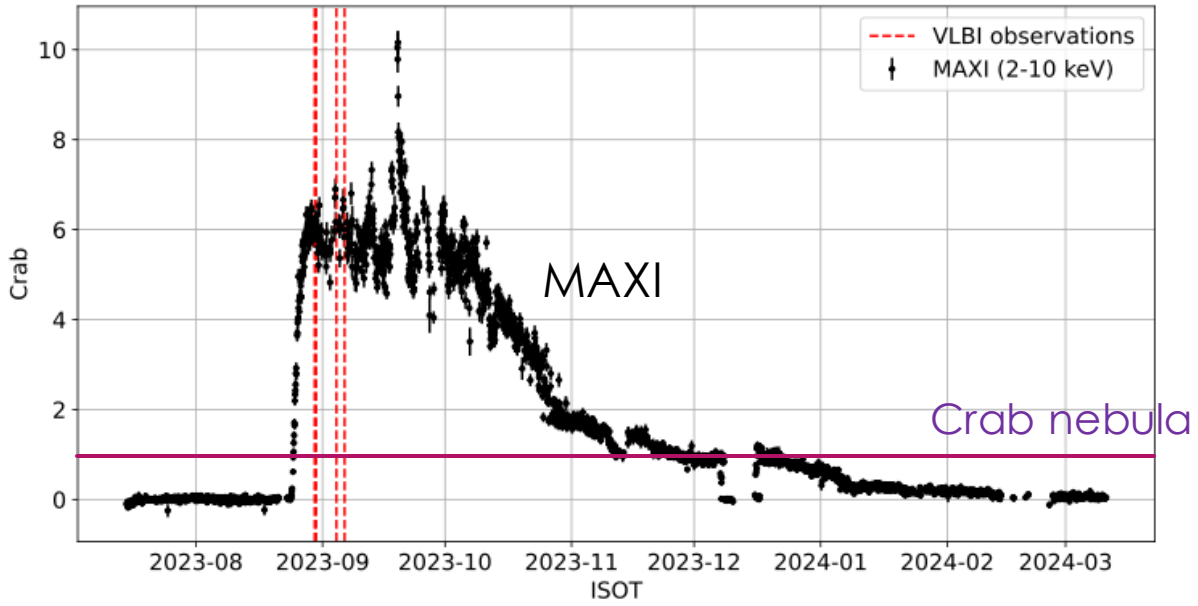
Can reach PF > 50%

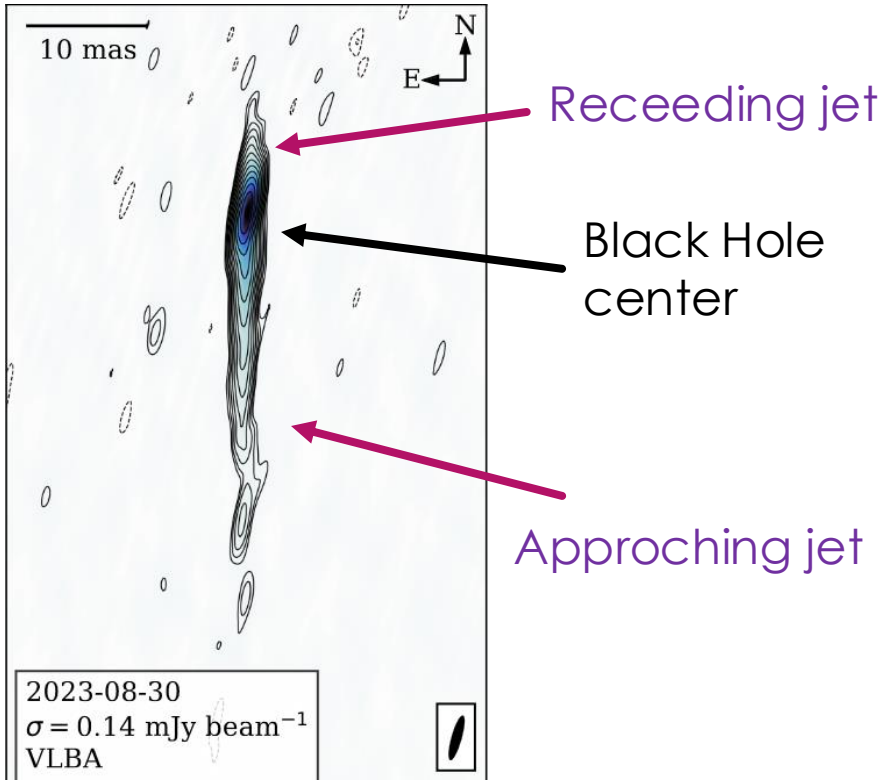
PA perpendicular to magnetic field B

- Compton scattering: PF < 20%

# Swift J1727.8-1613

- Very bright source (up to 10 Crabs) **Swift J1727.8 – 1613,** discovered in August 2023
- Seen at all energies, from radio to hard X-rays
- Compact jet aligned with North direction

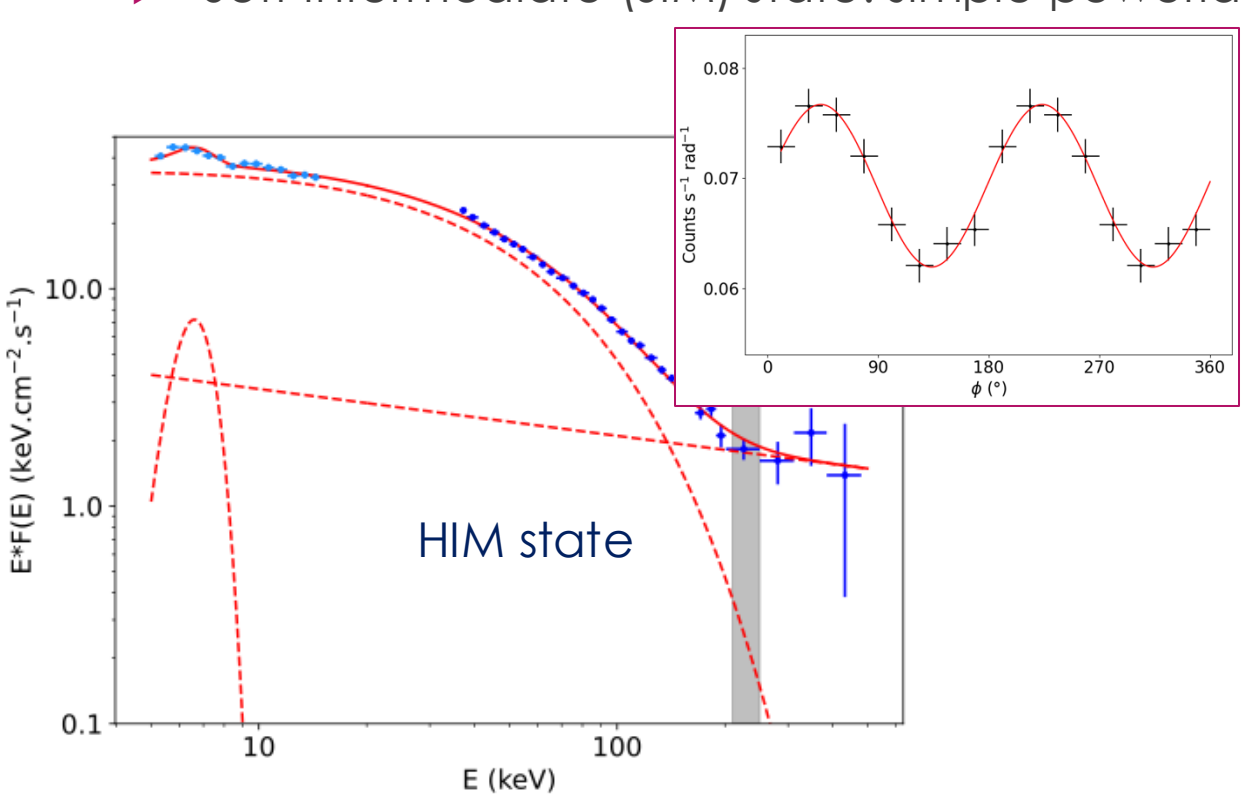


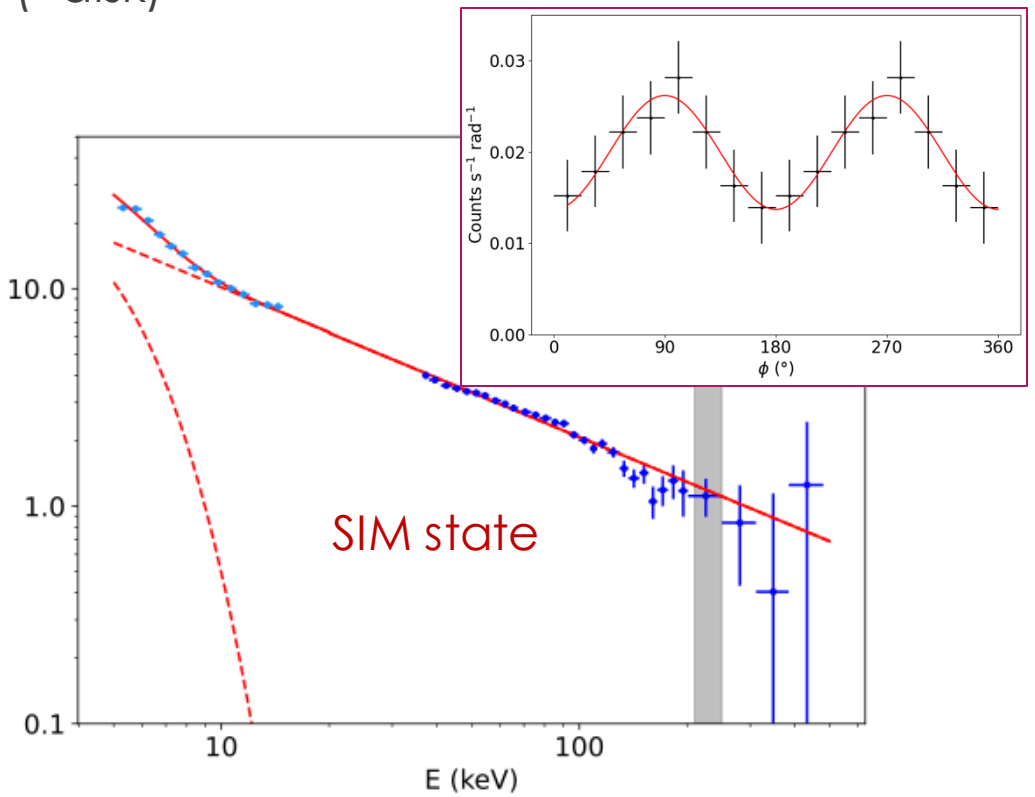




Radio image of compact jet (Wood+ 2024)

# Polarization and spectra

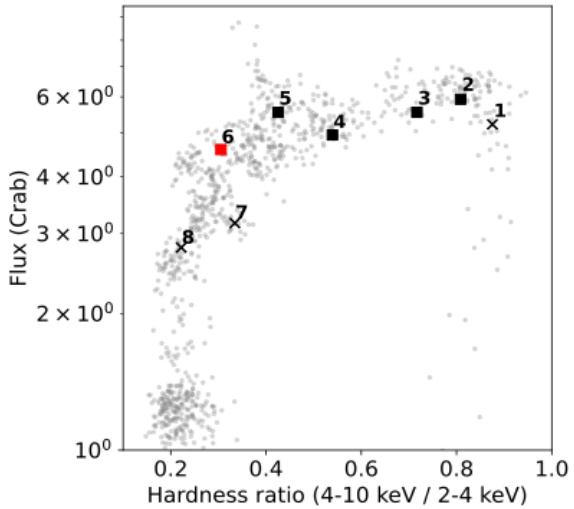
- Hard Intermediate (HIM) state: cutoff powerlaw + **'hard tail' powerlaw with Γ ~ 2**
- Soft Intermediate (SIM) state: simple powerlaw (+disk)



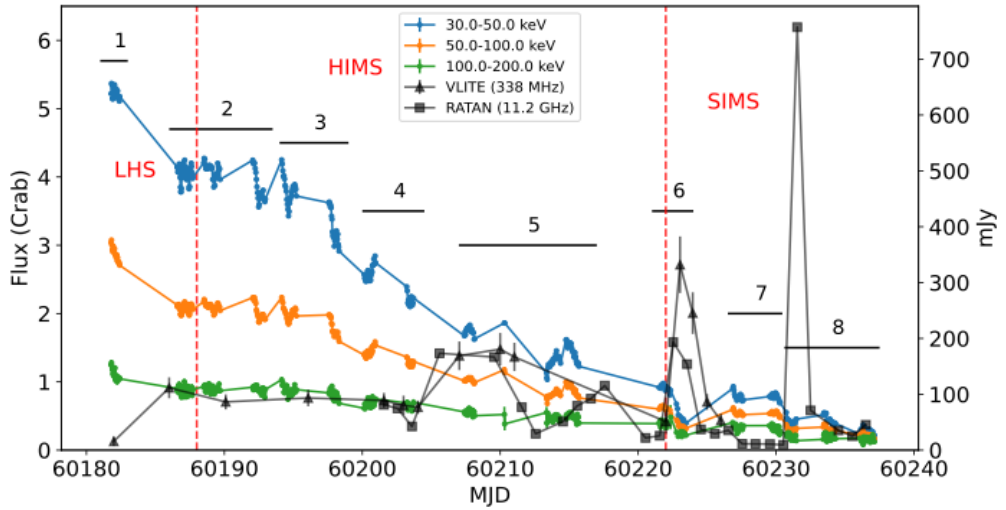



# Polarization evolution

- No detection in HS and late SIMS (Black crosses)
- HIM polarization (Black squares)
- **Jet-aligned polarization coincident with 1st radio flare (Red square)**

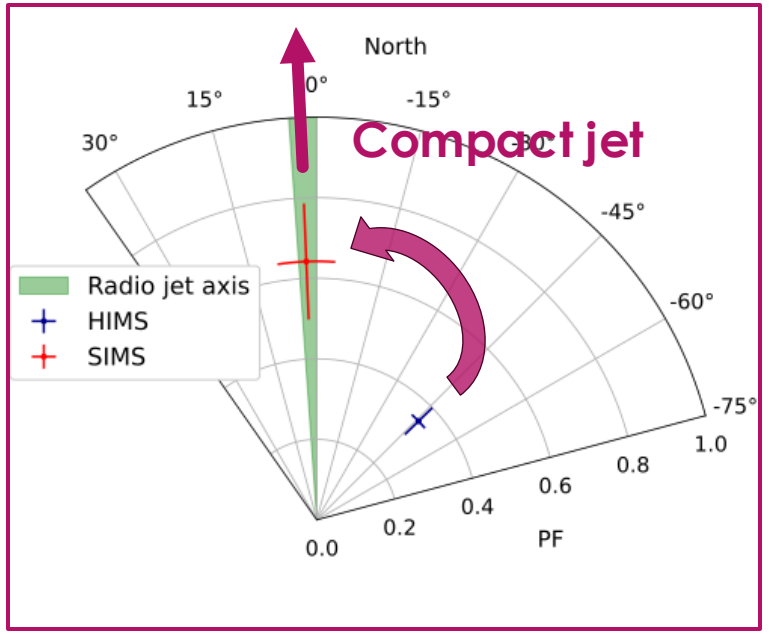



HID




ISGRI and radio light-curves

Polarization parameters




see Bouchet et al. 2024, A&A, 688:L5

# 3. Interpretation and future plan

# Swift J1727.8 polarization evolution

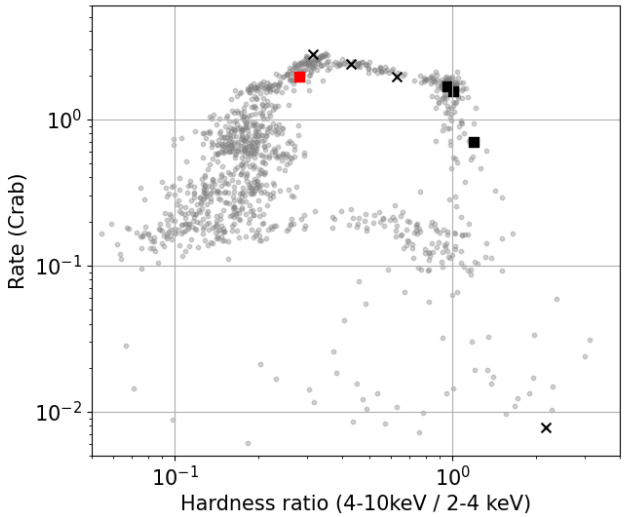
- 'Pure' Hard state ($\Gamma < 1.8$): no detected PF, similar to Cygnus X-1 (see Chattopaday+ 2024)
- HIMS: High level of polarization = **synchrotron emission**

| State | Detection > 200 keV ? | Polarized ? | Jet-aligned ? |
|---|---|---|---|
| Hard | ✅ | ❌ | |
| HIM | ✅ | ✅ | ❌ |
| **SIM start** | ✅ | ✅ | ✅ |
| SIM/Soft | ❌ | | |

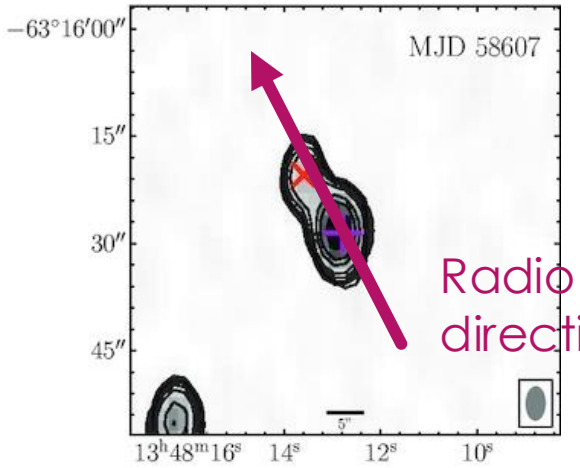
Summary of polarization results

# MAXI J1348-630

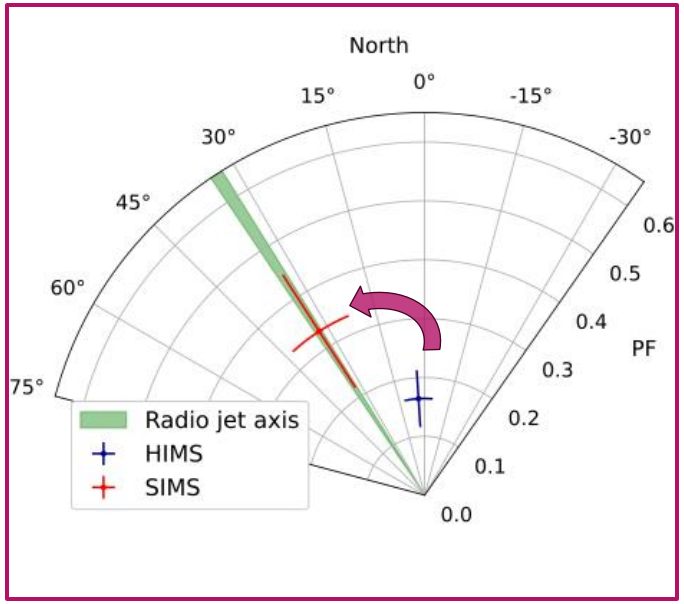
- Another bright Microquasar, outburst in 2019
- Polarization at 230-350 keV (wider energy band)
- Hint to similar behavior, but only 1 rev. in SIMS and no radio flare




Q-shape HID




Radio ejection (Carotenuto+2021)

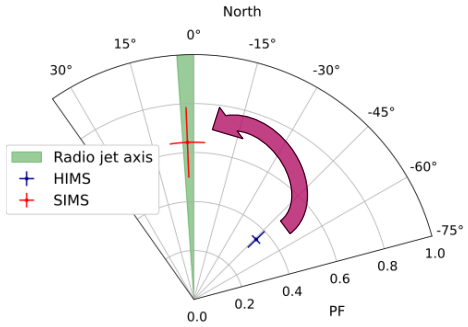



**SIMS polarization aligned with ejection axis ~ 33°**

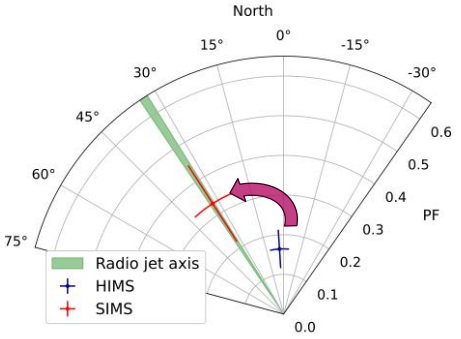
# Interpretation of SIMS alignment

- How does this 'polarization flip' happen?
- Aligned with jet = **B perpendicular to jet**
- B field compressed in a 'slab' during the ejection → high PF, depends on electron index and inclination?

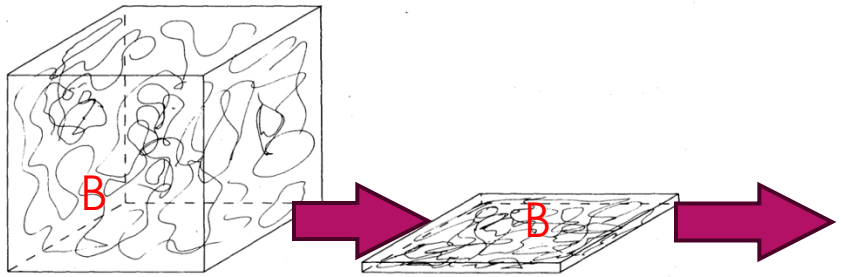
Polarization parameters




Swift J1727.8




MAXI J1348




**Orthogonal synchrotron polarization**

A possible explanation: B field orthogonal compression (see Laing 1980)

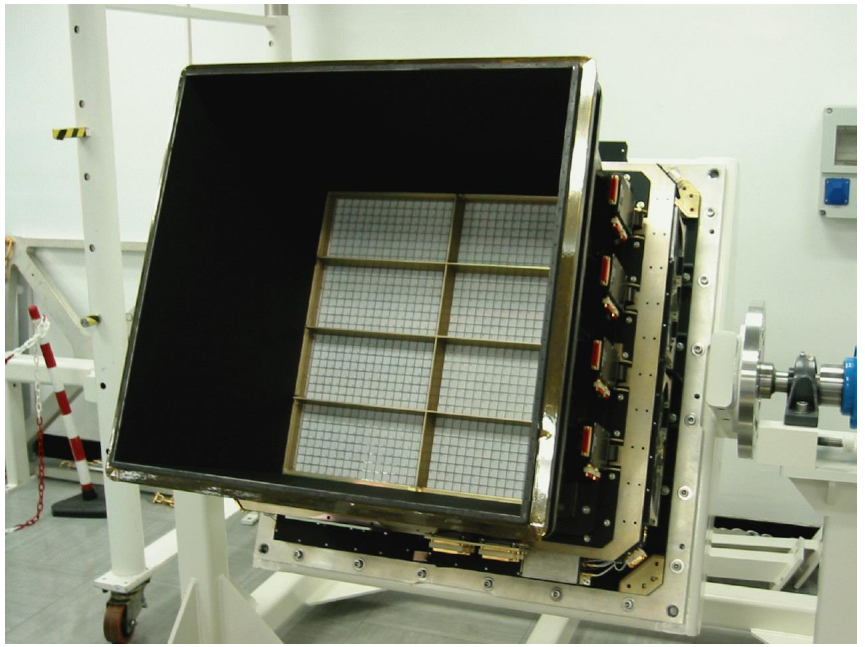
# Future plan

- Long-term study of persistent (Cyg X-1, GRS 1758-258) or “recurrent” (GX 339-4) sources

→ less bright, but more exposure

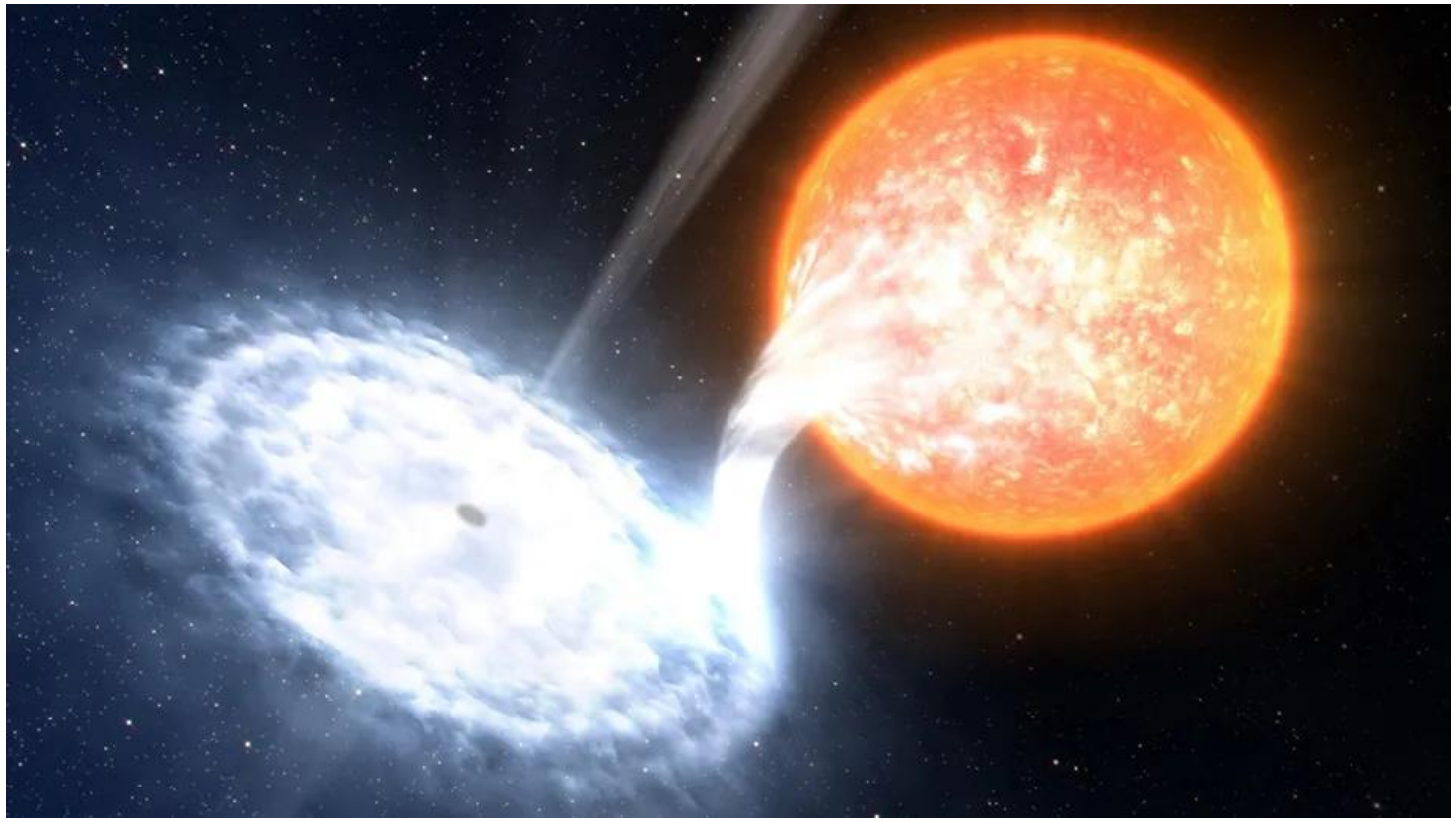
- Calibration with Crab nebula as a ”standard candle” (In-flight calibration of IBIS/Compton, in prep.)

- Opens possibilities for fainter sources



IBIS before launch

# Thank you!

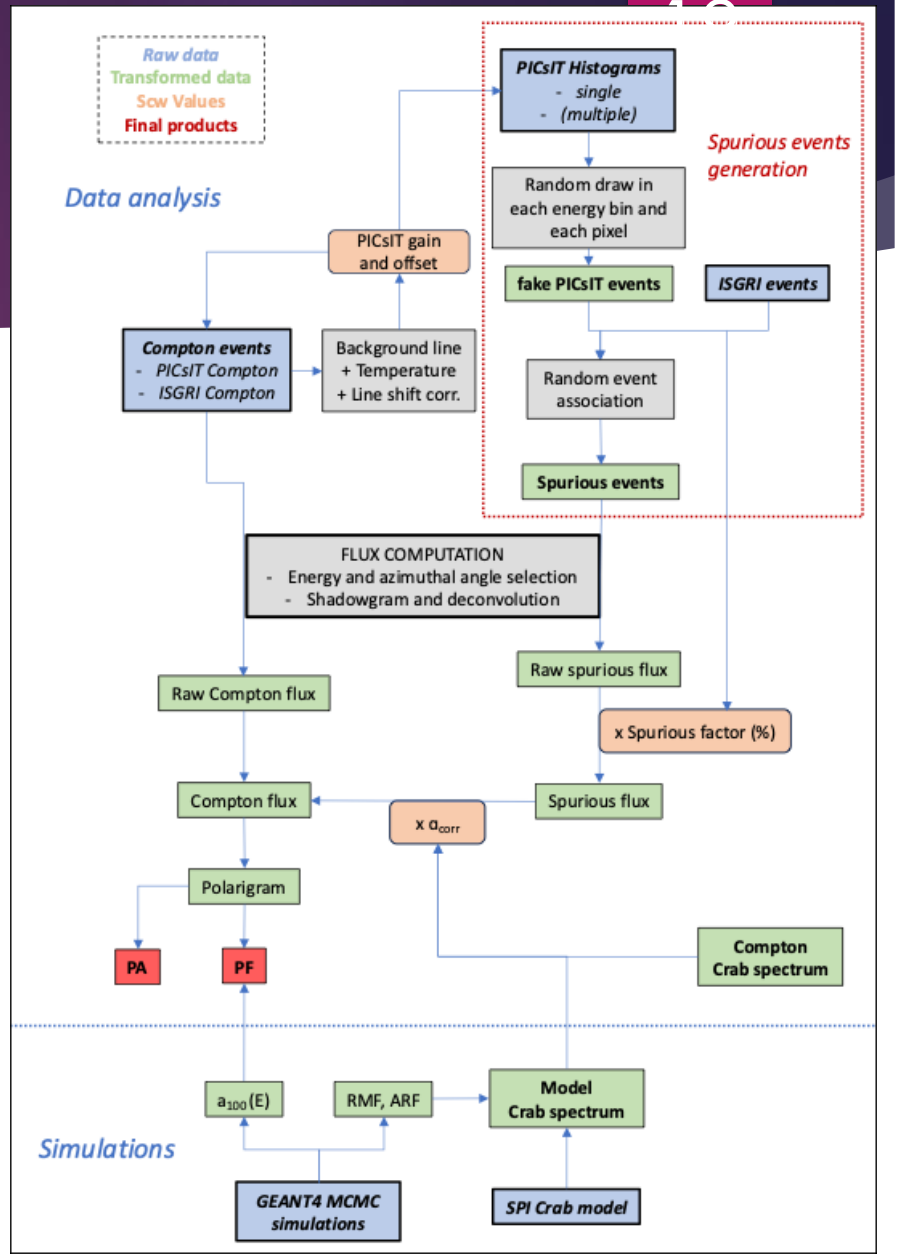


# Backup

# IBIS Compton software

- In reality: **spurious events** mixed with true Compton events!
- Solution: reconstruct spurious event and substract the polarigrams
- Cross-check with Crab spectra for final correction

$$N_{true\ Compton} = N_{raw\ Compton} - \alpha_{corr}\ N_{spurious}$$




Software workflow

# Long-term Crab nebula polarization

- Other high-energy mission to compare
- Preliminary result in 210-450 keV band :

**PA = 141 ± 4°** and **PF = 22 ± 7 %**

- Stable over time, compatible mainly with AstroSat and IXPE

| Instrument | Energy (keV) | Method | Material | Optics | PA (°) | PF (%) |
|---|---|---|---|---|---|---|
| INTEGRAL/SPI | 130–436 | Compton | Ge | Coded mask | 120 ± 6 | 24 ± 4 |
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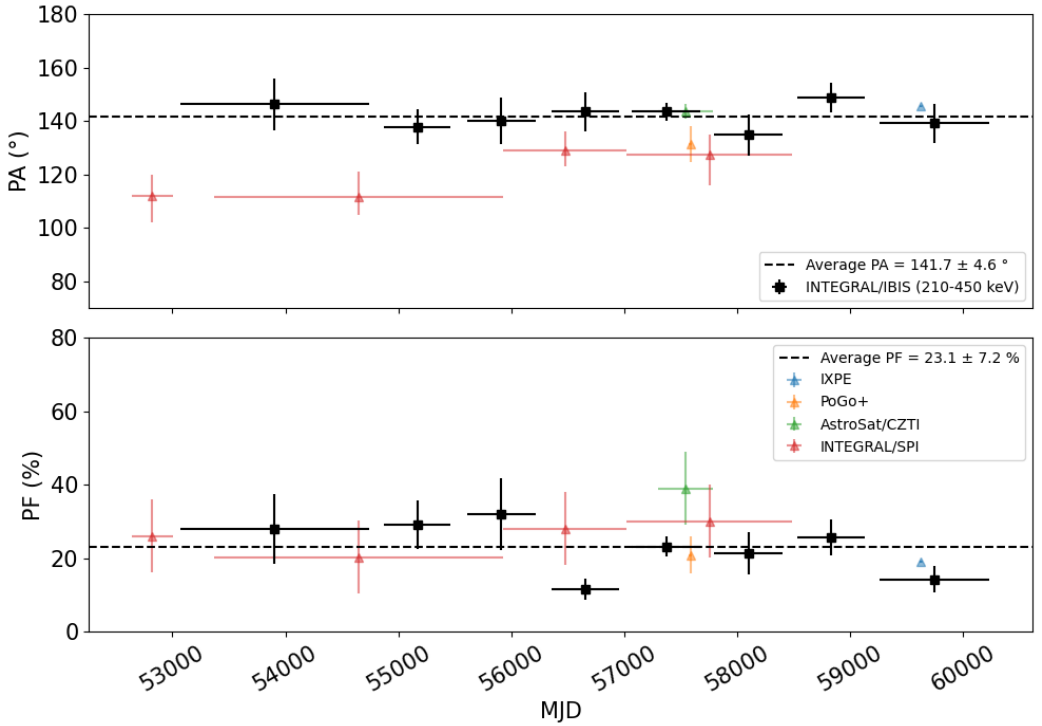
| INTEGRAL/IBIS | 210–450 | Compton | CdTe, CsI(Tl) | Coded mask | | |

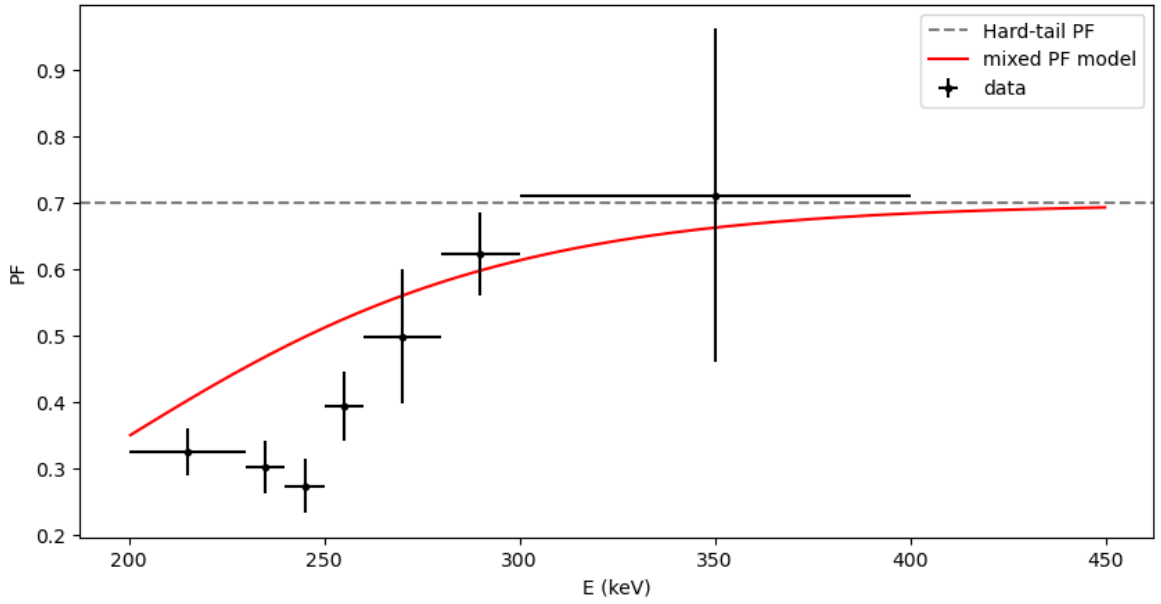
Other polarization experiments

Crab polarization 2004-2024

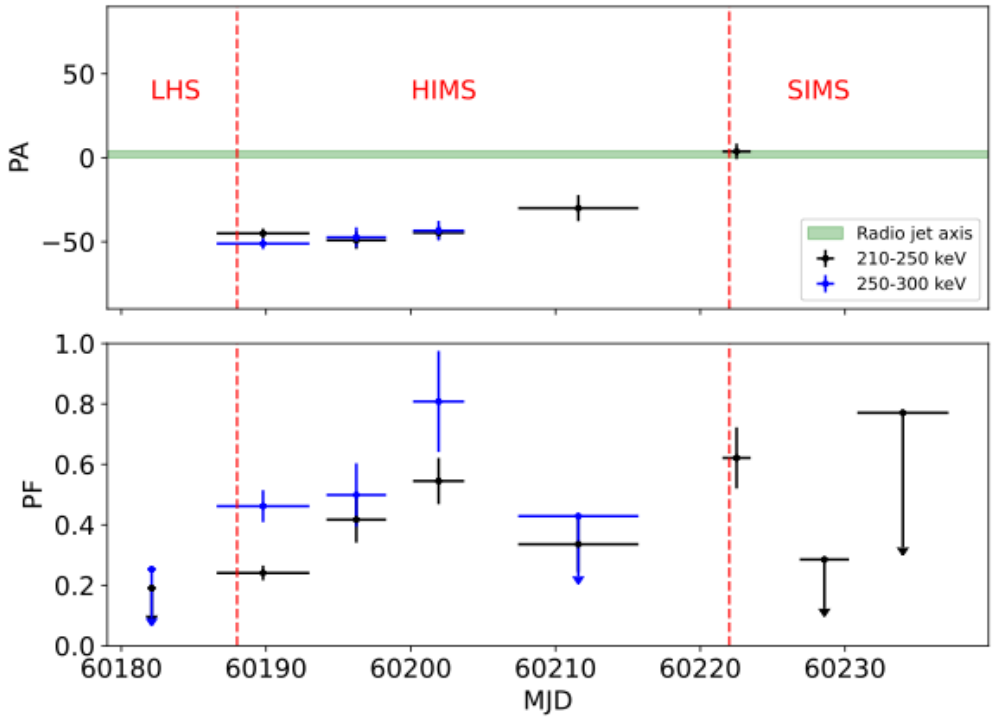



Inflight calibration of IBIS/Compton (Bouchet, Laurent, Rodriguez, Cangemi, in prep.)

# Swift J1727.8 results




PF energy dependency in HIMS




Evolution of PA/PF with time