Observation of microquasars high-energy emission with INTEGRAL

T. Bouchet[1], J. Rodriguez[1], F. Cangemi[2], P. Laurent[1]

[1]DAP-AIM, IRFU, CEA, Université Paris-cité, CEA Saclay, France

[2]APC, Université Paris-cité, France

CONTEXT

Microquasars are Black Hole X-ray binaries which can eject material in the form of a bipolar jet, similarly to quasar, but at much smaller scale. Their high-energy emission comes from an accretion disk (~1 keV) and from a hot corona near the Black Hole that up-scatters photons from the disk in the hard X-ray domain (1-100 keV). A high-energy component above 150 keV has been detected in some sources and its precise origin is still unknown: it could come either from Compton scattering of disk photons on coronal relativistic non-thermal electrons (a.k.a hybrid Comptonization), or from the synchrotron emission from the compact jet.

A careful modelling could discriminate between these two models, thanks to polarization measurement: a jet origin with an ordered magnetic field would produce a high polarization fraction (PF>70%), contrarily to relativistic Compton scattering.

The INTEGRAL satellite

INTEGRAL (INTernational Gamma-ray Astrophysical Laboratory) has been observing the X-ray sky for more than 20 years, thanks to its different telescopes:

- IBIS (15-400 keV), the imager with a high spatial resolution (12')
- SPI (20 keV – 8 MeV), the spectrometer capable of probing the soft gamma-ray spectra in great detail
- JEM-X (3-30 keV), to better constrain the soft X-ray emission

Compton Mode (0.2 - 2 MeV)

It is also possible to combine the two detector layers of the IBIS telescope (ISGRI+PICsIT) to reconstruct source fluxes through Compton scattering of photons on the first detector (ISGRI), then absorbed by the second detector (PICsIT).

We deduce the total energy of the photon from the energies deposited in each detector. The source position is determined with coded mask techniques using the Compton/ISGRI image.

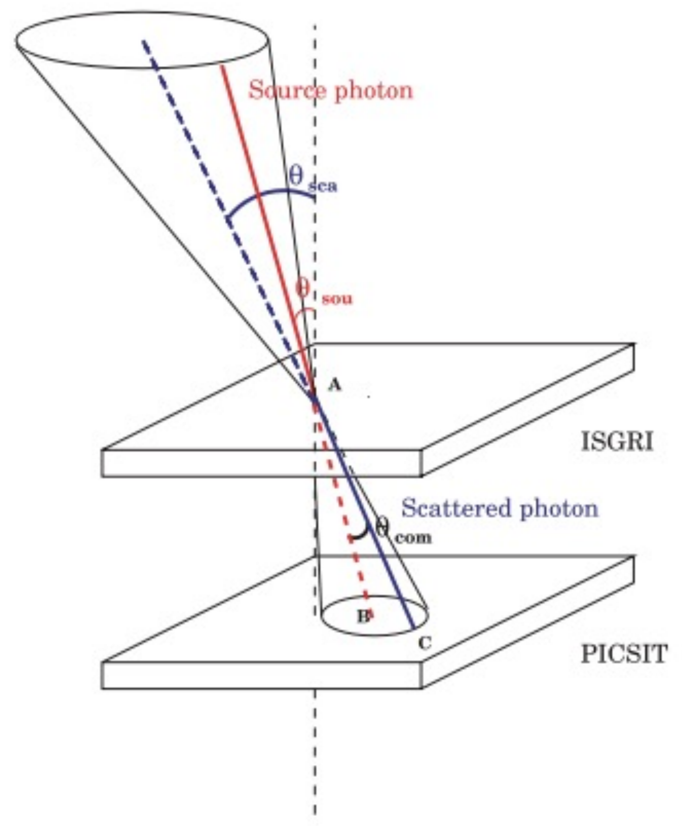

Fig. 1 : INTEGRAL Compton mode

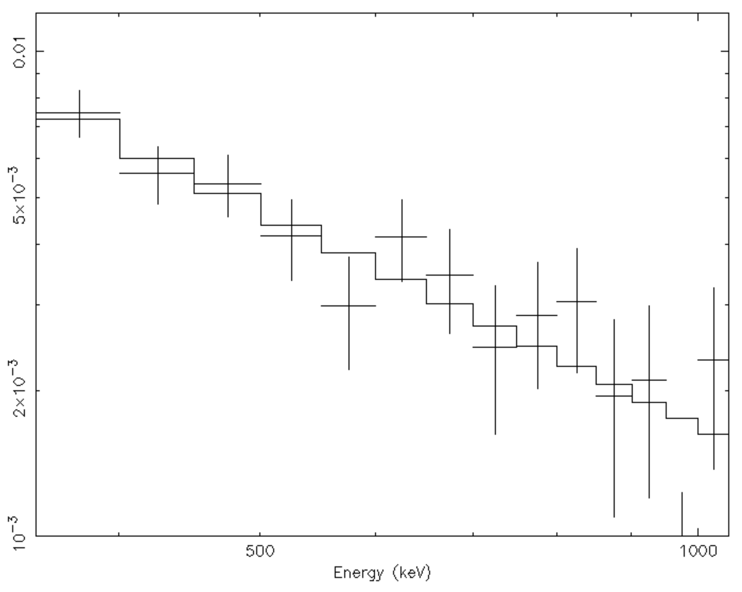

Fig. 2 : Spectrum of the Crab Nebula with the IBIS/Compton mode

This observation mode has been calibrated using a Monte-Carlo GEANT4 simulation. The rate of spurious events, which are two independent photons detected simultaneously by both detector, indistinguishable from Compton event, has also been carefully modelled and taken into account. [1]

Polarization measurement

For Compton events, the spatial distribution of the photon on PICsIT is also affected by the source polarization.

The azimuthal angle of the scattered photon (ϕ) will be modulated as:

$\mathbf{N(\phi) = C\,(\,1 + a_0 \cos(\,2\,(\phi - \phi_0)\,)\,)}$, with C the total count-rate and a_0 the amplitude of the modulation ($a_0 = 0$ for an unpolarised source).

From this asymmetry in angle distribution, we can deduce:

- the **Polarization Angle:** $\mathbf{PA = \phi_0 - \pi/2}$
- the **Polarization Fraction:** $\mathbf{PF = a_0 / a_{100}}$ with a_{100} the amplitude for a fully polarized source (computed through simulations)

We accumulated 12 Ms of Crab Nebula* observations to test the validity of our method. We found **PA=117±5 ° and PF=17±2% in the 200-400 keV band, in good agreement with previous measurement using an independent method with the INTEGRAL/SPI instrument. [2]**

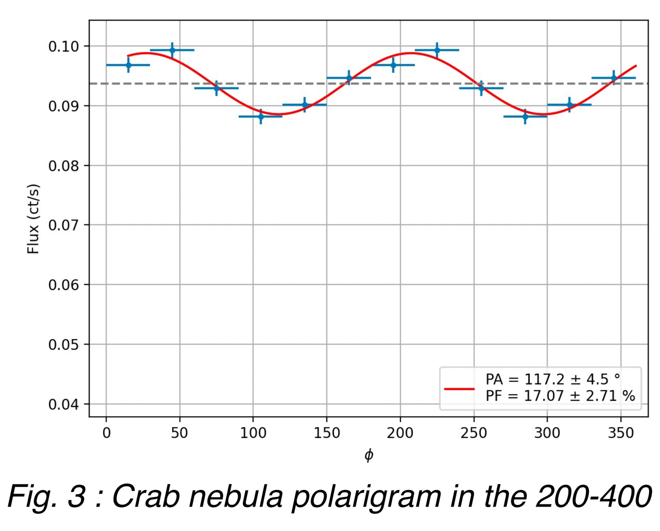

Fig. 3 : Crab nebula polarigram in the 200-400 keV range

* *The Crab Nebula is a bright and relatively stable source, making it a « standard candel » for X-ray astronomers*

A newly discovered Black Hole

Microquasars typically enter in outburst for a few months and go back to quiescence for many years.

A new source named **Swift J1727.8-1613** was discovered in August 2023 with a particularly high flux (4.2e-8 ergs/cm^2/s in the 30 - 100 keV energy range), it was quickly identified as a BH X-ray binary.

Continuum fit

The dominant component below 100 keV is the Comptonized corona, with a cut-off energy around 60 keV. The spectral shape of this emission was stable throughout the source hard-state observations.

A hard-tail is clearly detected until at least 500 keV, which follows a power-law index of ~ -1.8

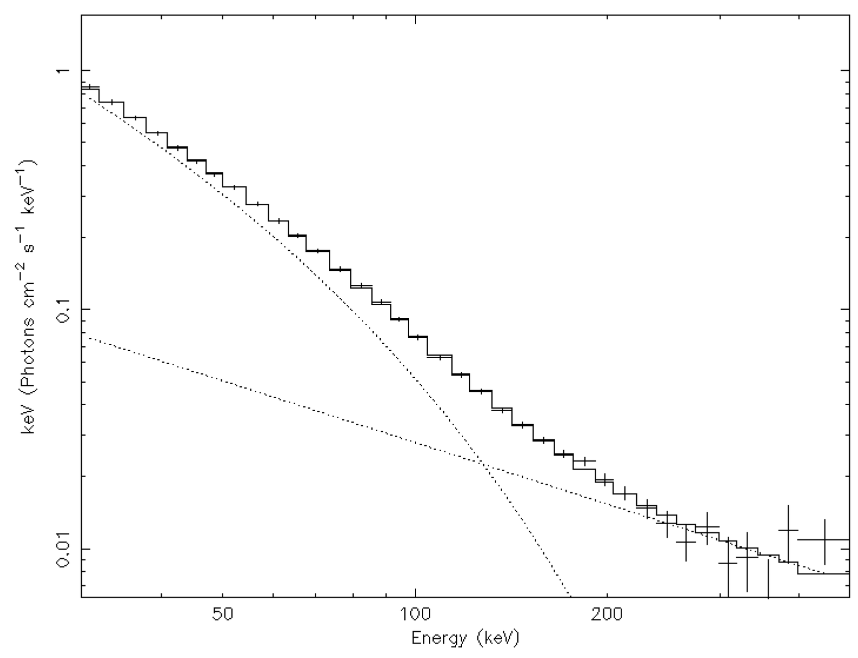

Fig. 4 : INTEGRAL/ISGRI observation of Swift J1727.8-1613 at the beginning of September

Compton mode results

Thanks to the source high brightness we were able to monitor the high-energy flux obtained with the IBIS/Compton mode, as well as its polarization angle in the low-energy band (150-300 keV).

The flux decreases progressively throughout the outburst in all bands, while the polarization stays around a stable value of PA = (137.8±1.7) °

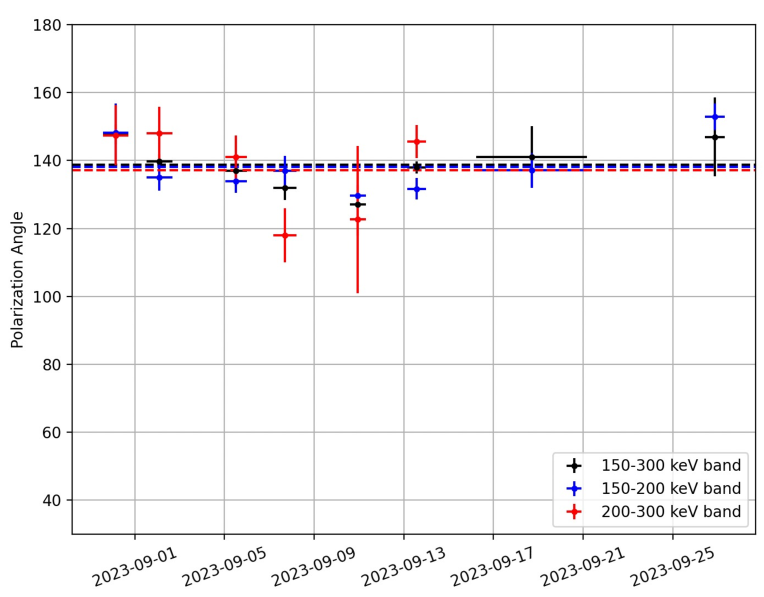

Fig.5 : Evolution of Polarization Angle of Swift J1727.8-1613 with time

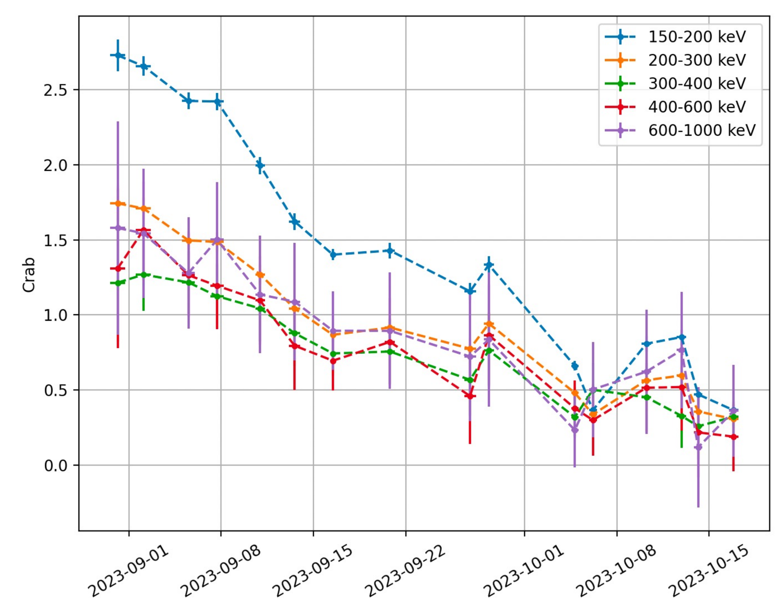

Fig. 6 : IBIS/Compton mode light-curve of Swift J1727.8-1613, normalized by the Crab nebula

Similar polarization angles were found in higher energy bands. **The polarization fraction was measured at 43±3% in the 200-300 keV band, and 78±16% in the 300-400 keV band.**

As seen in the continuum fitting, this energy domain is already dominated by the hard-tail, which would hint towards a **compact jet** origin for this >200 keV component.

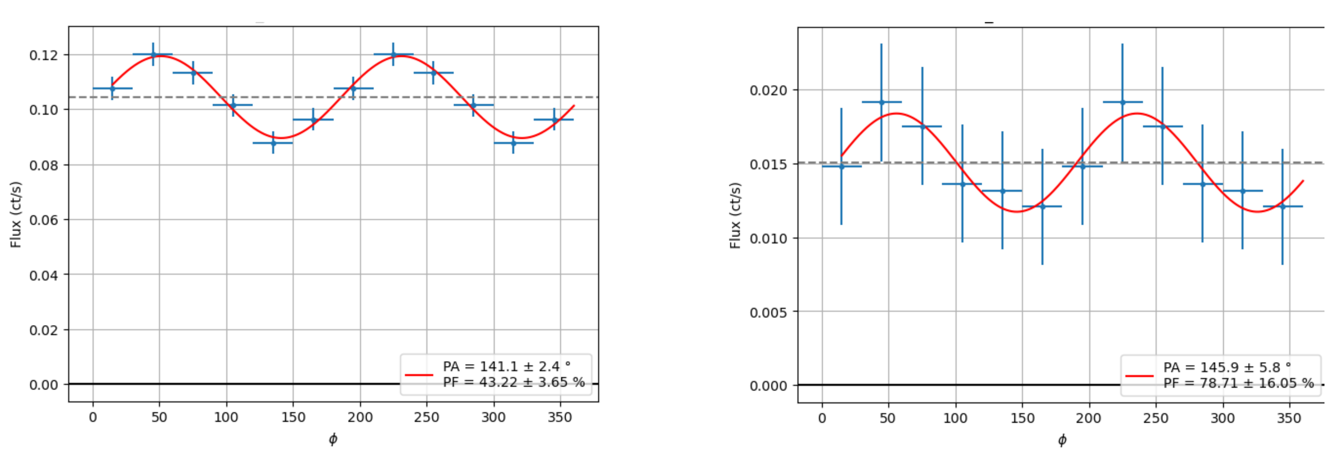

Fig. 7 : Swift J1727.8-1613 polarigram in the 200-300 keV band (left) and 300-400 keV band (right)

[1] Forot, M., Laurent, P., Lebrun, F., & Limousin, O. 2007, ApJ, 668, 1259

[2] Jourdain, E. & Roques, J.P. (2019), 2003-2018 Monitoring of the Crab Nebula Polarization in hard X-rays with INTEGRAL SPI.