Gamma-Ray Polarization in Cygnus X-1

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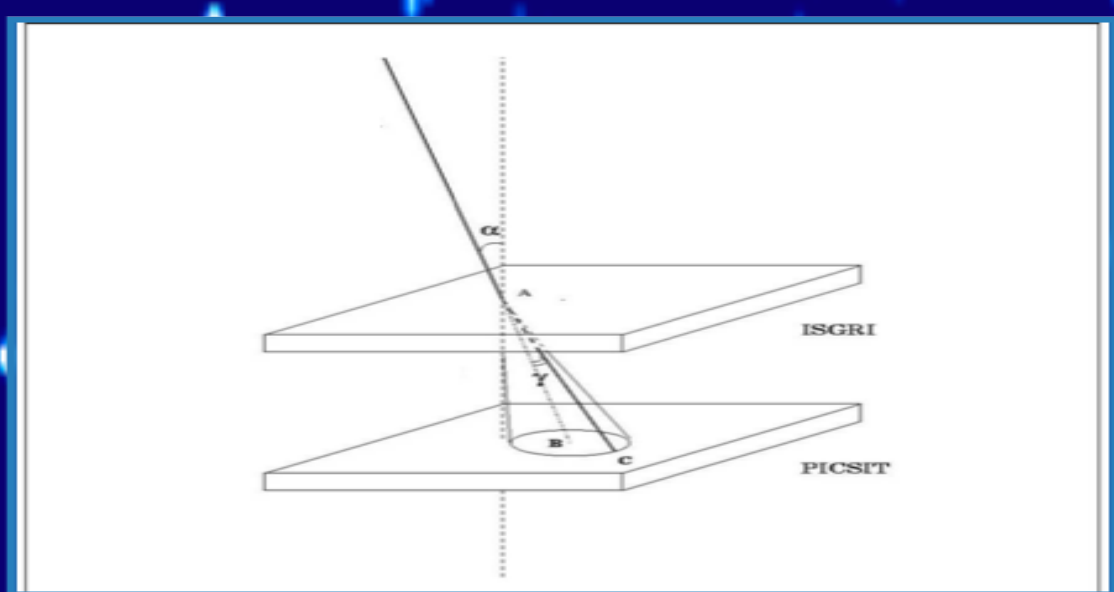
Abstract
(From Laurent, Rodriguez, Wilms, Cadolle Bel, Pottschmidt & Grinberg 2011, Science)

Because of their inherently high flux allowing the detection of clear signals, black hole X-ray binaries are interesting candidates for polarization studies, even if no polarization signals have been observed from them before. Such measurements may provide further detailed insight into these sources' emission mechanisms. We measured the polarization of the gamma-ray emission from the black hole binary system Cygnus X-1 with the INTEGRAL/IBIS telescope. Spectral modeling of the data reveals two emission mechanisms: the 250 - 400 keV data are consistent with emission dominated by Compton scattering on thermal electrons and are weakly polarized. The second spectral component seen in the 400 keV - 2 MeV band is by contrast strongly polarized, revealing that the MeV emission is probably related to the jet first detected in the radio band.

Cygnus X-1

- best known black hole (BH) X-ray binary in our Galaxy;
- widely observed with many telescopes over the whole electromagnetic band (e.g., Sunyaev et al. 1979; Gierlinski et al. 1997; Stirling et al. 2001; McConnell et al. 2002);
- located at 2.1 kpc - companion: high mass blue O star;
- radiates mainly in the X-ray and soft gamma-ray domains;
- X-ray luminosity thought to be produced by accretion of the companion's matter onto the BH;
- X-ray spectrum: combination of thermal spectrum (130 eV) + cut-off power law spectrum due to Compton-scattering of disc photons off high temperature thermal electrons (corona); recent additional spectral component of unknown origin observed (Cadolle Bel et al. 2006);
- compact radio jet ejected from the vicinity of the BH, with a kinetic power similar to the source's bolometric X-ray luminosity (Fender et al. 2006).



The INTEGRAL Compton Mode

The IBIS telescope on-board the INTEGRAL satellite (Fig. 1, top panel) has two layers of detection: ISGRI (15 - 400 keV) and PICsIT (250 keV - 1 MeV). Therefore, if the photons interact in both detectors, IBIS can be used as a Compton polarimeter (Forot et al. 2007, 2008; Dean et al. 2008; Gotz et al. 2009; Fig. 1, bottom panel).

Detections of both events allows to:

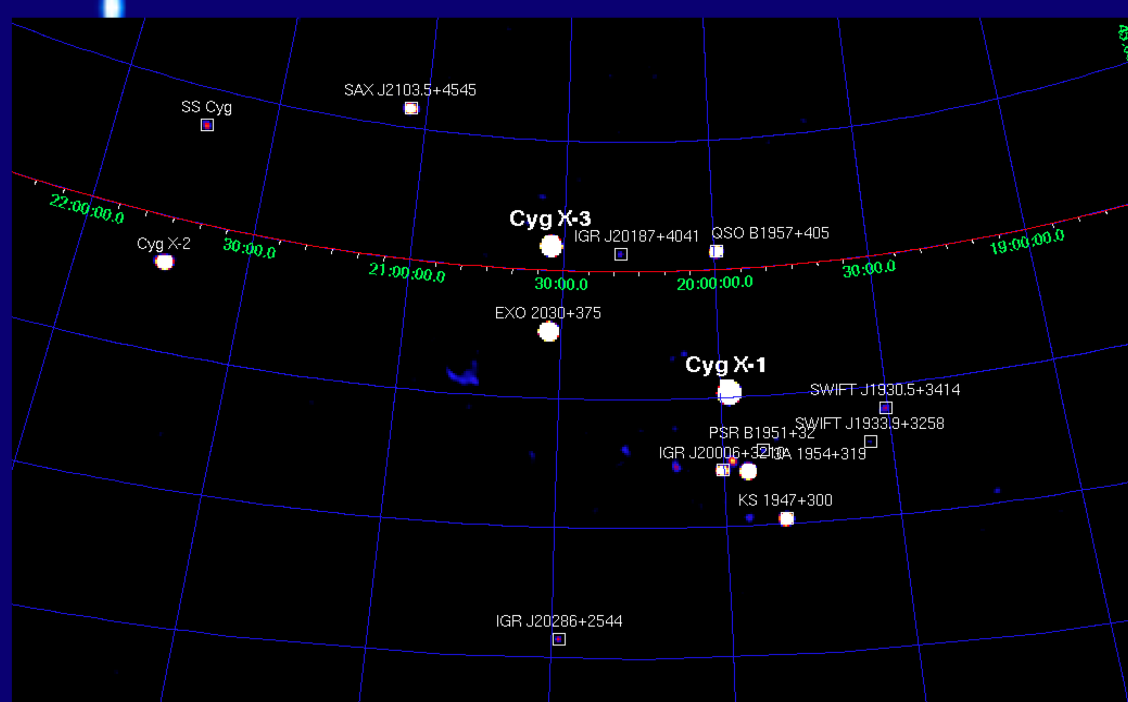
- reconstruct position to 12' precision;
- measure the Compton scattering angle;
- measure the polarization.

Clear polarization was detected for the Crab (Forot et al. 2008, Dean et al. 2008) which matches the optical measurements: 47 (-13, +19) % with a polarization angle of 100 ± 11 degrees.

Fig. 1: *Top:* Artist view of the INTEGRAL satellite with the instruments indicated. *Bottom:* Scheme of the Compton mode of IBIS. Polarization is given by $N(phi) = S\{1+a_0*cos(2*phi-2*phi_0)\}$.

Observations

We used the INTEGRAL data from 2003 to 2010 (Fig. 2) at less than 10 degrees off-axis and we selected times > 1000 s: this resulted in a total of 5 Ms accumulated good data. We summed up all IBIS data without discrimination on the spectral states, to increase the Signal-over-Noise ratio at high-energies.



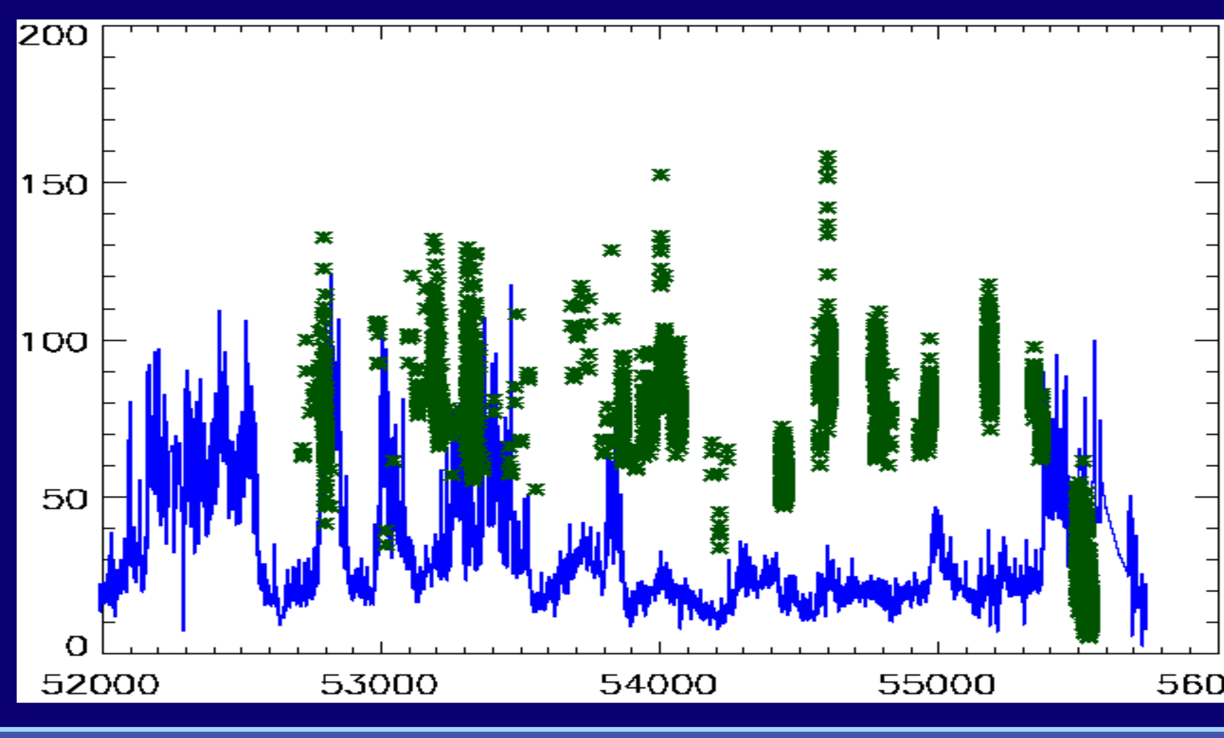


Fig. 2: *Left:* IBIS/ISGRI mosaic of Cygnus X-1, showing the crowded field of view around the source, and *Right:* accumulated ASM (2 - 12 keV) and ISGRI (18 - 40 keV) light curves of the source in counts per second, from MJD 52000 to 55750.

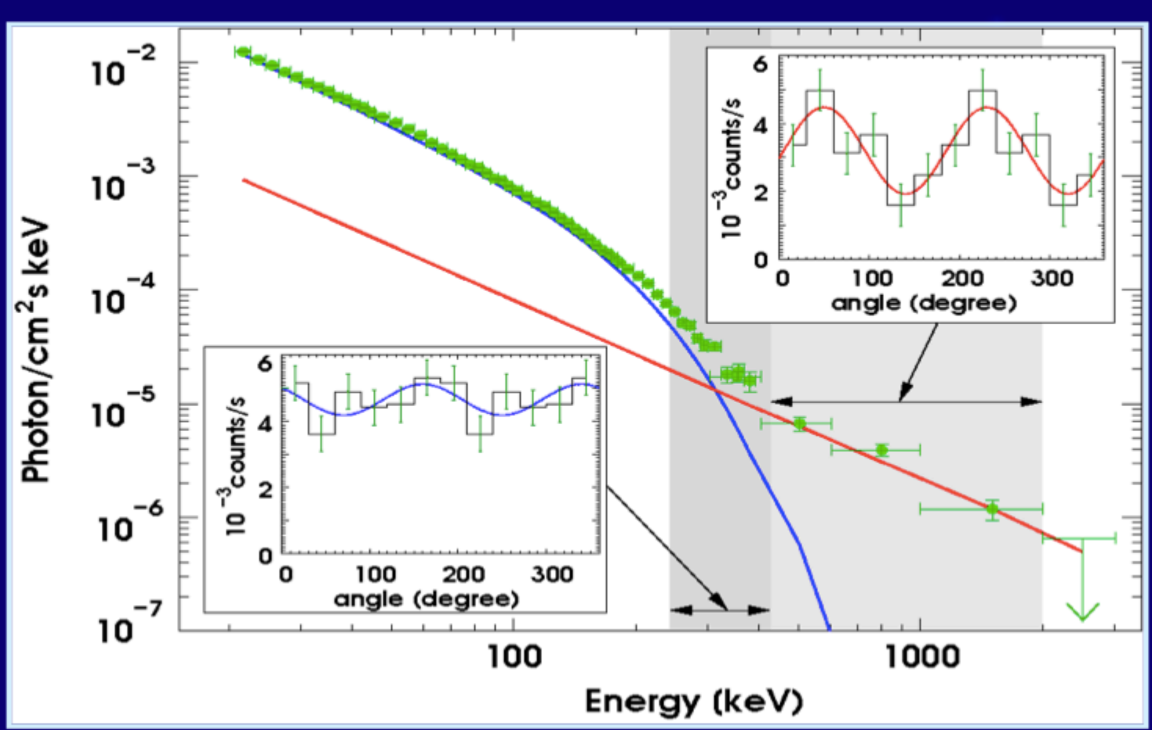


Fig. 3: Cygnus X-1 spectra and polarimetry in the 200 - 400 keV and 0.4 - 2 MeV energy ranges (from Laurent et al. 2011).

Results and Conclusions

The hard tail (> 500 keV) is confirmed (Grove et al. 1998, Cadolle Bel et al. 2006). Spectral analysis > 20 keV show two components are required:

- thermal Comptonization around 50 keV (corona);
- power law above 450 keV, with photon index of 1.6 (synchrotron emission from the jet)

=> signatures of two different high-energy emission processes from the source, whose locations have not been previously constrained.

We measured the polarization signal between 250 and 400 keV (Fig. 3). As expected from a zone where Compton scattering on thermal electrons dominates (Sunyaev et al. 1985), the emission in this band is weakly polarized (upper limit of 20% for the polarization fraction Pf). In contrast, the signal from the 400 - 2000 keV band, in which the hard tail dominates, is highly polarized: Pf = 67 ± 30%. This result is no longer consistent with Compton scattering on thermal electrons: such a high Pf is probably the signature of synchrotron or inverse Compton emission from the jet already observed in the radio band (Fender et al. 2004). Unfortunately, current knowledge of the jet at radio wavelengths does not allow discriminating between the two processes. The hard tail measurement is consistent with extrapolated jet from IR (Rahoui et al. 2011). This is the first detection of jet emission at MeV energies! Future work is on-going to continue these studies separating the spectral states, based on the classification work of V. Grinberg et al. (accepted in A&A; see her poster at this conference).

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