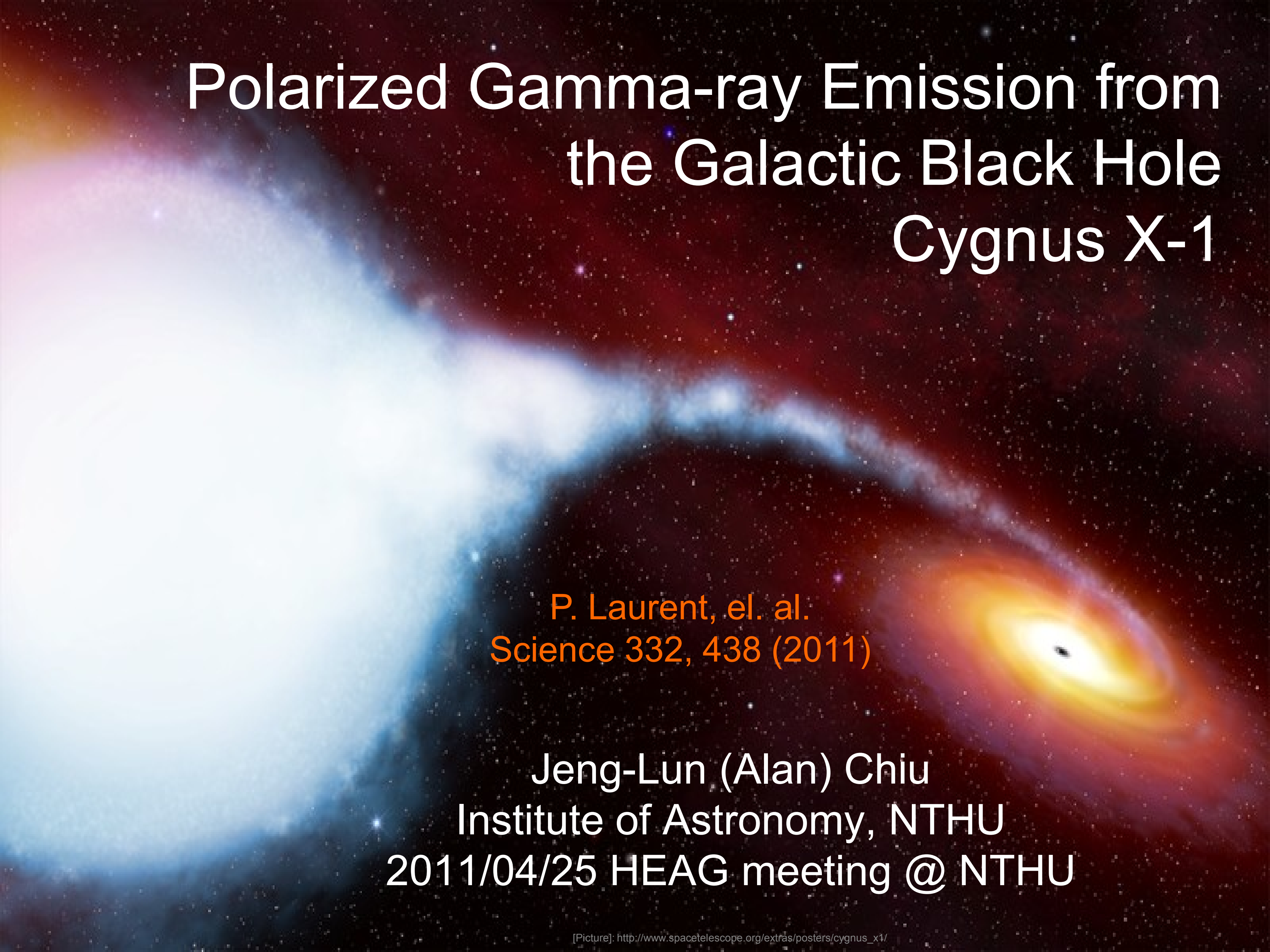

Polarized Gamma-ray Emission from the Galactic Black Hole Cygnus X-1

P. Laurent, el. al.
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News

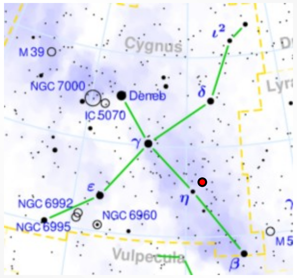
Because of their inherently high flux allowing the detection of clear signals, black hole x-ray binaries are interesting candidates for polarization studies, even if **no polarization signals have been observed from them before**. Such measurements would provide further detailed insight into these sources' emission mechanisms.

P. Laurent, el. al. measured the polarization of the gamma-ray emission from the black hole binary system Cygnus X-1 with the International Gamma-Ray Astrophysics Laboratory Imager on Board the Integral Satellite (**INTEGRAL/IBIS**) telescope.

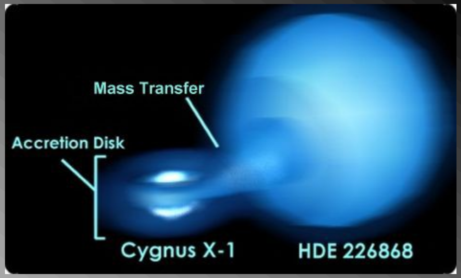
Spectral modeling of the data reveals **two emission mechanisms**:

1). The **250- to 400-keV** data are consistent with emission dominated by Compton scattering on thermal electrons and are weakly polarized.

2). The second spectral component seen in the **400-keV to 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



- **Location:** (RA, Dec) = (19h 58m 21.676s, +35°12”05.78”)
- **Distance:** ~ 2.1 kpc away from Earth
- **Mass:** ~8.7 $M_\odot$
- **X-ray binary** with a high-mass blue O star (HDE 226868: a 20-40 $M_\odot$ supergiant).

- Radiates mainly in the x-ray and soft gamma-ray domains;

a) The x-ray luminosity is thought to be produced by accretion of the companion’s matter onto the BH.

- b) The well-studied x-ray spectrum is a combination of **a thermal spectrum** with temperature around **130 eV** and **a cutoff power-law spectrum**, due to the Compton scattering of the disk photons off high-temperature thermal electrons located in a corona close to the BH.

  (M. Bałucińska-Church, et. al., Astron. Astrophys. 302, L5 (1995) ; M. Gierliński et al., MNRAS 288, 958 (1997).)
- Recently, an additional spectral component of unknown origin was observed by the spectrometer on INTEGRAL (SPI) telescope.

  (G. Vedrenne et al., Astron. Astrophys. 411, L63 (2003))
- Finally, a compact radio jet is ejected from the vicinity of the BH, with a kinetic power similar to the source’s bolometric x-ray luminosity.

  (A. M. Stirling et al., MNRAS 327, 1273 (2001) ; R. P. Fender et al., MNRAS. 369, 603 (2006).)

The Polarization Measurement

- In brief, a Compton polarimeter uses the polarization dependency of the differential cross section for Compton scattering, where linearly polarized photons scatter preferentially perpendicularly to the incident polarization vector. By examining the scatter-angle azimuthal distribution of the detected photons, a sinusoidal signal is obtained from which the PA and the Pf with respect to a 100% polarized source can be derived.

- Gamma-ray polarization measurements are particularly difficult, the main difficulty being the exclusion of systematic/detector effects in the azimuthal Compton events distribution. To exclude these systematic effects, The process detailed in (*M. Forot, et. al., 2008*) was considered.

- Only considered events that interacted once in the upper CdTe crystal layer, Integral Soft Gamma-Ray Imager (sensitive in the 15- to 1000-keV band), and once in the lower CsI layer, Pixelated CsI Telescope (sensitive in the 200-keV to 10-MeV band),
- With reconstructed energy was in the **250- to 2000-keV** energy range.
- These events were automatically selected on board through a time coincidence algorithm.
- The maximal allowed time window was set to **3.8 ms** during our observations, which span between 2003 and 2009, for a total exposure of more than **5 million seconds**, which is **~58 days**.

Energy Spectrum of Cygnus X-1

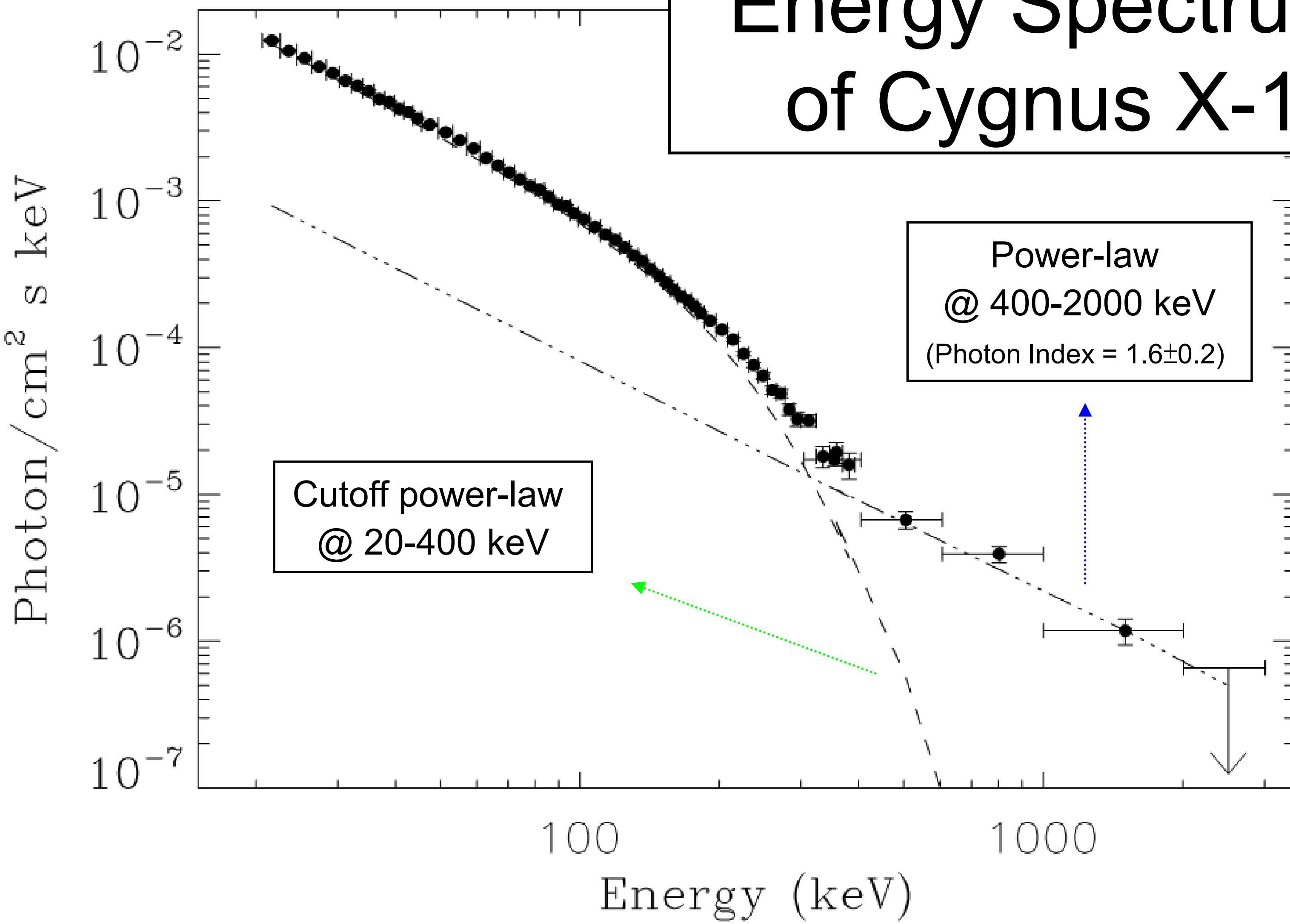


Fig.1. Cygnus X-1 energy spectrum as measured by the INTEGRAL/IBIS telescope and obtained with the standard IBIS spectral analysis pipeline. **Two components** are clearly seen: **a "Comptonization" spectrum** caused by photons upscattered by Compton scattering off thermally distributed electrons in a hot plasma **(dashed line)**, and **a higher-energy component (solid line)** whose origin is not known.

Polarization of Cygnus X-1

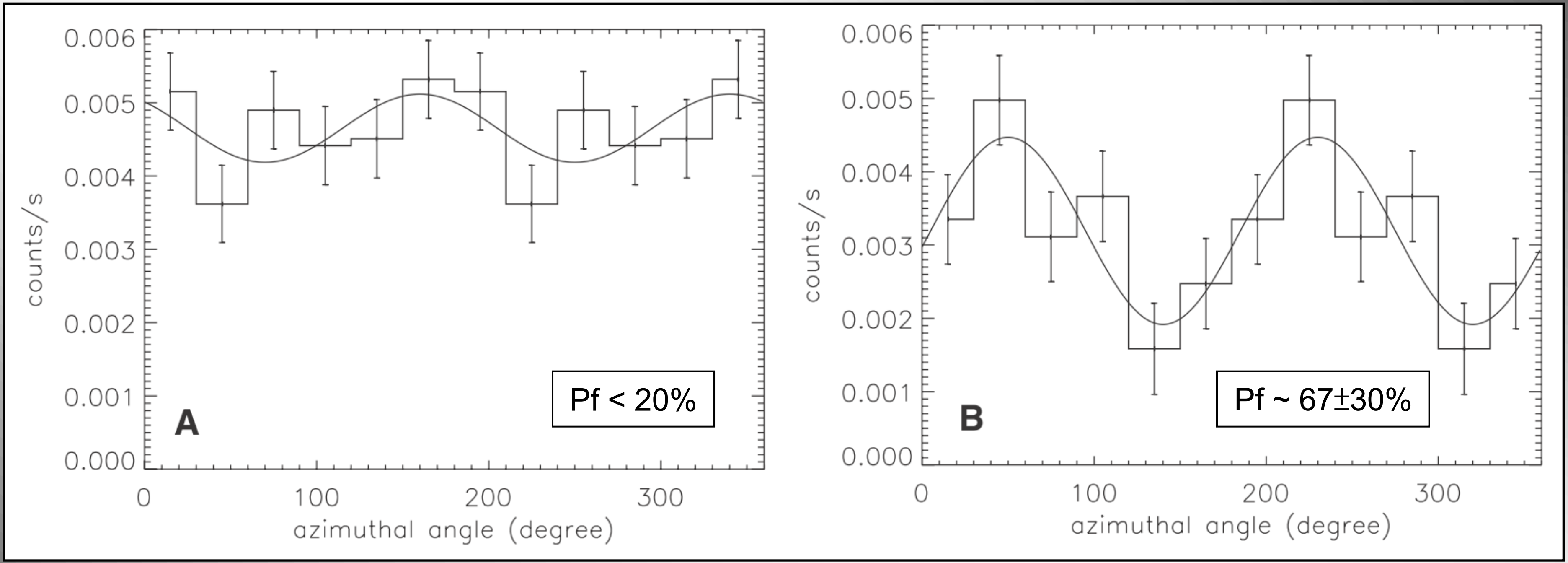


Fig.2. Cygnus X-1 polarization signal measured in two adjacent energy bands. This distribution gives the source count rate by azimuthal angle of the Compton scattering. In the 250- to 400-keV energy band **(A)**, the signal is **consistent with a flat signal**, indicating that the observed gamma rays are weakly polarized, or even not polarized. In the 400- to 2000-keV energy band **(B)**, the signal is now **highly modulated**, indicating that the observed gamma rays are highly polarized.

Implications (1)

- Such a high polarization fraction is probably the signature of synchrotron or inverse Compton emission from the jet already observed in the radio band.
- Unfortunately, current knowledge of the jet at radio wavelengths does not allow discriminating between the two processes.

- To have such a clear polarimetric signal, the magnetic field has to be coherent over a large fraction of the emission site. Such a coherent magnetic-field structure may indicate a jet origin for the gamma rays above 400 keV.
- In addition, because the gamma rays emitted in BH x-ray binaries are generally thought to be emitted close to the BH horizon, and because the synchrotron photons we observed in the hard tail are too energetic to be effectively self-Comptonized, these observations might be evidence that the jet structure is formed in the BH vicinity, possibly in the Compton corona itself.
- Another possibility is that the gamma rays are produced in the initial acceleration region in the jet, as observed at higher energies by the Fermi Large Area Telescope from the microquasar Cygnus X-3.

Implications (2)

- The spectrum observed above 400 keV is consistent with a power law of photon index 1.6±0.2. This means that this spectrum, if due to synchrotron or inverse Compton emission, is caused by electrons whose energy distribution is also a power law with an index p of 2.2±0.4, consistent with the canonical value for shock-accelerated particles p = 2.

- Synchrotron radiation at MeV energies implies also that the electron energy, for a magnetic field of 10 mG, which is reasonable for this kind of system, would be around a few TeV.
- Inverse Compton scattering of photons off these high-energy TeV electrons, whose lifetime due to synchrotron energy loss is about 1 month, could also be the origin of the TeV photons detected from Cygnus X-1 with the *Major Atmospheric Gamma-ray Imaging Cerenkov telescope experiment* and possibly also the gamma rays claimed by *Astrorivelatore Gamma ad Immagini Leggero/Ligh Imager for Gamma-Ray Astrophysics*.

- The position angle (PA) of the electric vector, which gives the direction of the electric field lines projected onto the sky, is **140°±15°**.
- This is at least 100° away from the compact radio jet, which is observed at a PA of 21° to 24°.
- Such deviations between the electric field vector and jet direction are also found in other jet sources, such as Active Galactic Nuclei or the galactic source SS433.

Thank You

Reference:

- Laurent, P., Rodriguez, J., Wilms, J., Cadolle Bel, M., Pottschmidt, K., Grinberg, V., Science 332, 438 (2011)

References of Pictures:

- http://www.spacetelescope.org/extras/posters/cygnus_x1/
- http://zh.wikipedia.org/wiki/File:Cygnus_constellation_map.png
- http://library.thinkquest.org/25715/discovery/binary.htm

Possible candidate for NCT?

- Flux of Crab (0.2-1MeV): ~1.7 x 10^{-2} ph/cm^2/sec (J. Liang, 2010)
- Polarization of Crab: Pf = 46±10 % (M. Forot, 2008), Pf > 72% (Dean, A. J., 2008).
- The 3σ MDP of NCT'09 flight was estimated as 124% for a 28ks observation, at least 9 or 3 times longer observation time is needed for the above detections (J. Liang, 2010).
- Alternatively, adding the collimator on the NCT'09 instrument could make 35% MDP at 3σ significance level in a two-day observation (J. Liang, 2008).

- Flux of Cyg X-1 (0.2-1MeV): ~1 x 10^{-2} ph/cm^2/sec (J. Liang, 2010)
- Polarization of Cyg X-1: Pf ~ 67±30%
- Detectable with NCT using new configuration next time?