Rapid variations of polarisation in X-ray binaries

Dave Russell
New York University Abu Dhabi
dave.russell@nyu.edu

In collaboration with Tariq Shahbaz (IAC, Tenerife)
I’d also like to thank Rob Fender, Elena Gallo, Poshak Gandhi, Marion Cadolle Bel, Richard Plotkin

28th Texas Symposium on Relativistic Astrophysics, Geneva, 16th December 2015
X-ray Binary Jets

Radio emission: → is synchrotron in nature → unambiguously originates in collimated outflows (2 types of jet)

The approximate spectrum of a steady, **hard state** jet:

- Optically thick
- Optically thin (inner regions)

\[ F_\nu \propto \nu^{-0.6} \]

- The total jet luminosity is highly dependent on the position of the spectral break(s)
- How does the jet spectrum evolve during outbursts? → **Time evolution** (impossible for AGN)
- What are the conditions in the inner regions of the jets? → Polarisation
Polarisation of optically thin synchrotron emission

• In NIR, the observed emission of X-ray binaries can be highly polarised
• Depends on magnetic field configuration
• Ordered field $\rightarrow$ up to $\sim$80% polarised

\[ FLP_{\text{thin}} = f \frac{p + 1}{p + 7/3} = f \frac{1 - \alpha_{\text{thin}}}{5/3 - \alpha_{\text{thin}}} \]

• Tangled field $\rightarrow$ $\sim$ no net polarisation (low $f$)

Some radio data exist:
A few % polarised
(papers by e.g. Brocksopp, Curran)

Some optical data exist:
A few % polarised due to scattering
(e.g. Dolan, Gliozzi)

Very little opt/NIR data exist, but growing field (Shahbaz, Russell, Baglio, Chaty)

Shahbaz et al. 2008
Jet emission in the optical/NIR

Jet break seen in GX 339-4 in mid-IR in the **hard state** – the break is variable in time

Gandhi et al. 2011
We need polarisation data in the hard state

- We have been monitoring GX 339-4 with the Faulkes Telescope South
- Optical drop when the source left the hard state as jet is quenching (Cadolle Bel et al. 2011)
- This happens in every outburst in which there are state transitions (Buxton et al. 2012)
- The infrared component is highly variable (Casella et al. 2010, Kalamkar et al. 2015)
VLT observations of GX 339-4 in the hard state

→ We observed GX 339-4 during a hard state with VLT+ISAAC

→ We detect significant, variable linear polarisation in the near-infrared (when the jet dominated)

→ Polarisation variability timescale: < 60 sec

We infer a predominantly tangled, variable magnetic field near the jet base (1 – 3 % polarised)

→ The PA of polarisation is ~ perpendicular to the PA of the resolved radio jet

→ The magnetic field is approximately parallel to the jet axis
Polarisation of neutron star XRBs

The results imply a predominantly tangled, likely variable magnetic field near the jet base of Cyg X-2 and Sco X-1.

NIR spectropolarimetry (Shahbaz et al. 2008)

All detections are stronger at low frequencies.

The results imply a predominantly tangled, likely variable magnetic field near the jet base.

Cyg X-2 has an infrared excess (Wang & Wang 2014)

The radio jet of Cyg X-2 has now been resolved (Spencer et al. 2013)

Sco X-1

NIR (Russell & Fender 2008) and optical (Schultz et al. 2004) polarisation
We took time-resolved NIR polarisation observations with WHT + LIRIS of Cyg X-2, simultaneously with X-rays (Swift and RXTE) in 2010.
A multiwavelength campaign on Cyg X-2

We took time-resolved NIR polarisation observations with WHT + LIRIS of Cyg X-2, simultaneously with X-ray (Swift and RXTE) in 2010

The X-ray data suggest the source was in the normal branch at the time of our observations → transient jets are launched during this state

Migliari et al. 2007 (GX 17+1)
A multiwavelength campaign on Cyg X-2

We took time-resolved NIR polarisation observations with WHT + LIRIS of Cyg X-2, simultaneously with X-ray (Swift and RXTE) in 2010.
We took time-resolved NIR polarisation observations with WHT + LIRIS of Cyg X-2, simultaneously with X-ray (Swift and RXTE) in 2010.
BH XRBs in quiescence have jets

V404 Cyg has flat radio spectrum (Gallo et al. 2005, 2007) with instabilities (Rana et al. 2015)

Jets exist in quiescence

Swift J1357.2–0933 has a steep IR–optical spectrum, high rms variability (20 – 30%)
Optical, NIR, WISE mid-IR (3.4 to 22 μm) power-law with index -1.4 (Shahbaz et al. 2013)
Could be a thermal, possibly Maxwellian distribution of electrons in a weaker jet
Jet break is seen by Plotkin et al. 2015
New results from quiescent jets

We took NIR polarisation observations with WHT + LIRIS of Swift J1357.2–0933 in quiescence

4.2 m William Herschel Telescope

- The synchrotron emission is polarised at a level of $8.0 \pm 2.5\%$ (J to K) (a detection of intrinsic polarisation at the $3.2\sigma$ level)
- The mean magnitude and rms variability of the flux agree with previous observations (fractional rms of 15–21 per cent)
- These properties imply a continuously launched (stable on long timescales), highly variable (on short timescales) jet, which has a moderately tangled magnetic field close to the jet base
And finally…. V404 Cyg

- Shahbaz et al. in prep: time-resolved optical polarimetry of V404 during brightest flaring episodes of the 2015 outburst, with Telescopio Nazionale Galileo (TNG)
- A polarisation flare is seen just before a bright optical & X-ray flare
- Position angle implies the B field is perpendicular to the jet axis (known from radio; Miller-Jones et al. in prep) \(\rightarrow\) internal shocks?

see also
ATel #7674, #7678, #7696
Conclusions

• NIR-optical synchrotron emission from jets in X-ray binaries is polarised

• The results so far suggest:

• Near the jet base the magnetic field is probably:
  → generally turbulent (only partially ordered) and rapidly changing
  → parallel to the jet axis (but perpendicular in V404 Cyg: shocks?)

• Open questions:
  → What are the timing properties of the variable polarisation?
  → Does polarisation correlate with anything in the inflow?
  → What drives the magnetic field changes?

• More data and more models are needed to explain the observations

Thanks for listening