Polarised radio emission from X-ray binary jets

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Why study X-ray binary jets?

Scale models of AGN
- Probes of jet launching
- How do jets couple to the accretion flow?
- What is their feedback effect?

Timescales proportional to compact object mass
- XRBs evolve on human timescales: unique probe
- Application to AGN (scaling relations)

Plotkin et al. (2012)

Fender & Belloni (2012)
AGN on fast-forward

Less spatial resolution in $R_g$, higher time resolution

- Real-time jet evolution

V404 Cyg: $9 \, M_\odot$
M-J et al. (in prep)

M87: $6.6 \times 10^9 \, M_\odot$
Walker et al. (2008)
Evolution of an XRB outburst

Fender & Belloni (2012)
Transient outbursts: discrete ejecta

Early work: bright sources Cyg X-3, SS 433

Hjellming & Johnston (1981)

• 1-20% linear polarisation
• Data during flaring events

Seaquist et al. (1974);
see also Gregory et al. (1972)
GRO J1655-40

- More variable at high frequency
- Smoothed and delayed at low $\nu$
- Classical synchrotron bubble
- Some events depart from model
- *Not a single bubble*
  - Unsurprising given VLBI images

Hannikainen et al. (2000)
GRO J1655-40 (continued)

- Stable initial EVPA
- B-field perpendicular to jet direction
- Late evolution
- Rapid initial RM evolution: local effects
  - B-field realignment?

Tingay et al. (1995)

Hannikainen et al. (2000)
"Rotator" events

Smooth rotations
- Several tens of degrees
- Different frequencies move together
- Associated with radio flaring

![Graph showing LP position angle vs MJD-51926.0]

![Graph showing Flux Density (mJy), α, FPF (%) vs MJD-56000]

1.8 GHz, 7.5 GHz, 5 GHz, 9 GHz, 5.5 GHz, 21 GHz, 26 GHz
Magnetic field alignment

Mechanisms for giving B parallel to jet axis

- Helical field
- Lateral expansion
- Velocity shear
- Bow shocks

Curran et al. (2014)
Spatial resolution

Polarised ejecta, depolarised core

SS 433, 1.415 GHz, 1998 mar 5–7

Roberts et al. (2008)

Fender et al. (1999)
A sequence of discrete ejecta

B-field aligned with local velocity

- Unresolved hotspot geometry?
  - Shear/lateral expansion

Dreher et al. (1987)

Miller-Jones et al. (2008)
Jets impacting ISM

XTE J1908+094

- PA swings indicate structural changes

Rushton et al. (2017)
Jets impacting ISM

**XTE J1748-288**
- Typical synchrotron polarization
- Jets hit a `wall’ ~1 arcsec from core
- Orders field, FP starts to rise

**Miller-Jones et al. (2008)**

**Brocksopp et al. (2007)**
Circular polarisation in GRS1915

- Seen subsequent to major ejection events
- Source-integrated levels 0.1-0.4%
- Steep spectrum
- Unrelated to LP or I
- Likely a compact source that is a small fraction of total emission
- Amplitude correlated with times of spectral index changes
  - New ejection events

Fender et al. (2003)
Also GRO J1655-40, SS 433

- V evolves on a shorter timescale than I
- Higher fractional variability
- Sign evolves; realignment of field close to BH
- Possible causes:
  - Faraday conversion of LP to CP
  - Synchrotron/gyrosynchrotron

SS 433

Fender et al. (2000)

Macquart et al. (2000)

GRO J1655-40
Hard state: steady, compact jets

**Partially self-absorbed, conical outflows**
- Directly resolved in several sources
- Flat or slightly inverted radio spectra
- Few percent linear polarization
- EVPA aligned with jet axis
  - Perpendicular B-field

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Markoff (2010)  
Gallo et al. (2004)  
Corbel et al. (2000)  
GX 339-4
Determining the quiescent jet axis

1989 outburst of V404 Cyg
- Significant LP detected
- PA stabilised during hard state decay phase
- Alignment with jet axis?

Han & Hjellming (1992)
Determining the quiescent jet axis

VLBI in quiescence determines parallax distance
- Plot astrometric residuals

Remember this?

Polarised emission from astrophysical jets - 14 June 2017
Tracking time-variable polarisation

Simultaneous multi-wavelength coverage

- Preliminary polarisation calibration at the VLA

Tetarenko et al. (2017)

Work by C. MacPherson
Cyg X-1: jet emission propagates through wind

- Polarisation detected at $\phi=0.5$, but not at $\phi=0$
- Track around full orbit; RM probes wind

Szostek et al. (2007)
Polarization in NS XRBs

Circinus X-1

- High accretion-rate NS XRB
- Stable PA over 10 years
- A few percent LP
- B aligned perpendicular to jet axis in ejecta – shocks?
- Core has B parallel to jet axis
Summary

XRBs allow us to study jets and jet/disc coupling in real time

• Examine sequence of events
  – Ejecta launching
  – Shocks forming (internal/external)
• Typical LP fractions:
  – ~1% in steady, compact jets
  – 1-25% in transient ejecta
• A few cases with measured CP

• Use polarization as probe of jet structure, stellar wind
• Paucity of spatially-resolved polarization
  – Sensitive VLBI arrays
  – Techniques to deal with rapidly-evolving structure