Jets from X-ray binaries

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Outline

- X-ray binaries: overview
- The empirical picture
  - Luminosity correlations
  - Radio flares and major ejection events
  - Accretion disc winds
- Jet power
  - Jet power and spin
  - Jet power and particle content
X-ray binaries: overview

- Multi-wavelength emitters
- Highly variable (ms to years = “Human” timescales)
- Transient: outburst (~1 year) / quiescence (~10 years)
- Several accretion states
- Intermittent jets
The empirical picture

The hard state

- From $\sim 10^{32}$ ergs/s (quiescence) up to $\sim 10^{37}$ ergs/s
- Corona dominates X-ray emission
- Strong X-ray variability (frequency range 0.01-100 Hz)
- Compact jets
Compact jets

- Few m.a.s. = few 10 A.U.
- Steady emission
- Flat spectrum from radio to IR
- Self-absorbed synchrotron emission
- Internal shocks (see Julien’s talk)
Universality of accretion-jet coupling

$$L_R \propto L_X^{0.6} M^{0.8}$$

Self-absorbed synchrotron emitting jets + Radiatively inefficient accretion flow


Stellar mass BH

Stellar mass and supermassive BH
Dichotomy

"Standard" black holes

$L_R \propto L_X^{0.6}$

(Corbel et al. 2003  Gallo et al. 2003)

Outliers

Same correlation index but lower normalisation?

Behaviour at low luminosity?

Radio-quiet stellar-mass black holes?
Transition between

- Different correlation index
- Transition between the 2 tracks
- Two populations statistically distinct
- Standard model seriously questioned...

Two modes of disc-jet coupling?
Possible interpretation: Radiatively efficient jet-emitting accretion flow

Transition efficient $\rightarrow$ inefficient accretion flow below a critical accretion rate.

Re-condensation of optically thin gas within the inner regions enhances seed photons for Comptonization (Meyer-Hofmeister & Meyer, 2014)
The empirical picture

From hard to soft

- “Usually” above $10^{37}$ erg/s
- Corona emission drops
- Dramatic change in spectral shape
- Marginal change in broadband luminosity
- Broadband noise drops. Strong QPOs appear.
- Radio flares (single or sequence)

Courtesy G. Pooley
Radio flares and major ejection events

- Spatially resolved as radio knots moving at relativistic speed
- Substantial mass ejection and/or internal shock propagation?
- Coronal plasma ejected?
- Spectrum evolution follows the ‘standard’ expanding synchrotron bubble model (e.g. van der Laan 1966)
- Jets/ISM interaction sometimes observed in X-rays

Mirabel & Rodriguez 94

Corbel et al. 2002
The empirical picture

The soft state

- Disk blackbody dominates X-ray (peak at ~1 keV)
- Very low X-ray variability (< 5% r.m.s.)
- No jets emission detected
- Strong accretion disc winds detected as blueshifted absorption lines in X-ray

Neilsen & Lee 2012
**Accretion disc winds**

- Winds only visible in soft state of high inclination sources \(\rightarrow\) Equatorial winds
- Mass ejected \(\approx\) Mass accreted
- \(V_{\text{wind}} \approx 1000\) km/s
- Jets/winds dichotomy?
Magnetically driven winds

Chakravorty et al. 2016

MHD wind model can reproduce most of the observations

Wind could be present in hard state as well but non detected (thermal instabilities)
Jet power and BH spin

Accretion-powered jets

Spin-powered jets
Blandford & Znajek (1977)

\[ P_J \propto a^2 \]
Jet power and BH spin

- No evidence for spin powering of compact jets
- Potential contribution to transient jets power (but controversial, e.g. Russell et al. 2013)
- But methods for estimating spin and jets power are uncertain…

**Compact jets**

Fender et al. (2010)

**Transient jets**

Narayan & McClintock (2012)
Jet particle content

- Electron:positron, electron:proton ?
- Important consequences for jet power and formation mechanism
- No clear evidence yet for the presence of baryons in jets except in SS433

Dubner et al. 1998
Baryons in jets from 4U 1630-47?

- Detection of blueshifted iron lines in X-ray coincident with re-appearance of jets in radio

But no detections during the rest of the outburst...

Baryons could be launched during specific phases only

Diaz-Trigo et al. 2013

Nielsen et al. 2014