The dynamics of microquasar jets in HMXBs

Relativity meeting
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Interaction w/ medium

M87, Virgo cluster (Hubble WFPC2)

Cygnus X-1 (Gallo 2005)
Adavantage to study X-ray Binaries

- Short time scale and small physical scale → allow us to study jet ejection episode (cf. AGN ~ $10^6$ yr)
- The origin of accreting gas is rather clear.

Cygnus X-1 (Gallo 2005)
Circum-binary environment

\[ \dot{M} \sim 10^{-7} - 10^{-5} M_\odot \text{yr}^{-1} \]

Sketch of Circum-binary environment (Fender & Maccarone, 2003)
Caveats

Hatchett-McCray effect (Gies et al. 2008)

(Oskinova et al. 2012)

(Blondin et al. 1994)
Numerical Setup

- 3D Hydrodynamic simulation with FLASH3
- Ballistic Jet from cylindrical nozzle
- Spherical wind set to the typical parameters for OB type star

Parameter Study
- Jet power of $10^{35}, 10^{36}, 10^{37}$ erg s$^{-1}$
- Jet orientation of $30^\circ, 60^\circ, 75^\circ$
Evolution of the jet

Jet evolution

Orbital motion
Analytic approach

Pressure equilibrium between the Jet pressure and the wind ram pressure.

Jet bending angle:

\[
\frac{\Delta \Phi_{m,w}}{\Phi_{m,j}} \bigg|_{\theta \gg 1} \approx \frac{C}{4\pi} \frac{\dot{M} v_w}{l} h_0 v_j \left(1 + \frac{9}{2M_j^2}\right) L_j^{-1}
\]
Asymptotic angle

For Cygnus-X-1, in order to develop a stable jet:

\[ P_{\text{jet}} > 5.57 \times 10^{35} \text{ erg s}^{-1} \]

\[ \rightarrow \text{agree with Gallo et al. 2005} \]

(Yoon et al. 2013, in preparation)
Off-axis jet

- Misalignment by natal kick (Brandt & Podisadlowski 1995)
- Alignment time scale $\tau_{\text{align}} \sim 10^6$–$10^7$ yr (Martin et al. 2008)

- The jet of Cygnus X-3 is inclined to the orbital plane ($20^\circ < \Phi_{\text{jet}} < 80^\circ$) (Dubus et al. 2010)
Summary

- Studying the interaction of microquasar jets is essential to estimate core parameters and understand the jet dynamics.

- We’ve performed
  - 3 dimensional hydrodynamics simulation
  - analytic approach with small bending approximation to investigate asymptotic angle of the jet bent by the interaction with stellar wind from companion star in HMXBs.

- We’ve found
  - the angle is related to the parameters of the jet and the wind.
  - our analysis can be used to constrain observational parameters.
Other interests

LMXB

Late evolution of XRB in motion

\[ p_{\text{dyn}} = 4.1 p_{\text{ISM}} R \]

V\text{XB}

R_{eq}

P_{\text{ISM}}

Moving XRBs (Heinz et al. 2008)

Guitar Nebula (Chatterjee & Cordes 2002)

Pulsar wind nebular

Yoon et al. 2011

Yoon et al. 2013 in preparation
Thank you