HOW FAST ARE THE JETS IN BLACK HOLES?

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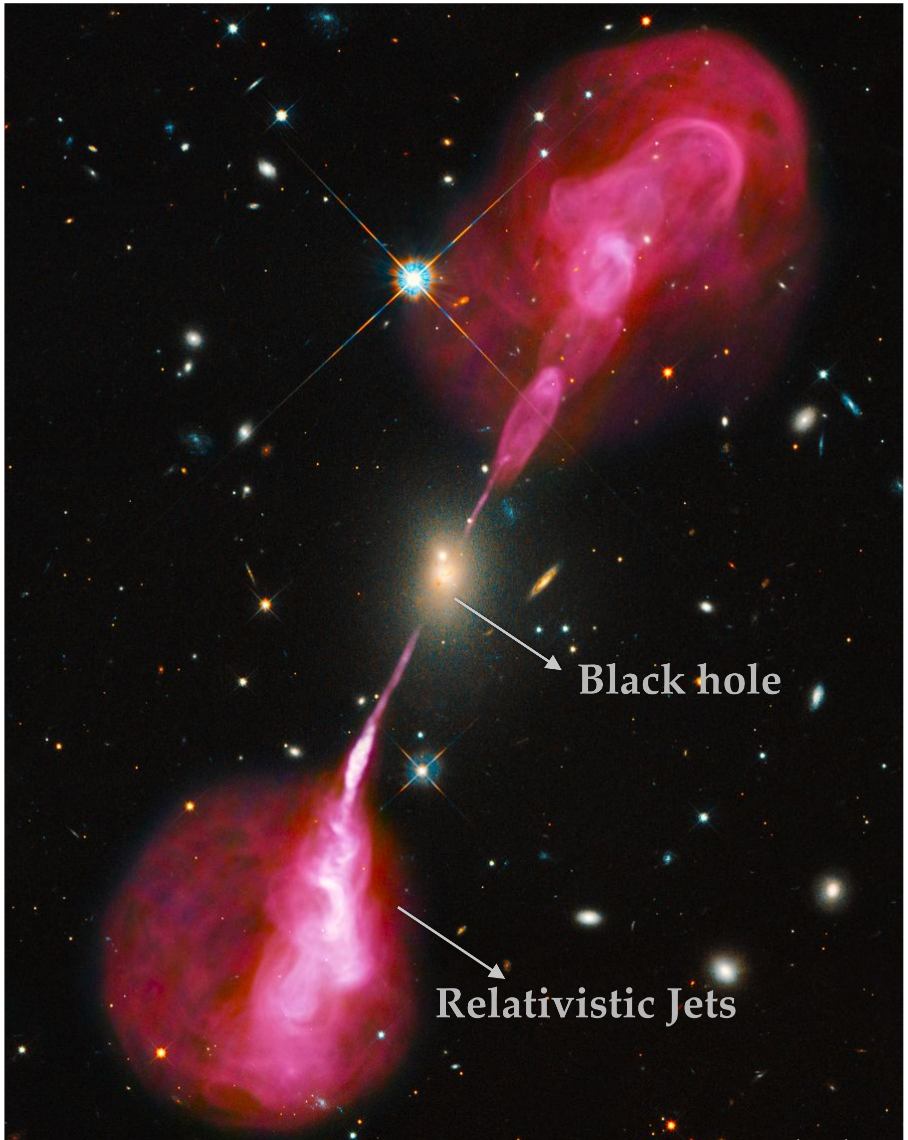
BLACK HOLES

Black holes are some of the strangest and most fascinating objects known to mankind. A black hole possesses such high gravitational power that it does not let even light escape its surface, making it practically impossible for us to directly observe it. A stellar-mass black hole is formed by the gravitational collapse of a star. We can observe it when a star or gas cloud coming in its vicinity gets ripped apart by its strong gravitational force. The disrupted matter from the star forms a flattened disc around the black hole, before falling into it, known as the accretion disc. The rotation and the magnetic field of the accretion disc can sometime eject huge amount of matter along the poles of the black hole. These bright outflows are termed as jets.

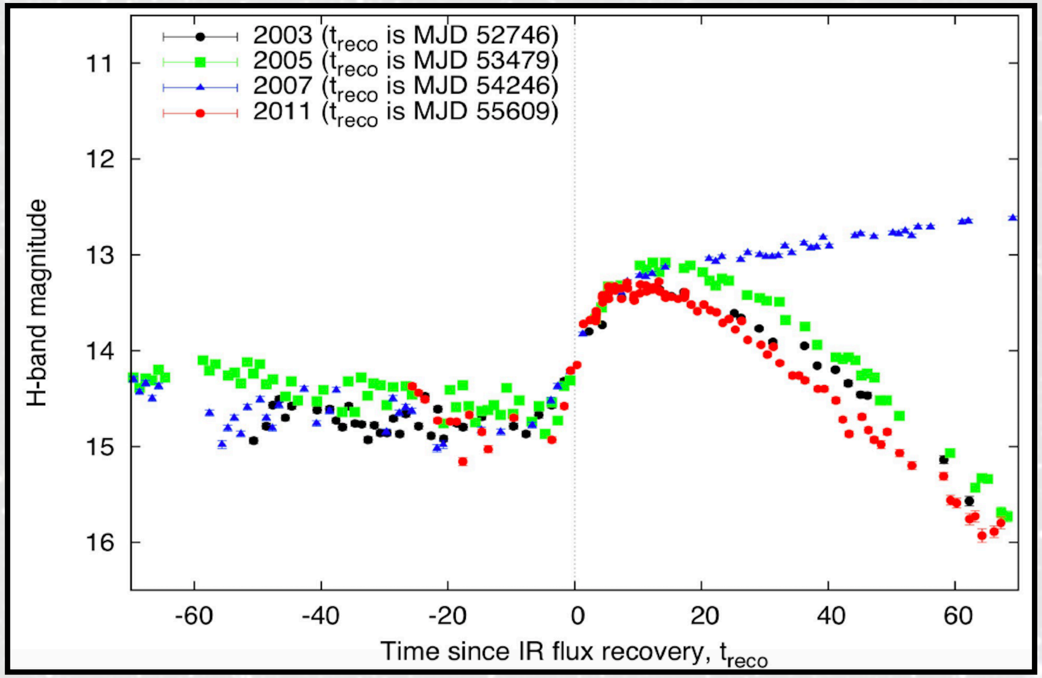
BLACK HOLE JETS

The flux of a jet can be modeled at first approximation using just two intrinsic parameters - the Lorentz factor (Γ), which describes how fast and relativistic a jet is, and the inclination angle. The Γ of jets in stellar-mass black hole is notoriously difficult to measure, with to date only weak constraints for a few of them. In this project, we are focussing on solving the question - **"How fast are the jets in stellar-mass black holes?"**.



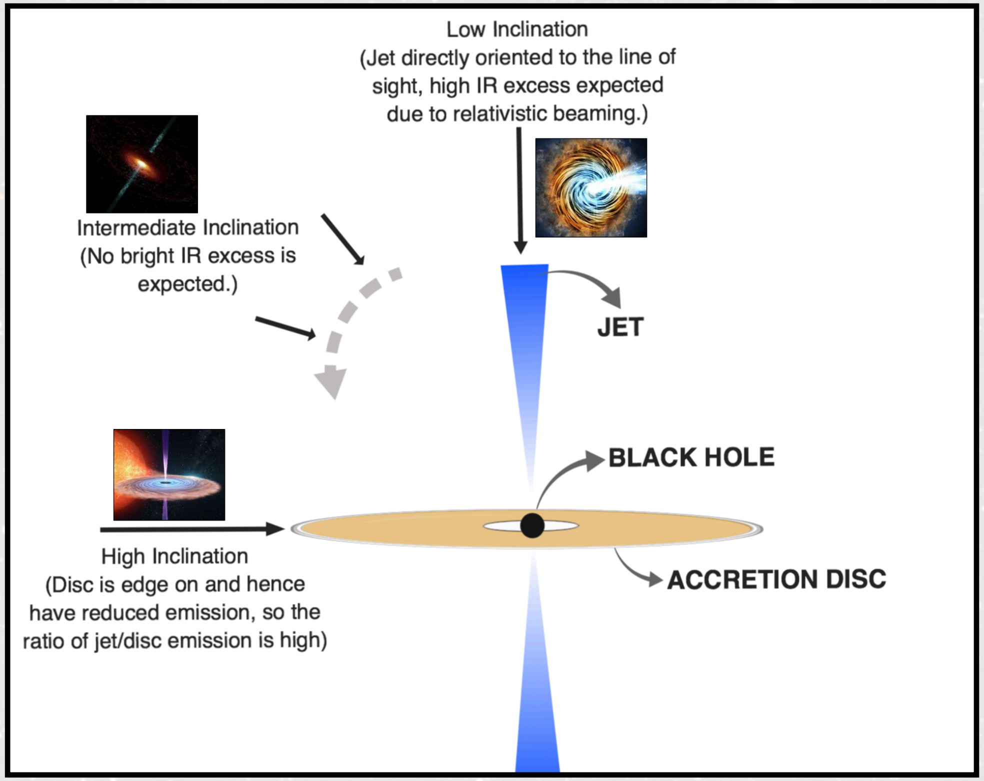
Credits: NASA, ESA, S. Baum and C O'Dea (RIT), R Perley & W Cotton (NRAO/AUI/NS)

WHAT WE USE : TOOLS



For some black hole X-ray binaries, the accretion disk tends to dominate the infrared (IR) emission throughout the outbursts. **However, for many sources, there is an IR excess observed during its evolution, probably owing to synchrotron emission produced in the jets.** To date, there is no explanation as to why some sources appear to have prominent IR excesses (e.g., see the IR light curve of GX 339–4 in H-band above). We use archival data from various Infrared telescopes to study the change of IR emission when the jet switches on/off in such stellar-mass black holes.

WHAT WE EXPECT : MODEL



Low Inclination
(Jet directly oriented to the line of sight, high IR excess expected due to relativistic beaming.)

Intermediate Inclination
(No bright IR excess is expected.)

JET

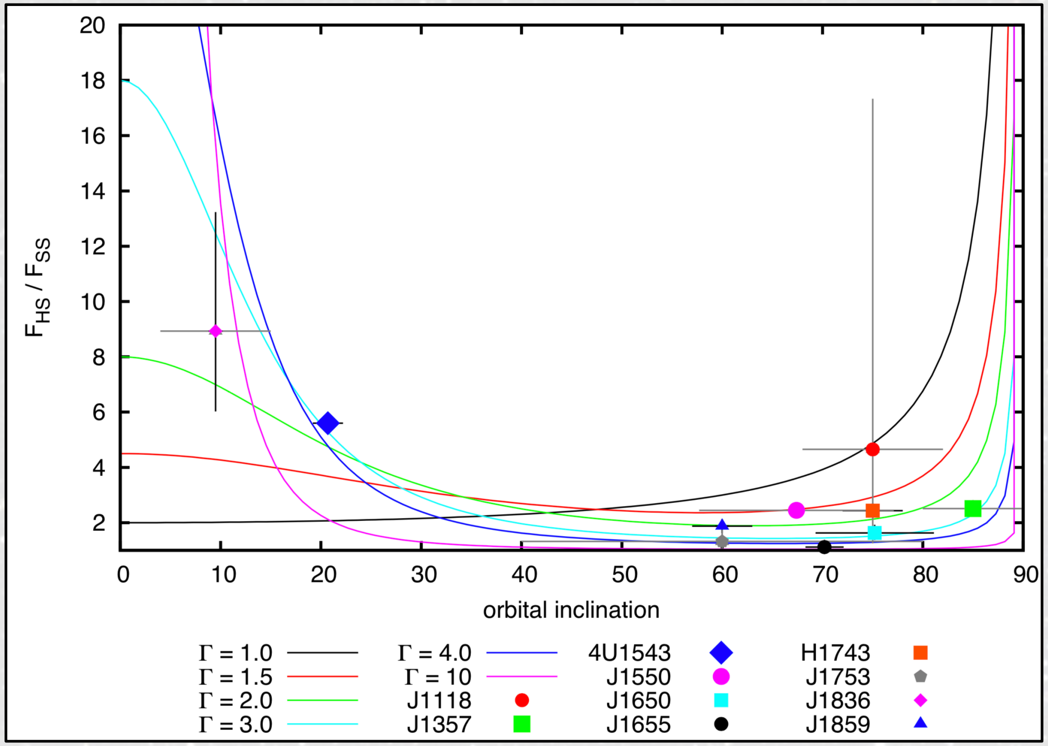
BLACK HOLE

ACCRETION DISC

High Inclination
(Disc is edge on and hence have reduced emission, so the ratio of jet/disc emission is high)

We explore whether relativistic beaming and relative disk emission can explain the IR excess observed in these sources. Theoretically, the jet luminosity should correlate with the inclination angle if the emission is subject to relativistic beaming. For high-inclination systems, the disk is almost edge-on, leading to relatively bright IR excesses. Similarly, when the inclination is low, the jet is oriented directly toward the line of sight, and a prominent IR excess is expected owing to relativistic beaming.

WHAT WE SEE : DATA / OBSERVATIONS

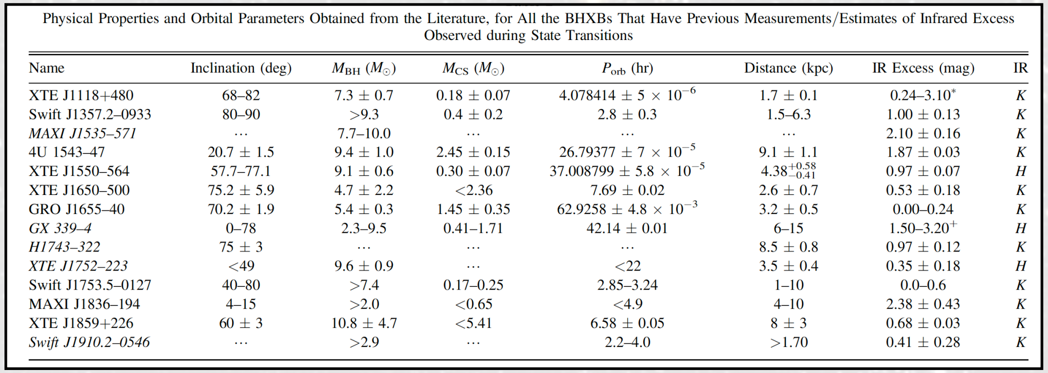


As expected, we see that the IR excess is high for both very low and very high inclination values, while the intermediate inclination range shows very little IR excess for all Lorentz factors. The different lines in the plot above show the IR flux change when the jet switches on/off (shown as ratio of IR emission in the hard state vs. the soft state), vs. the orbital inclination for different Lorentz factors. The points included are all the BHXBs with well-constrained measurements of inclination and reliable estimates of IR excess.

WHAT WE DO : METHODS

Assuming that the appearance/disappearance of the IR excess during state transition is occurring because the jet switches on/off in a black hole X-ray binary, we use a simple analytical model (see Page 2) to predict the relative flux excess expected for each source, by calculating the projected area of the accretion disk (to estimate the relative disk emission) and the Doppler beaming as a function of the Lorentz factor (to infer the jet emission).

In order to do that, we use the orbital period, inclination angles, the masses of the black hole and the companion star, our model and a bayesian framework to constrain the Lorentz Factors of jets in all the X-ray binaries for which reliable IR excess information is available in the literature.



Physical Properties and Orbital Parameters Obtained from the Literature, for All the BHXBs That Have Previous Measurements/Estimates of Infrared Excess Observed during State Transitions

Name	Inclination (deg)	$M_{\rm BH}$ ($M_\odot$)	$M_{\rm CS}$ ($M_\odot$)	$P_{\rm orb}$ (hr)	Distance (kpc)	IR Excess (mag)	IR
XTE J1118+480	68–82	7.3 ± 0.7	0.18 ± 0.07	$4.078414 \pm 5 \times 10^{-6}$	1.7 ± 0.1	0.24–3.10*	*K*
Swift J1357.2–0933	80–90	>9.3	0.4 ± 0.2	2.8 ± 0.3	1.5–6.3	1.00 ± 0.13	*K*
MAXI J1535–571	…	7.7–10.0	…	…	…	2.10 ± 0.16	*K*
4U 1543–47	20.7 ± 1.5	9.4 ± 1.0	2.45 ± 0.15	$26.79377 \pm 7 \times 10^{-5}$	9.1 ± 1.1	1.87 ± 0.03	*K*
XTE J1550–564	57.7–77.1	9.1 ± 0.6	0.30 ± 0.07	$37.008799 \pm 5.8 \times 10^{-5}$	$4.38^{+0.58}_{-0.41}$	0.97 ± 0.07	*H*
XTE J1650–500	75.2 ± 5.9	4.7 ± 2.2	<2.36	7.69 ± 0.02	2.6 ± 0.7	0.53 ± 0.18	*K*
GRO J1655–40	70.2 ± 1.9	5.4 ± 0.3	1.45 ± 0.35	$62.9258 \pm 4.8 \times 10^{-3}$	3.2 ± 0.5	0.00–0.24	*K*
GX 339–4	0–78	2.3–9.5	0.41–1.71	42.14 ± 0.01	6–15	1.50–3.20^{+}	*H*
H1743–322	75 ± 3	…	…	…	8.5 ± 0.8	0.97 ± 0.12	*K*
XTE J1752–223	<49	9.6 ± 0.9	…	<22	3.5 ± 0.4	0.35 ± 0.18	*H*
Swift J1753.5–0127	40–80	>7.4	0.17–0.25	2.85–3.24	1–10	0.0–0.6	*K*
MAXI J1836–194	4–15	>2.0	<0.65	<4.9	4–10	2.38 ± 0.43	*K*
XTE J1859+226	60 ± 3	10.8 ± 4.7	<5.41	6.58 ± 0.05	8 ± 3	0.68 ± 0.03	*K*
Swift J1910.2–0546	…	>2.9	…	2.2–4.0	>1.70	0.41 ± 0.28	*K*

Table with Physical Parameters of our sample

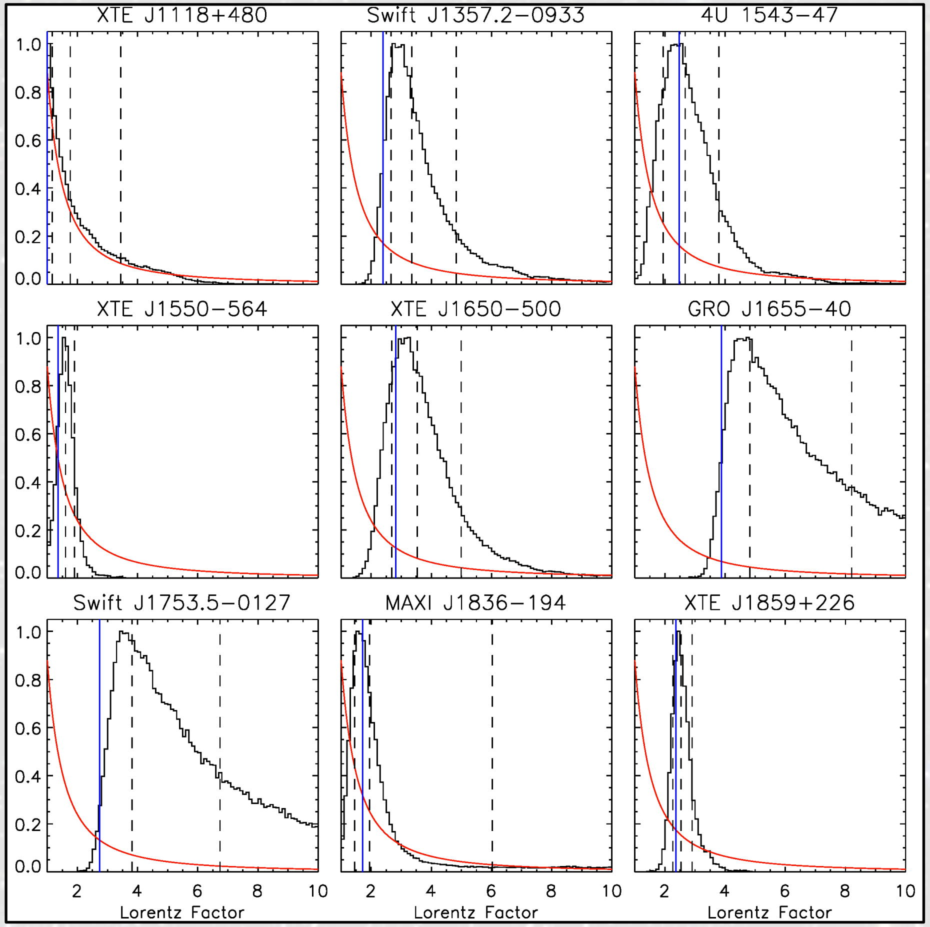
WHAT WE FIND : RESULTS, DISCUSSION & CONCLUSIONS

The NIR emission seen in black hole X-ray binaries is expected to originate mainly at the outer part of the accretion disk and from the jet. An excess of IR emission is observed in many binaries in the hard-state, when the jet switches on. We study this excess in IR emission, using a compilation of all the BHXBs in the literature for which an IR excess has been measured.

Using the amplitude of jet fade and recovery in IR wavelengths over state transitions and the known orbital parameters, we constrain for the first time the bulk Lorentz factors for nine stellar-mass black holes.

We find that all the well-constrained Lorentz factors of the BHXBs in our sample lie in the range 1.3 - 3.5.

Hence, we show that these jets can be as relativistic as the jets found in supermassive black holes. We also estimate a power-law form of parent Lorentz factor distribution for the stellar-mass black holes, which is astonishingly similar to their supermassive counterparts.



The histogram of the inferred jet Lorentz factors (Γ) for each black hole X-ray binary in our sample. The best-fit parameter estimates are plotted as vertical blue lines, and the 15.9, 50 and 84.1 percentiles are plotted as vertical dashed black lines.

Reference : P. Saikia, D. M. Russell, D. M. Bramich, J. C. A. Miller-Jones, et al., 2019, The Astrophysical Journal 887 (1), 21