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Using X-ray binary variability to understand jets

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Nathalie Degenaar (Amsterdam)



Relativistic jets: motivations to understand them

What we know from past slow and rapid variability studies

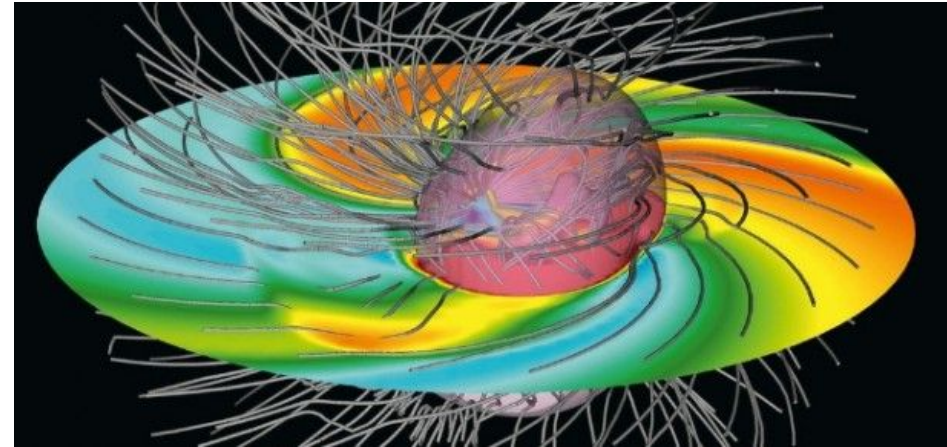
Jet bursts: a new tool



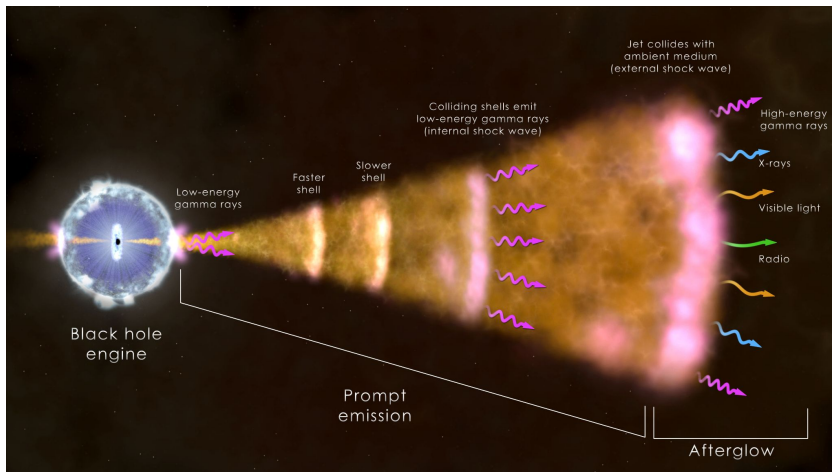
Why understand jets?



Feedback



Testing GRMHD

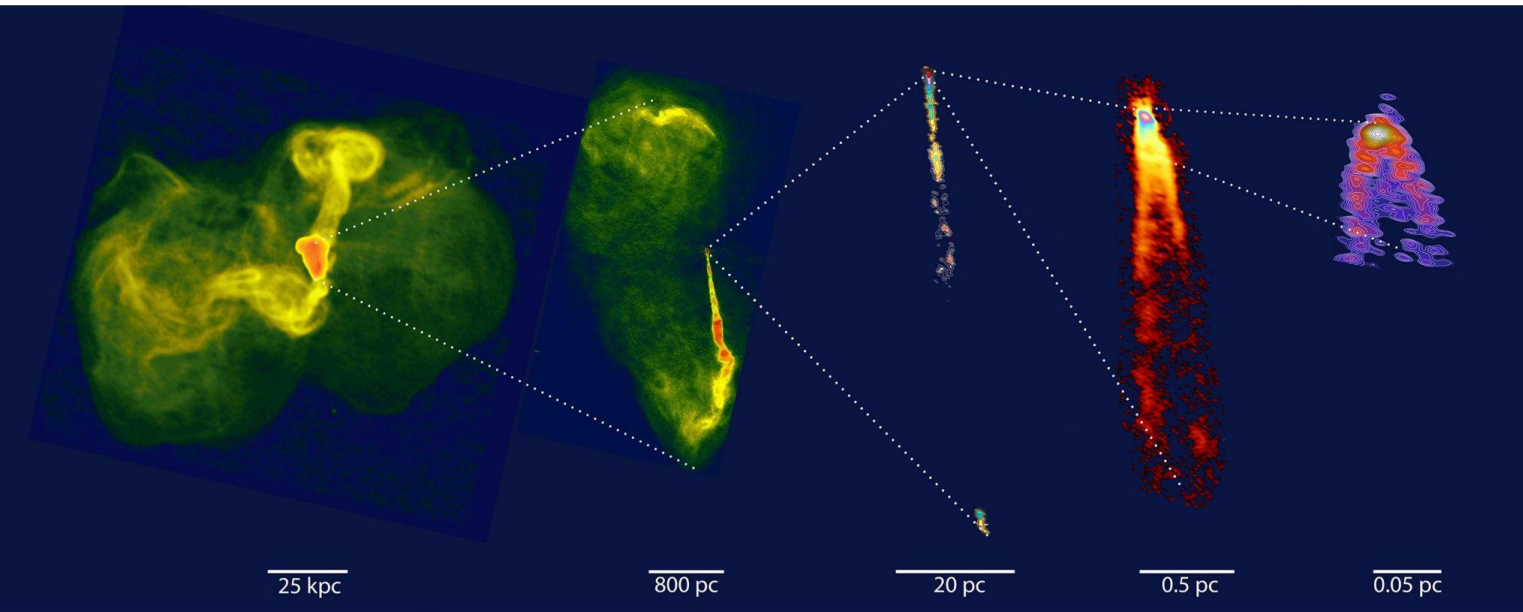


Understanding GRBs and kilonovae



Understanding exotic particle production

Astrophysical jets



From Blandford, Meier & Readhead 2019: M87 on different spatial scales



Why do the electron populations stay refreshed?

Are the positive charges mostly protons or positrons (or does this depend on the state of the system)?

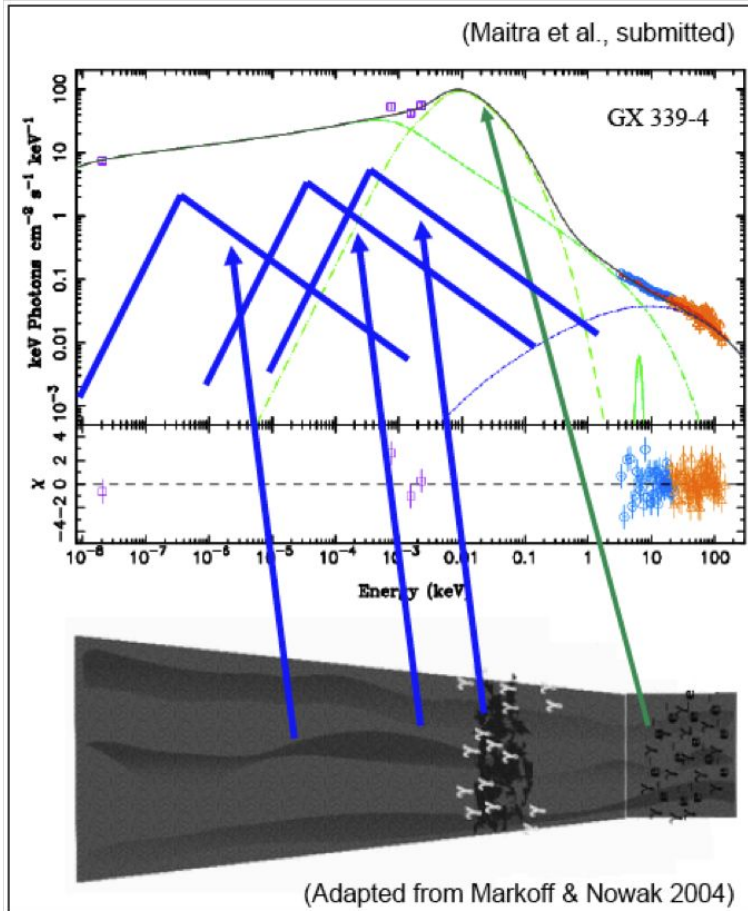
How does the speed depend on other quantities?

How are they launched and collimated? Does BH spin matter?

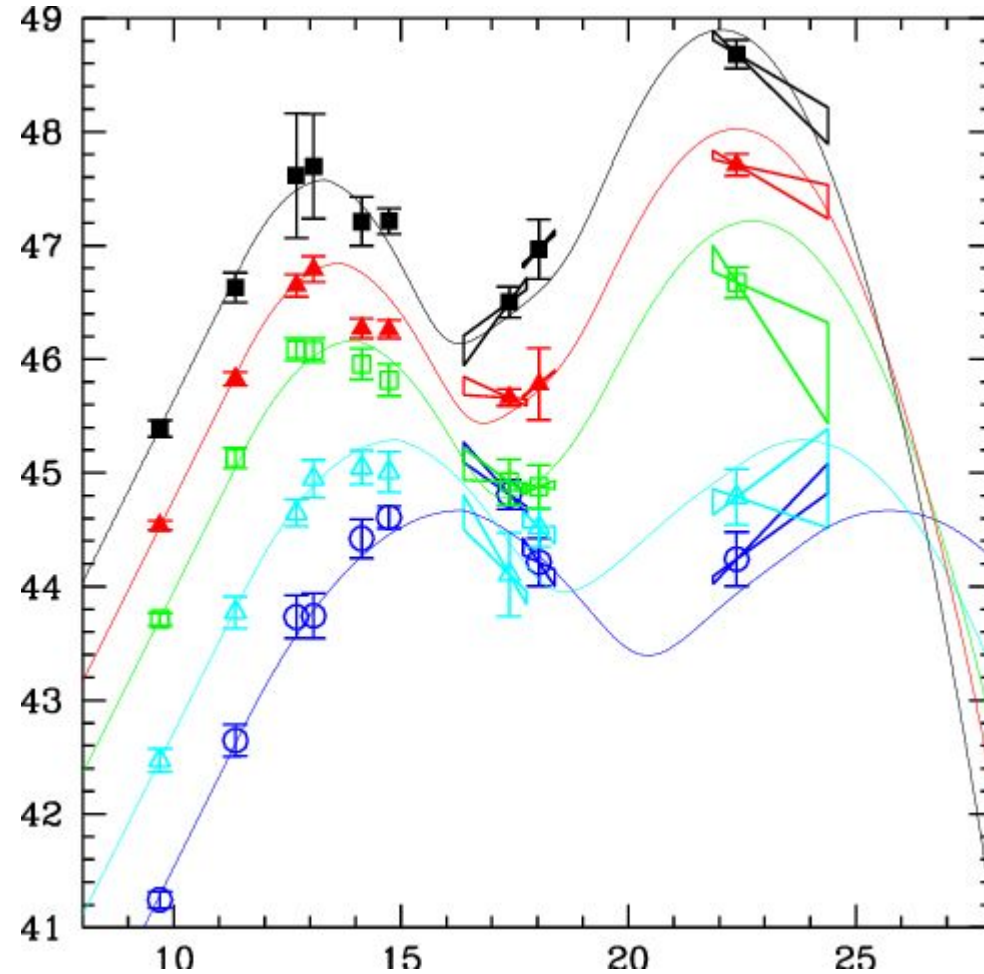
Must they be perpendicular to the accretion disks?



The “Standard” Model for Compact Jets



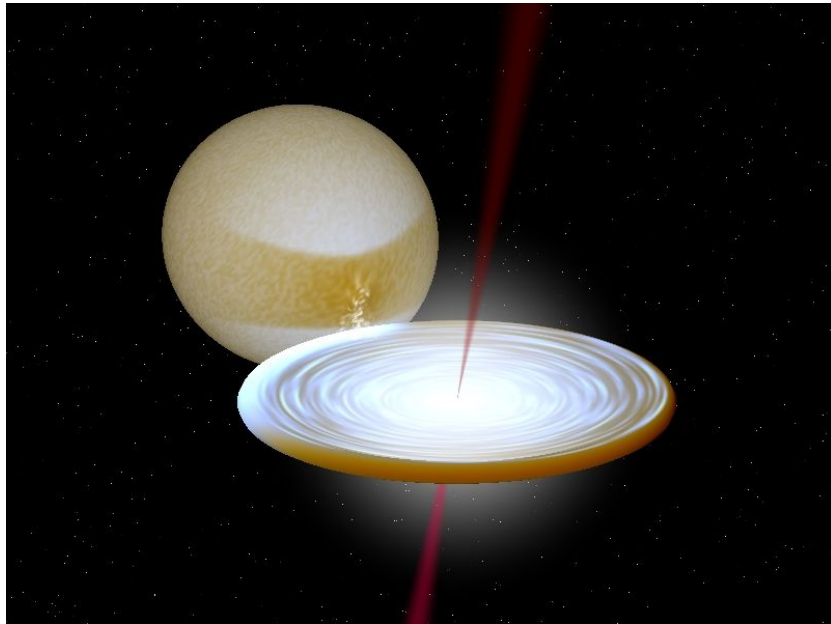
Flat spectrum can be explained by synchrotron self-absorption in conical jet (Blandford & Konigl 1979), if energy is replenished.



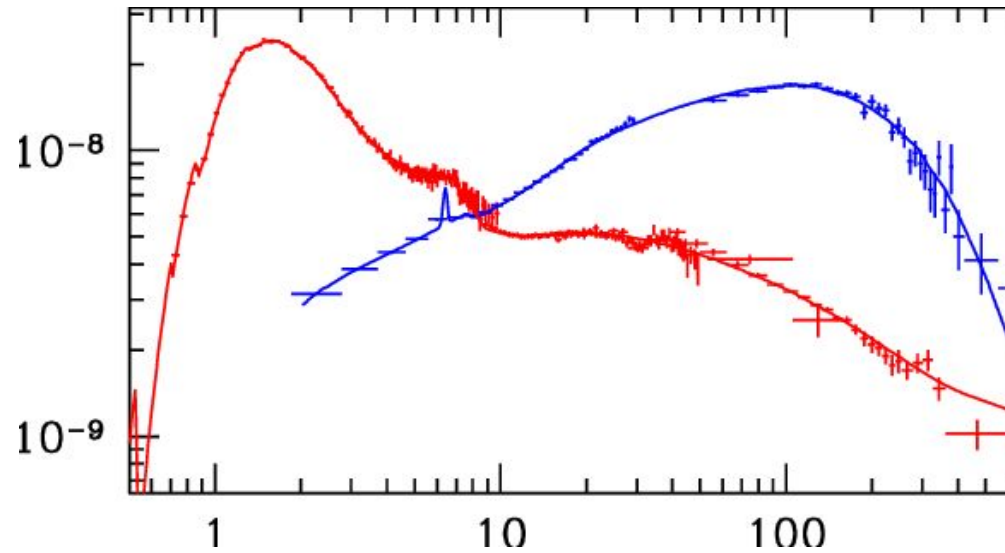
Blazar sequence, Fossati et al. 1998; more data show that things may be more complicated, but the basic picture probably still holds



X-ray binaries



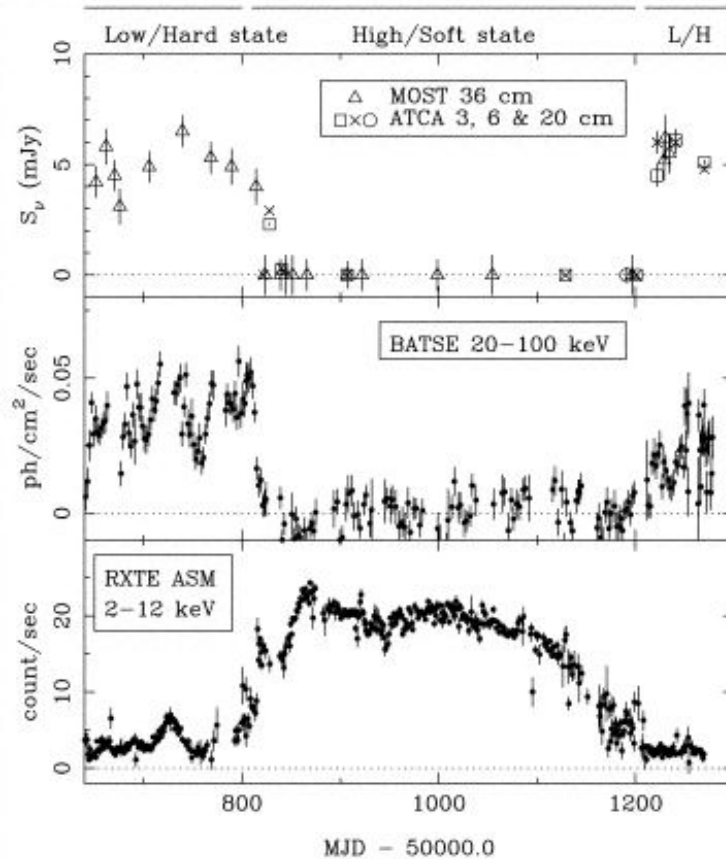
binsim/Rob Hynes, LSU



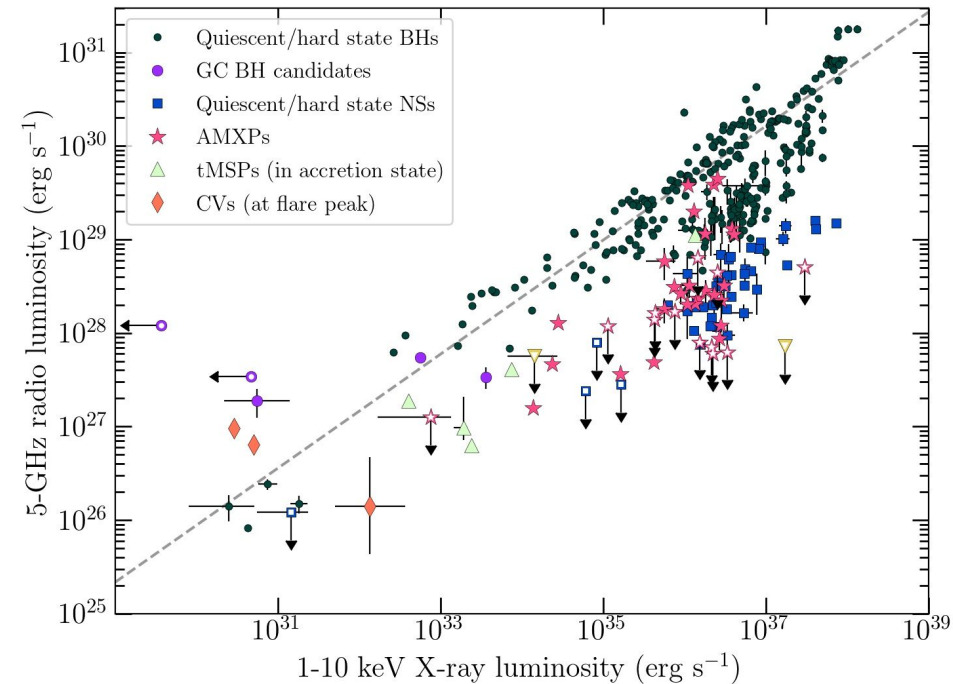
Gierlinski et al. 1999



Jets from X-ray binaries: the key to well-designed observational studies



From Fender et al. 1999; see also Tananbaum et al. 1972, Hannikainen et al. 1997

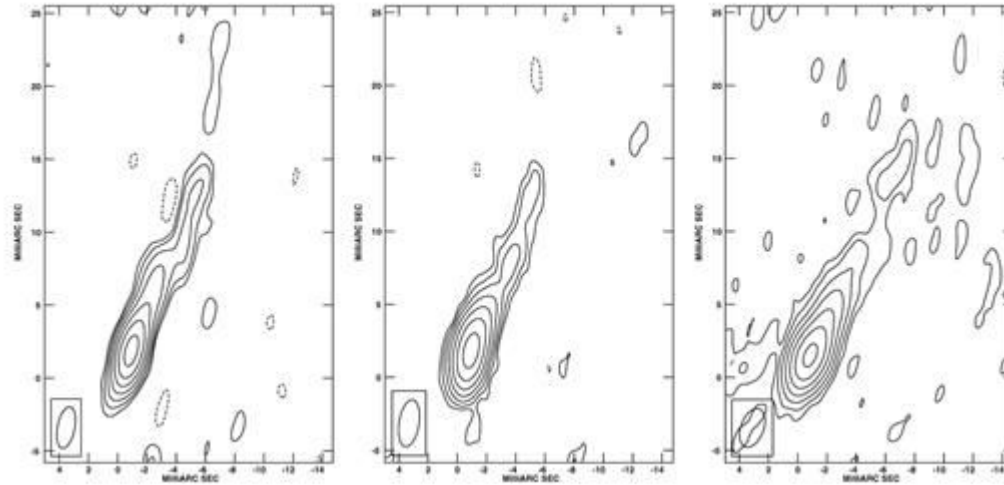


Bahramian et al. 2018; see also Hannikainen et al. 1997; Gallo et al. 2003

AGN viscous times are too long for this kind of work with individual sources!



Testing the model given the featureless spectra



Stirling et al. 2001

Cyg X-1 (at 2 kpc) is barely resolved, other objects are generally unresolvable

BK79 model predicts same size (in resolution elements) at all wavelengths, because both resolution and jet size are proportional to wavelength

Variability as the key to understanding



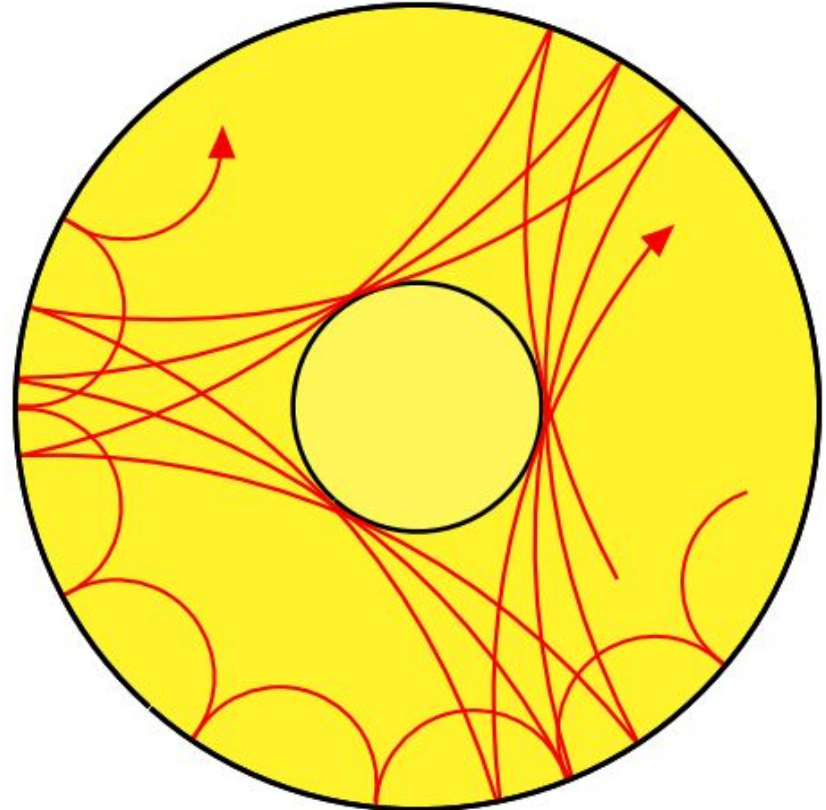
Core astronomical
tools:

Images

Spectra

Polarization

Variability



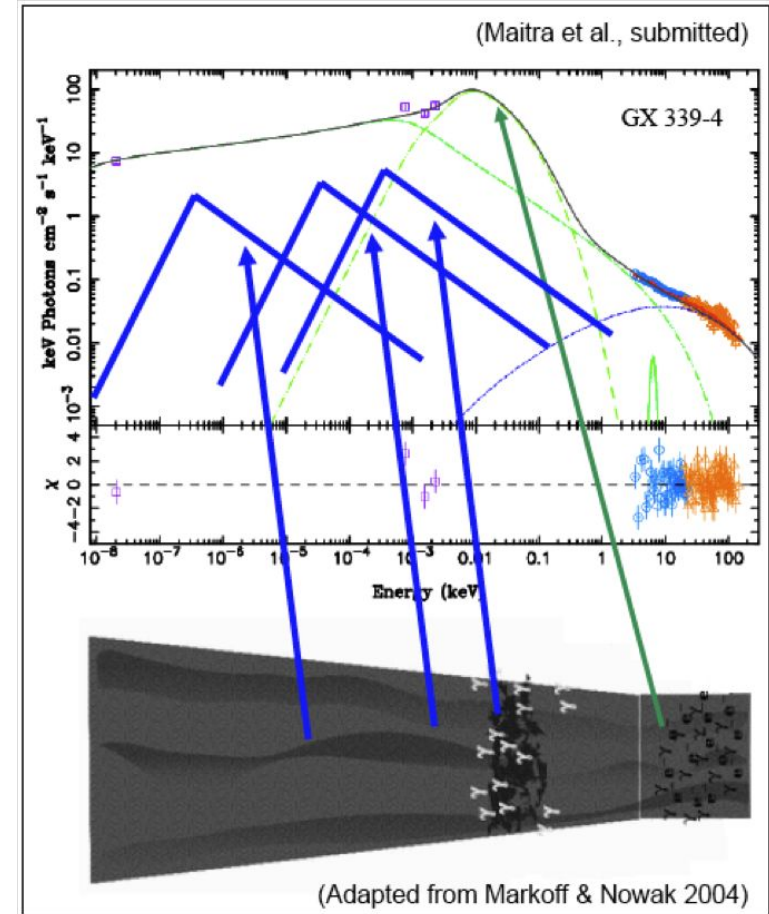


Variability quantities of interest

Characteristic
timescales

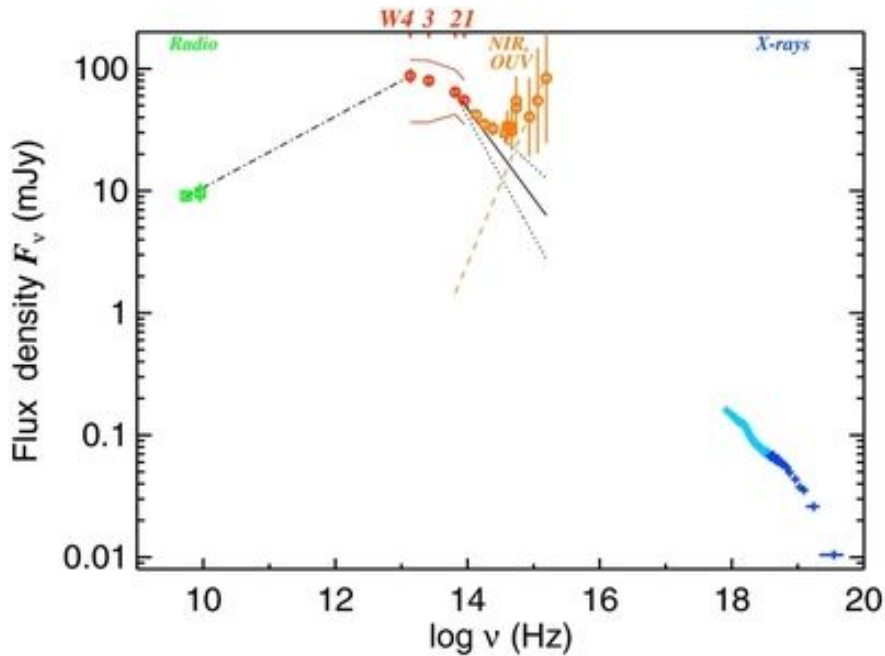
Lags of radio behind
IR (outer jet lags inner
jet)

Lags of radio behind
X-rays (jet lags
inflowing material)

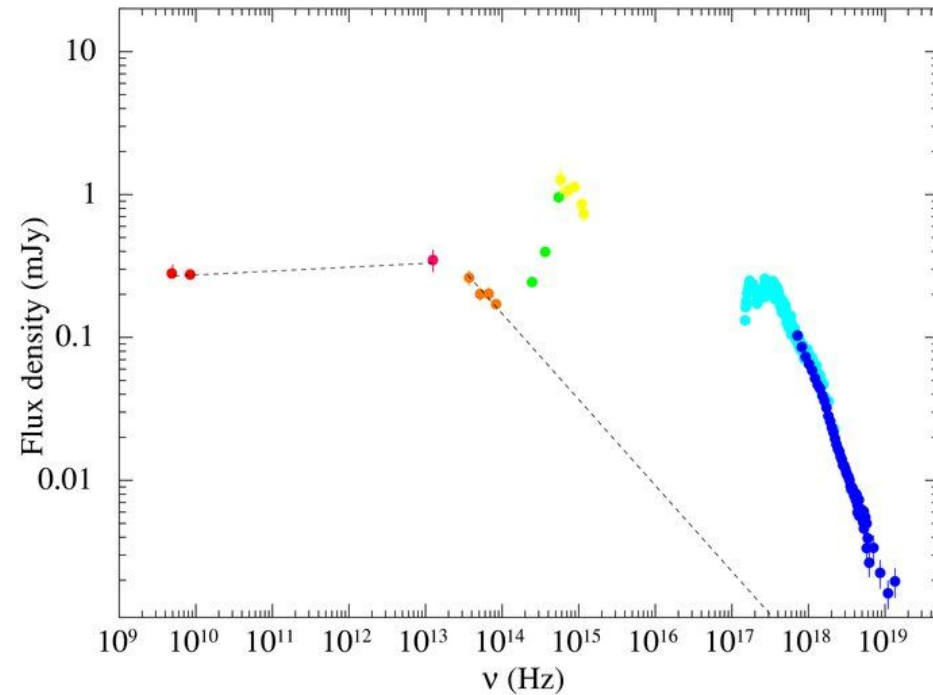




Spectral energy distributions of X-ray binaries



From Gandhi et al. 2011 - BH GX 339-4

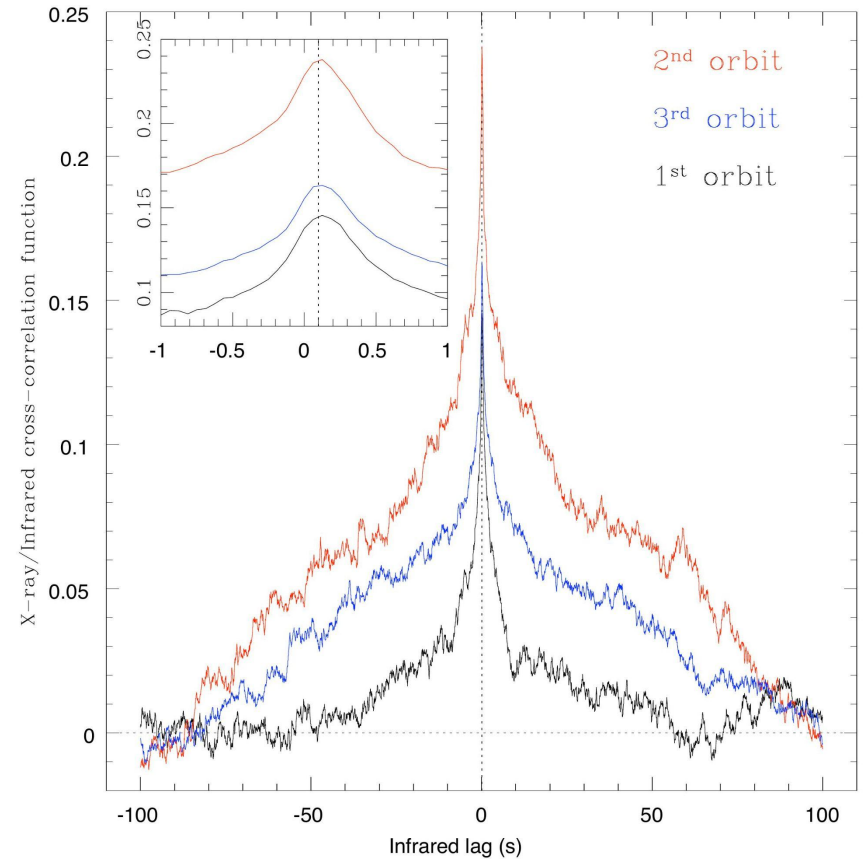
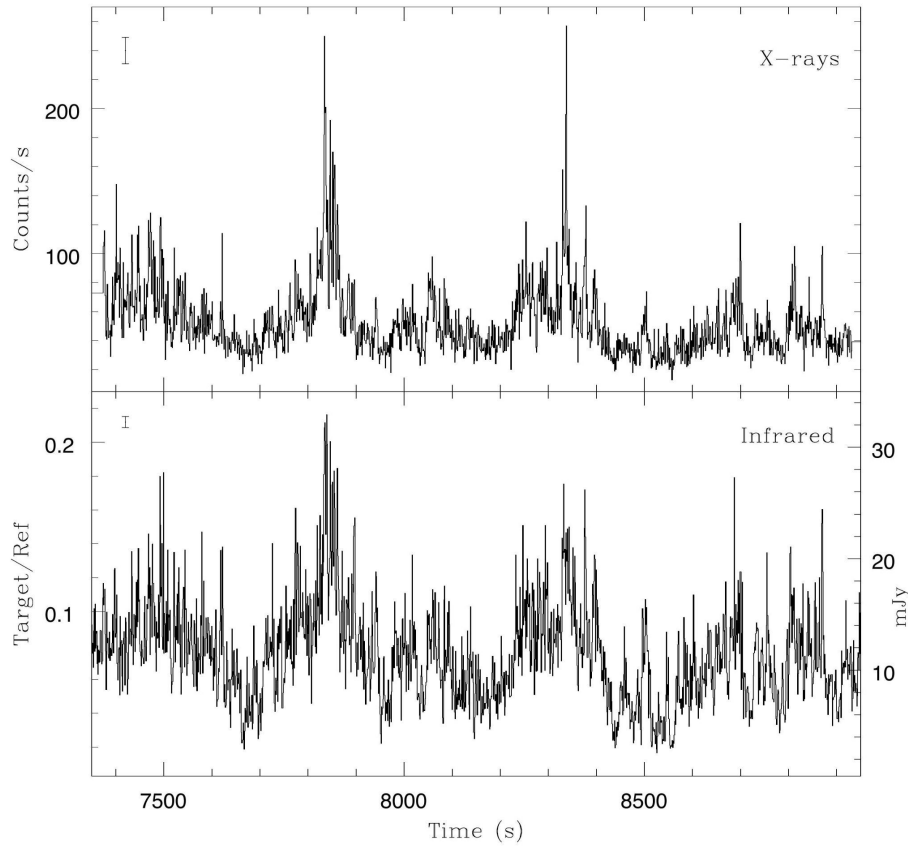


From Migliari et al. 2010 - NS 4U 0614+091

Optical can be reprocessed thermal emission from disk
and/or donor star emission and/or jet emission
IR through radio: often from jet
Radio should be furthest up the jet



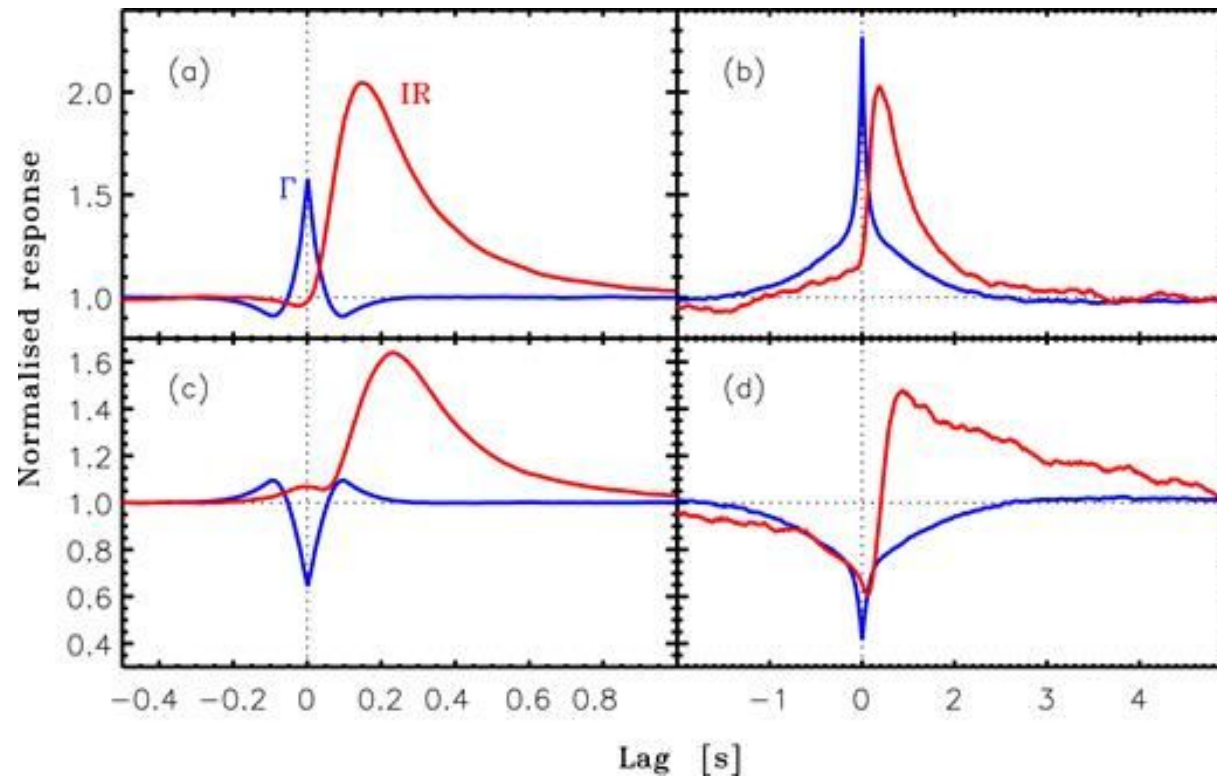
Variability studies: infrared



From Casella, TJM, et al., 2010



Internal shocks can explain things



Response of Lorentz factor and IR flux to changes in X-ray flux, from Malzac et al. 2018

Assumes $(\Gamma - 1) \propto L_X$



Bands most obviously from the jet

Further up the jet, timescales should be longer

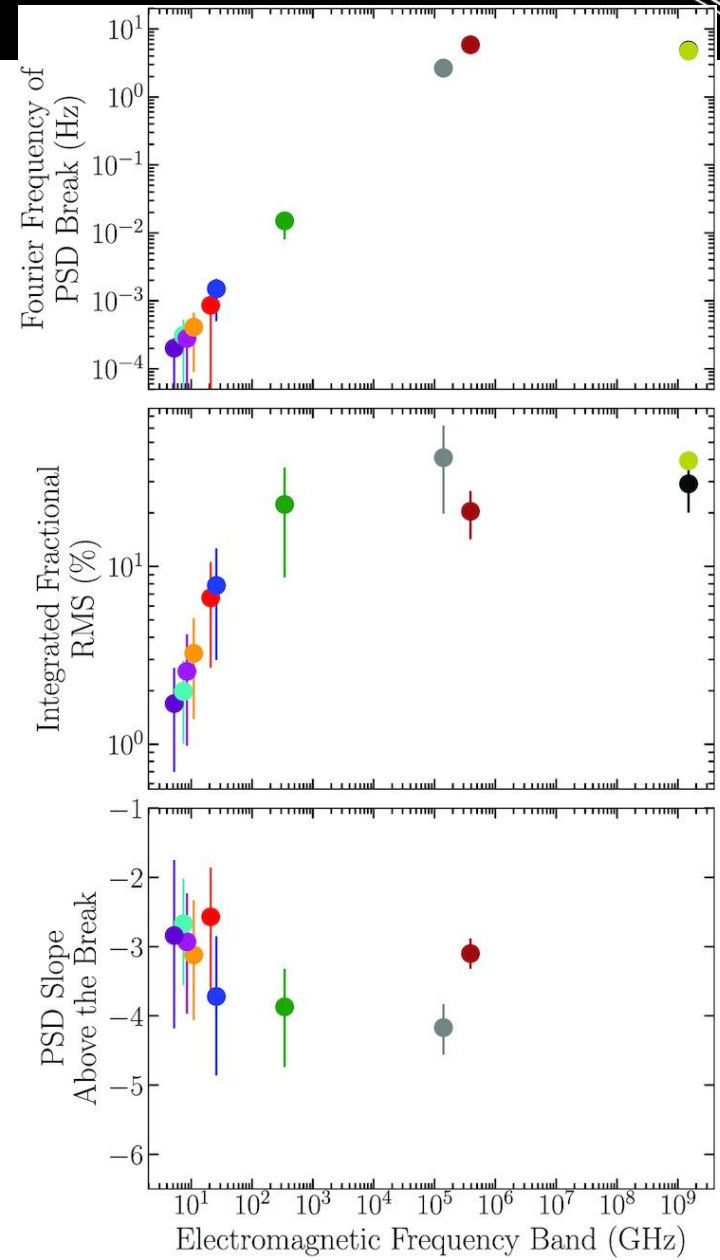
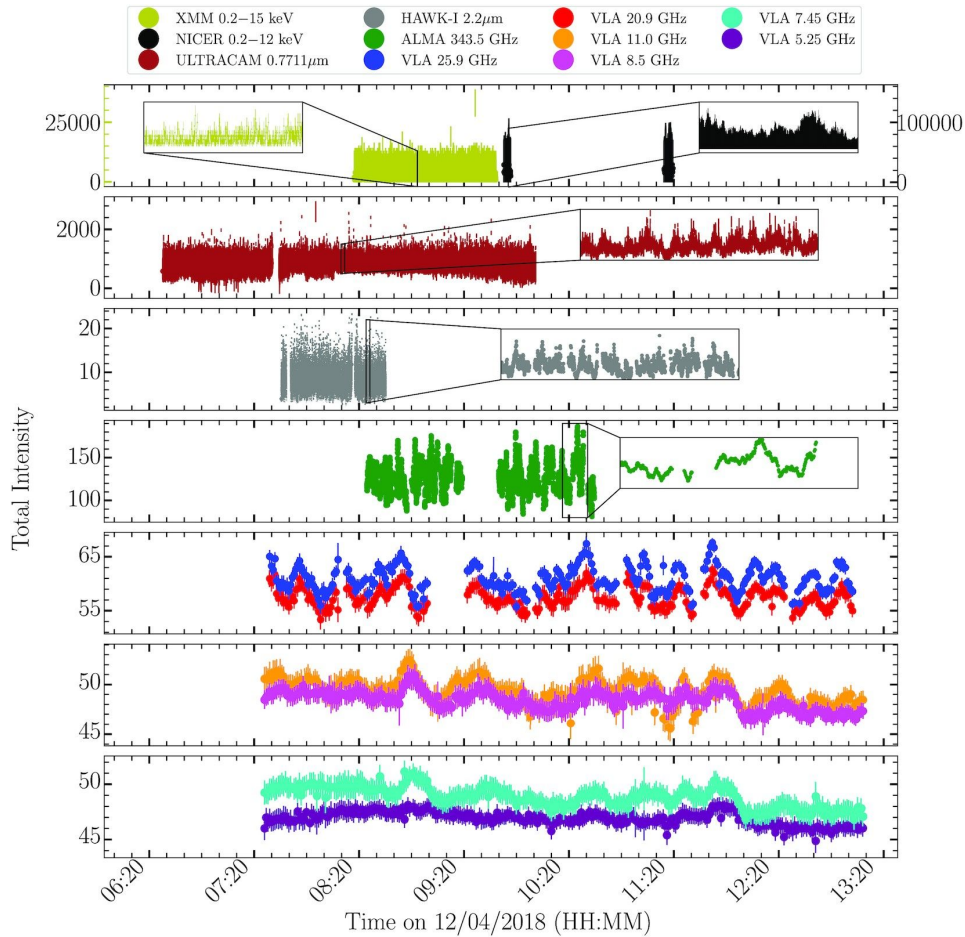
Getting lags at many frequencies can probe jet acceleration!

A failed attempt about 15 years ago





MAXI J1820+070 in radio and submm



Tetarenko et al. 2021



Some conclusions from this work

Jet base spatial scales typically at ~ 0.1 seconds lag

Jet Lorentz factors $< \sim 7$ for hard states, but some model dependence remains

Hard to have proton-dominated jets

(e.g. Casella et al. 2010; Tetarenko et al. 2019,2021, Zdziarski, Tetarenko & Sikora 2022)

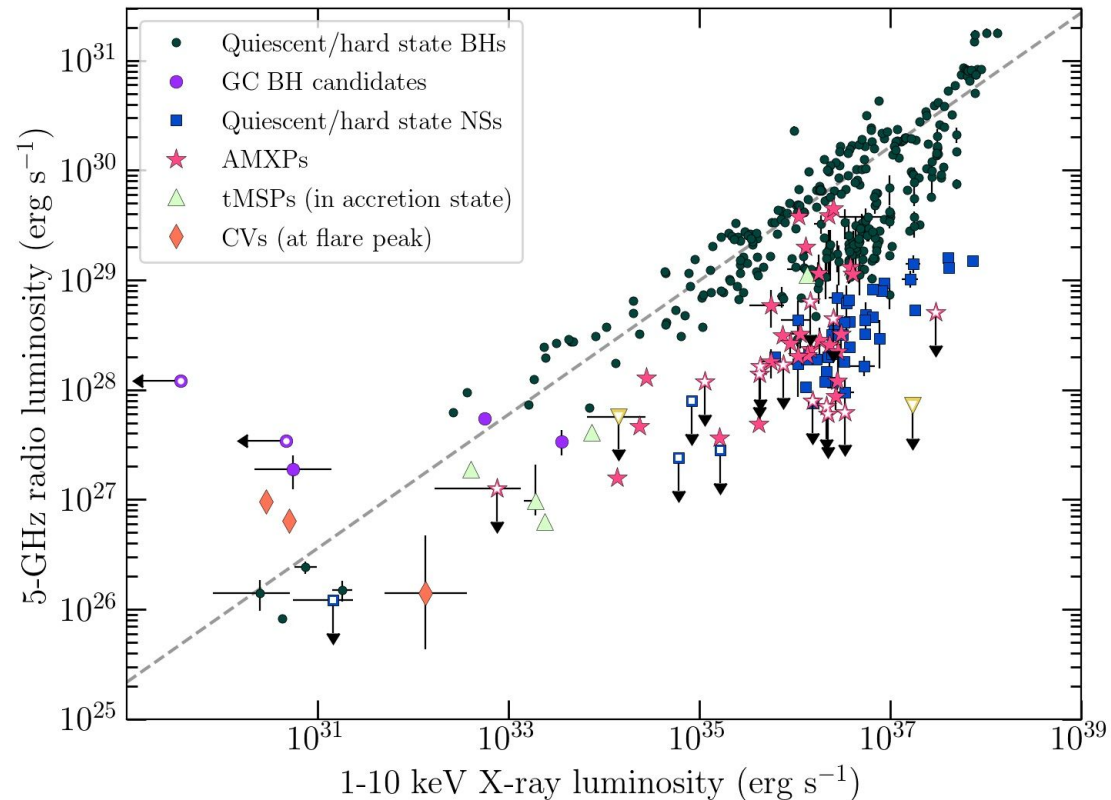
Neutron star jets



Fainter, less well studied

BUT have magnetic fields, and have directly measurable spin periods

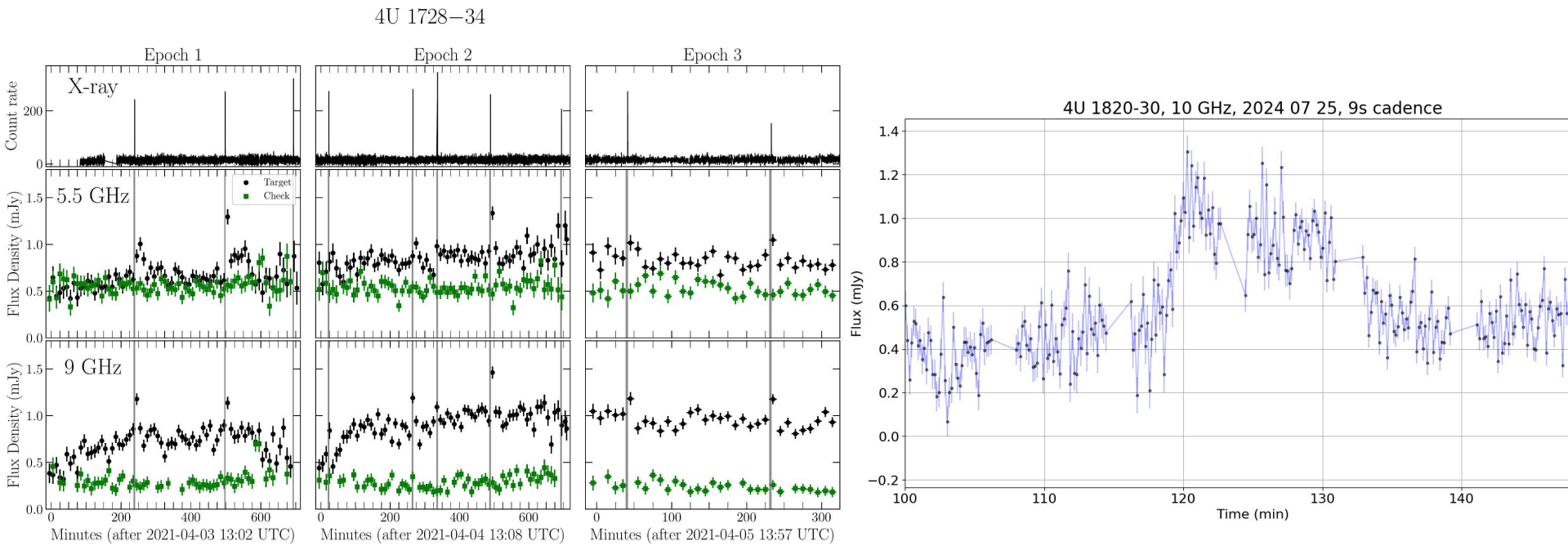
Probably slower, may allow looking at counterjets more easily



From Bahramian et al. 2018



Jets and bursts

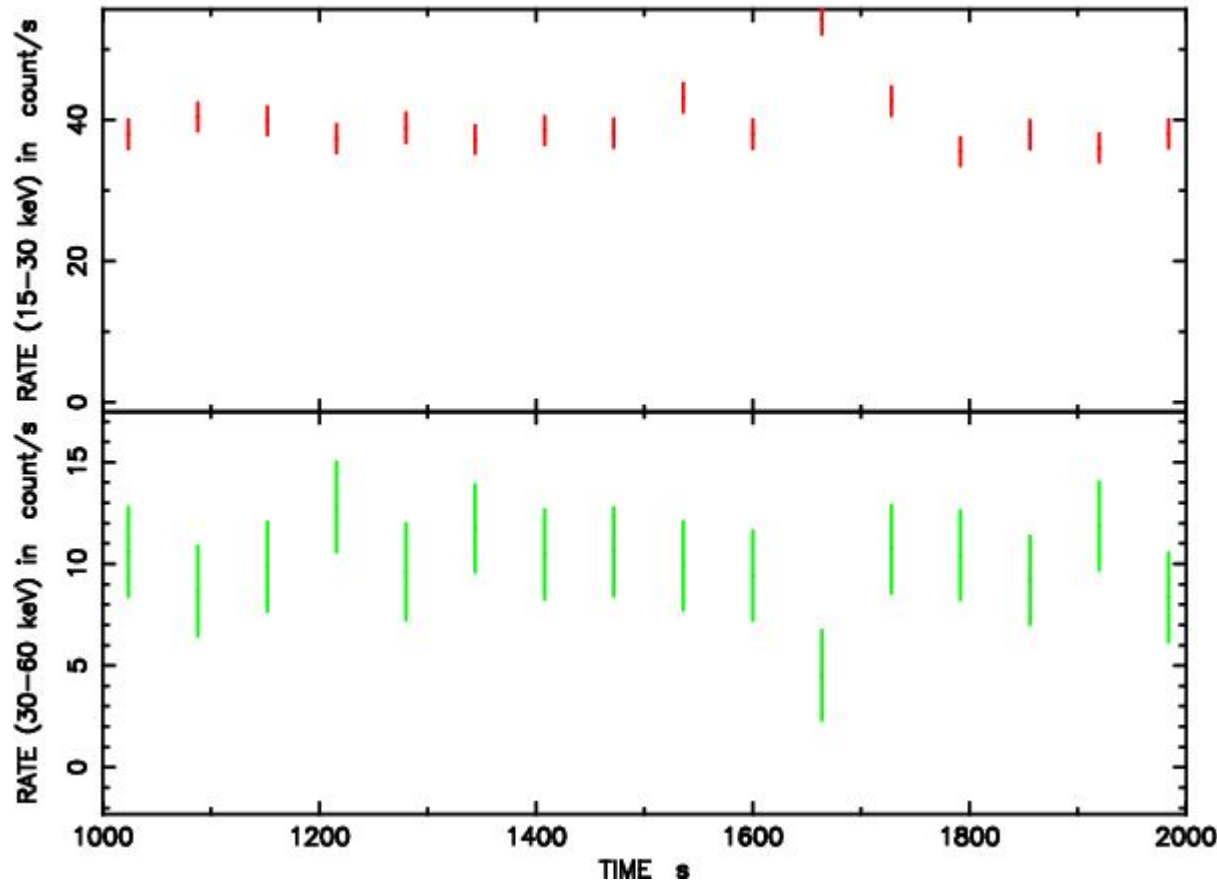


Russell et al. 2024; Pattie et al., in prep



Why this was a surprise

Quenching of Corona During a Type I Burst



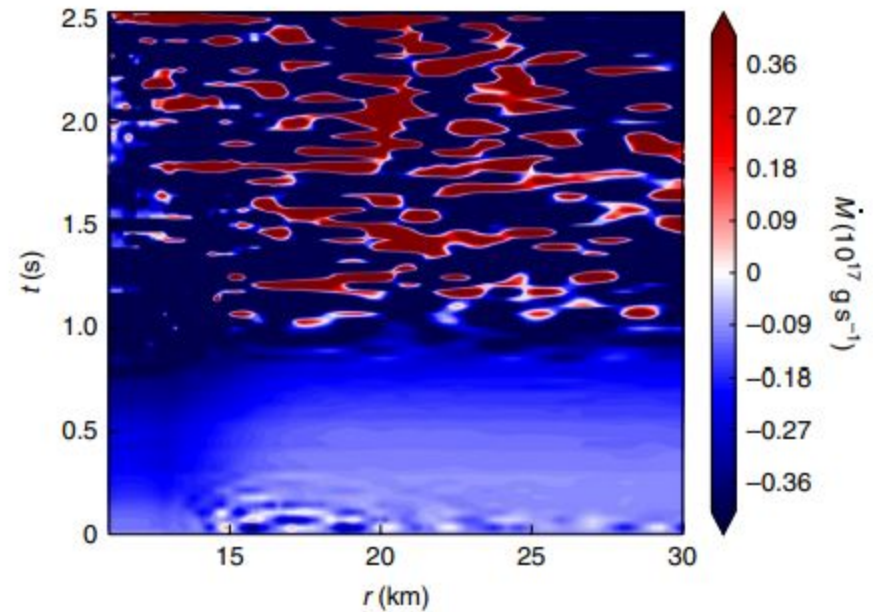
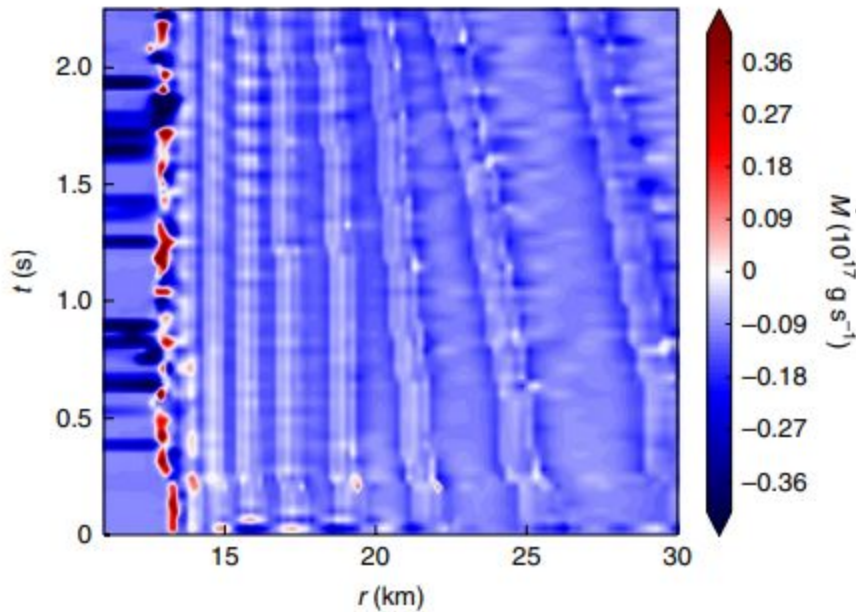
Hard X-rays
turn off in
bursts

Photons cool
the corona

Maccarone & Coppi 2003



Poynting-Robertson drag?



Fragile, Ballantyne & Blankenship (2020)



Jets are an important and ubiquitous phenomenon in nature

Variability is needed to understand them

Jet bursts open up a fundamental puzzle for GRMHD work