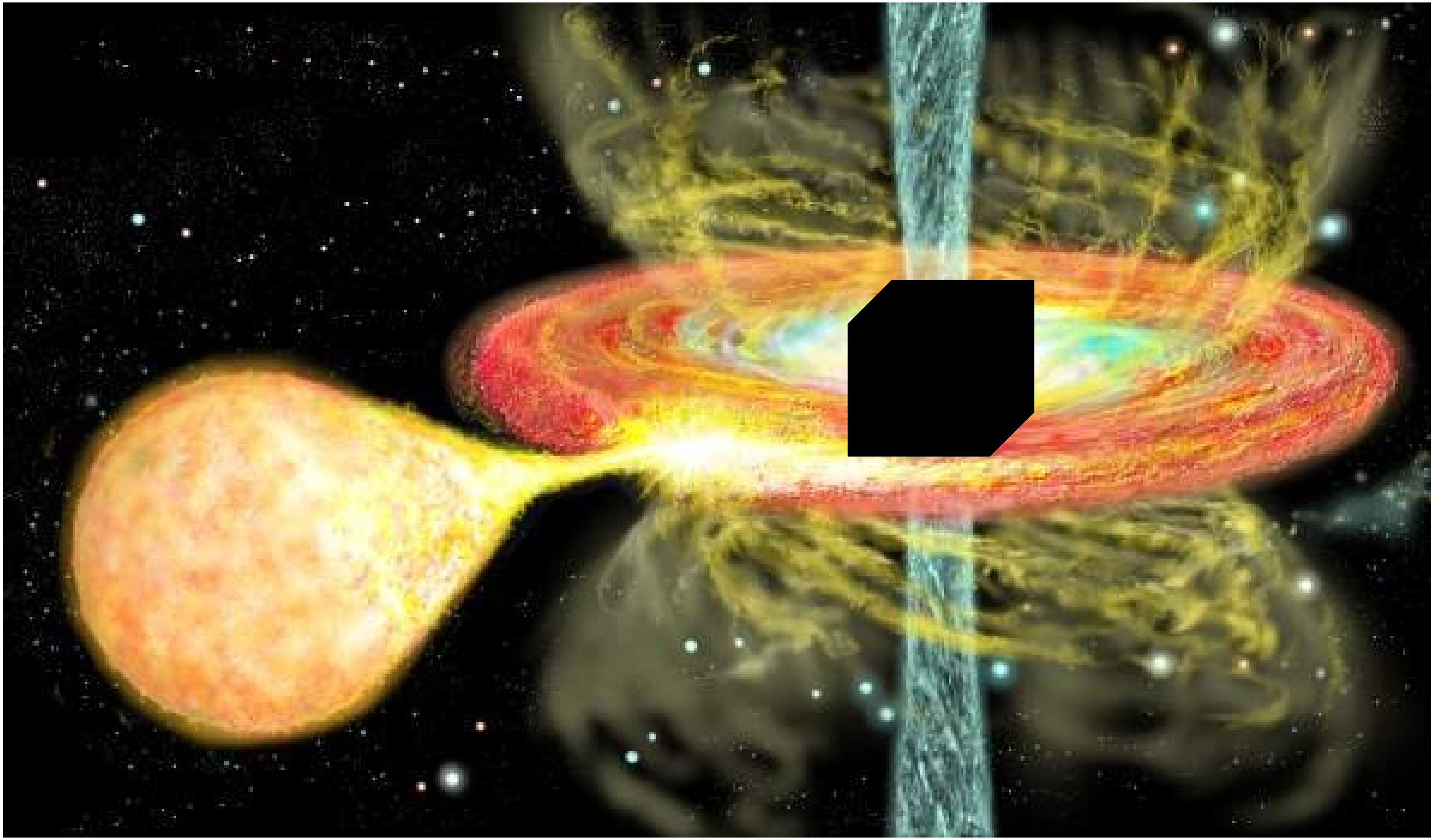
Jet Launching in X-ray binaries

Rob Fender (Southampton)

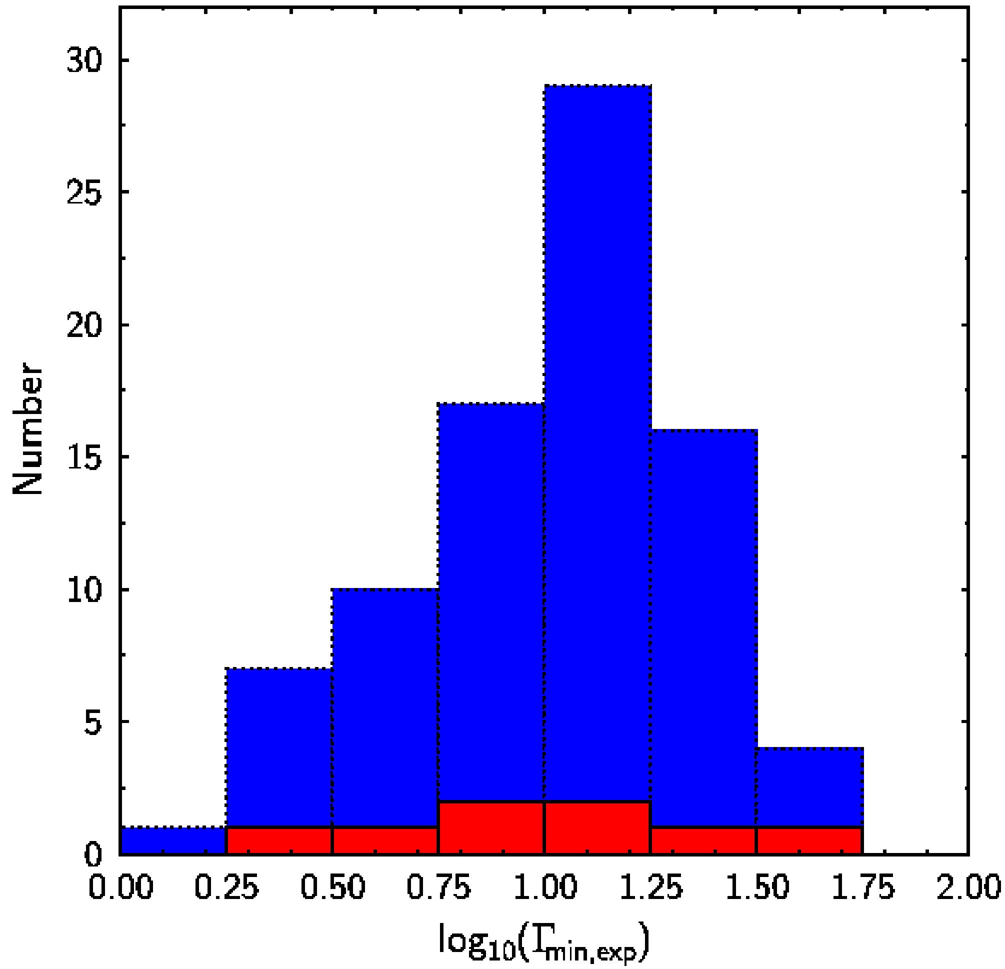
What we don’t know at all

- How the jets are formed



What we don't know very well

- How fast the jets are



The jets *may* be just as relativistic as those from AGN

XRB

AGN (Jorstad)

Miller-Jones, Fender & Nakar

What we do know (approximately)

- When the jets are formed – in particular the relation to X-ray ‘state’ (spectrum + timing properties)
- The associated power and its relation to accretion rate
- … and that we can compare them directly to AGN

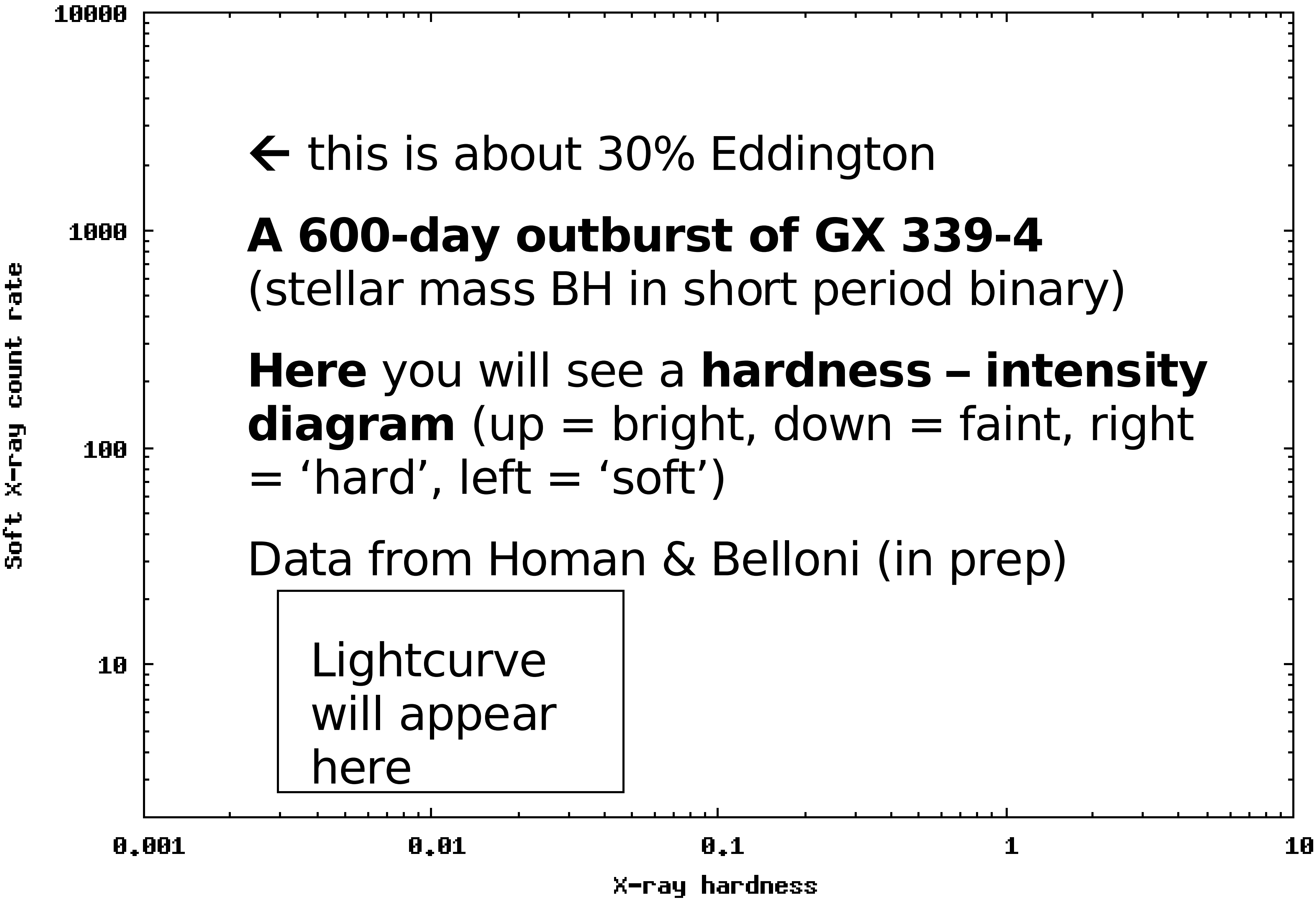
← this is about 30% Eddington

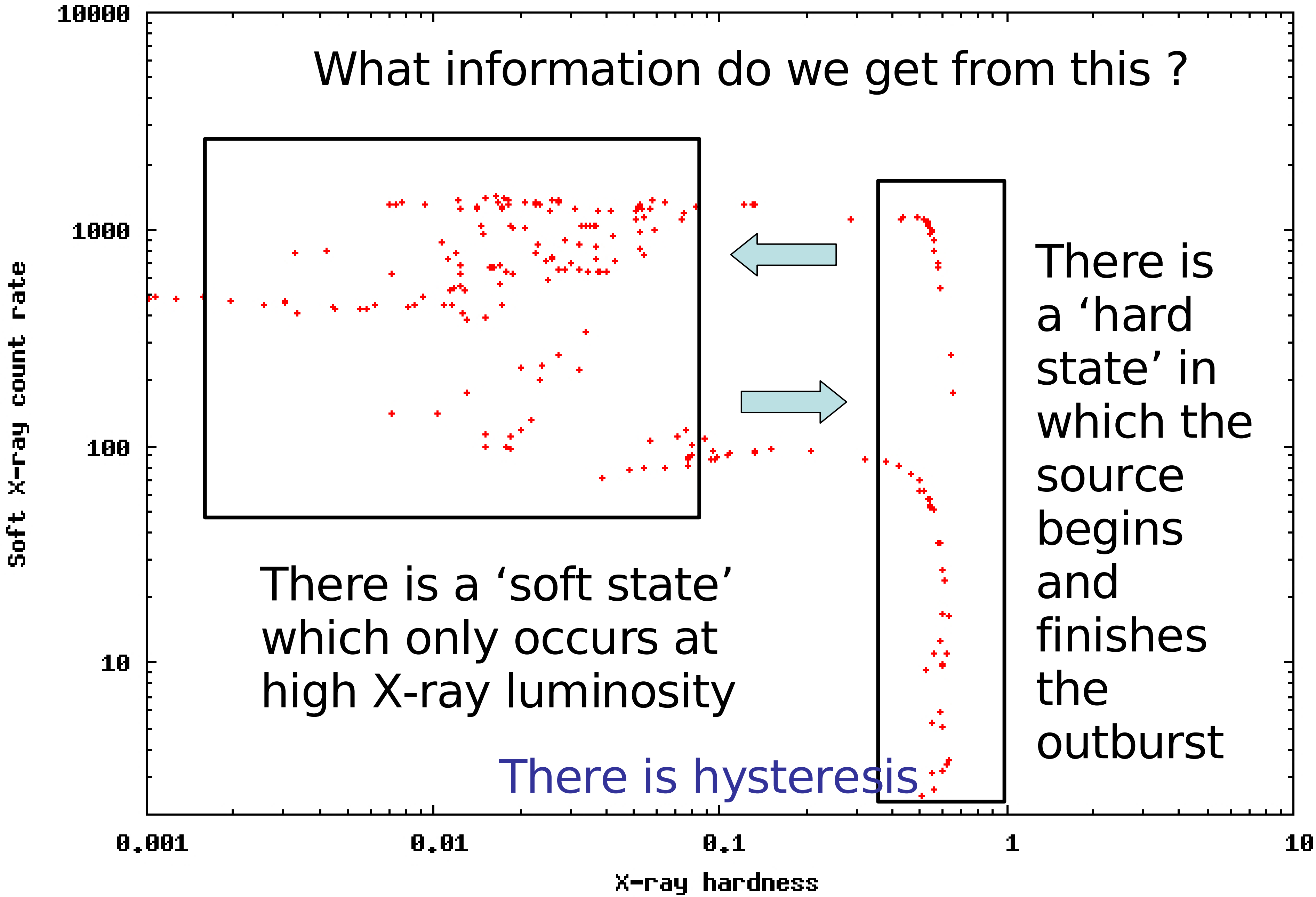
A 600-day outburst of GX 339-4
(stellar mass BH in short period binary)

Here you will see a **hardness – intensity diagram** (up = bright, down = faint, right = ‘hard’, left = ‘soft’)

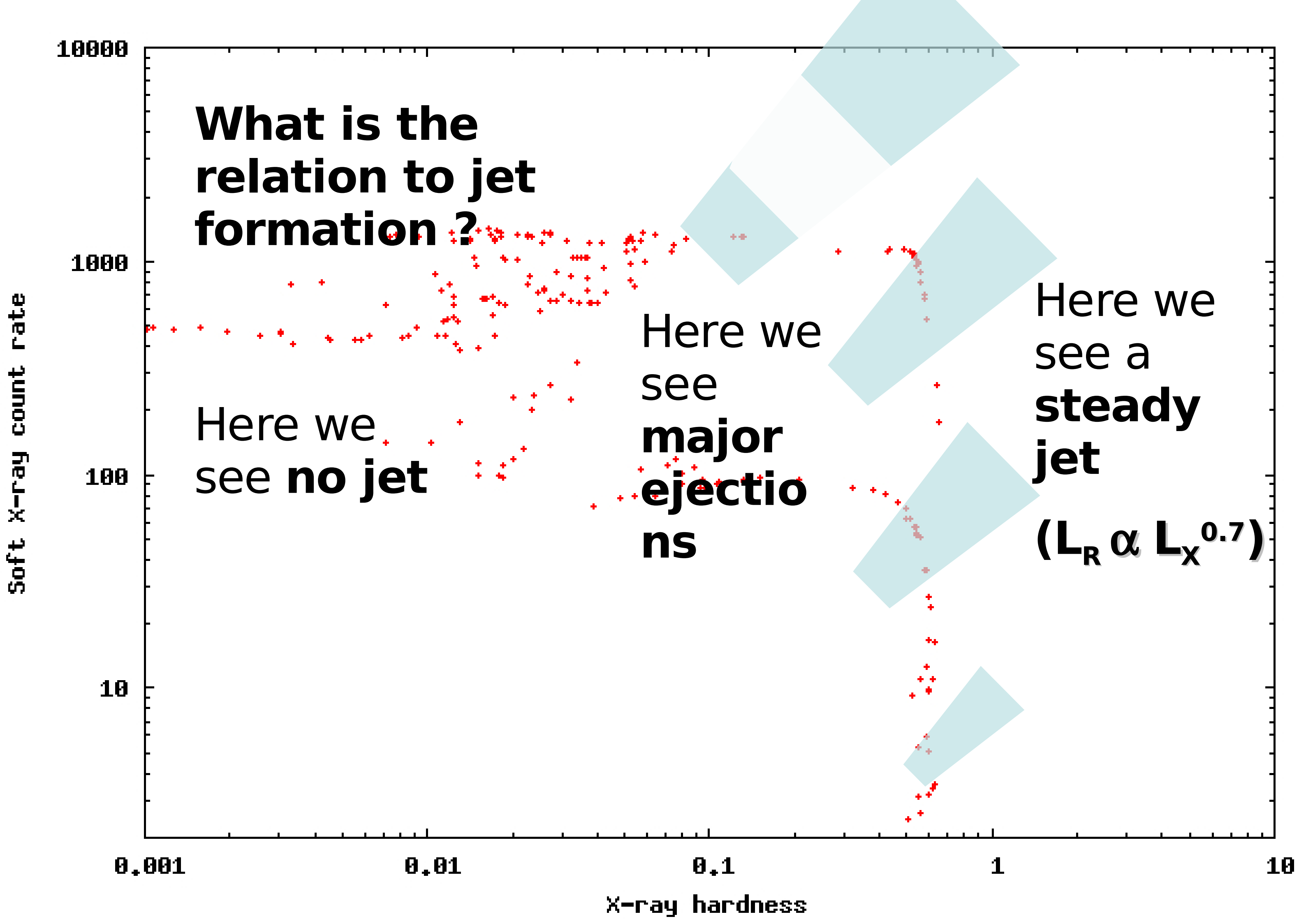
Data from Homan & Belloni (in prep)

Lightcurve will appear here



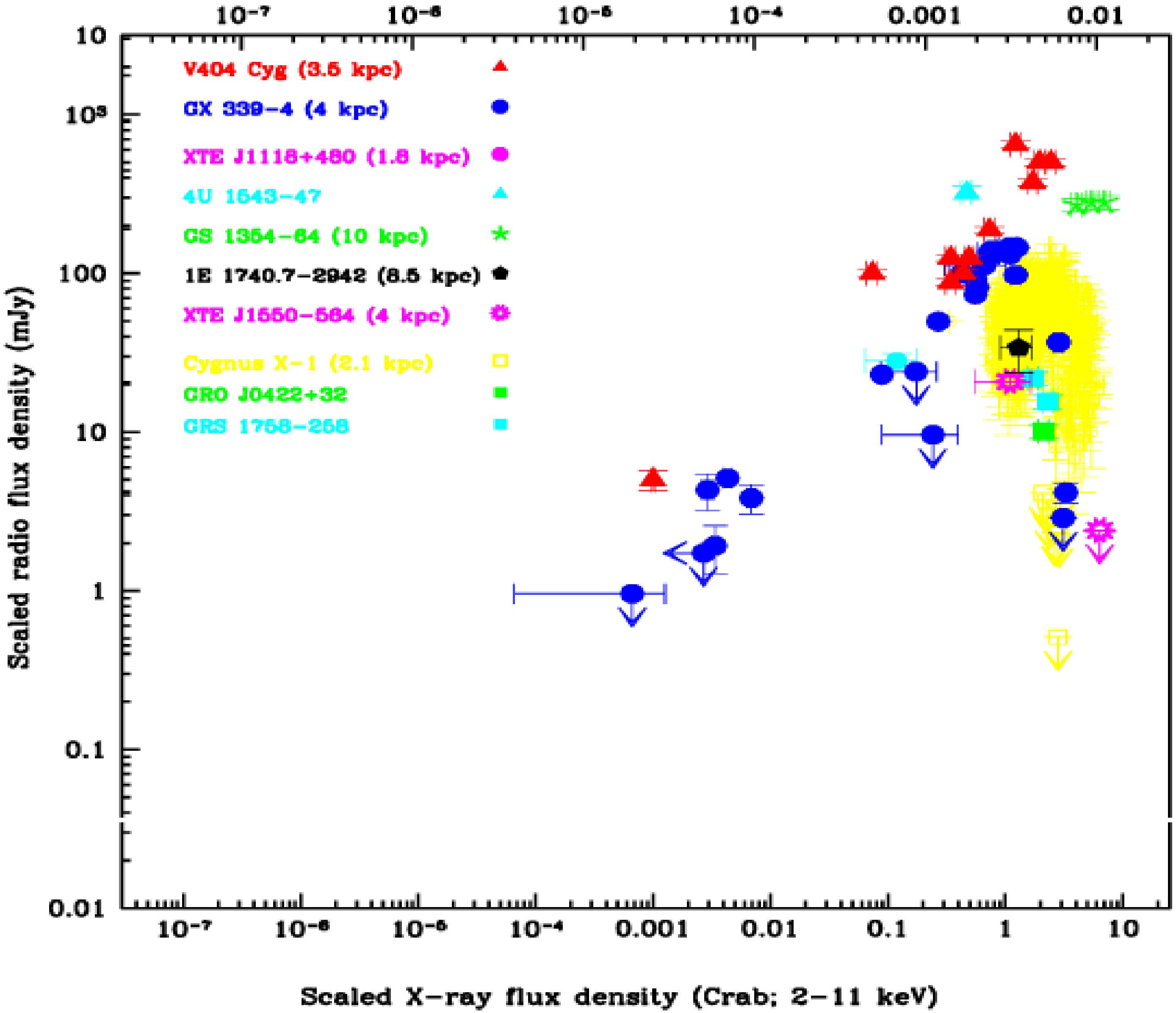


What information do we get from this ?
There is a 'soft state' which only occurs at high X-ray luminosity
There is a 'hard state' in which the source begins and finishes the outburst
There is hysteresis
10000
1000
100
10
Soft X-ray count rate
0.001
0.01
0.1
1
10
X-ray hardness



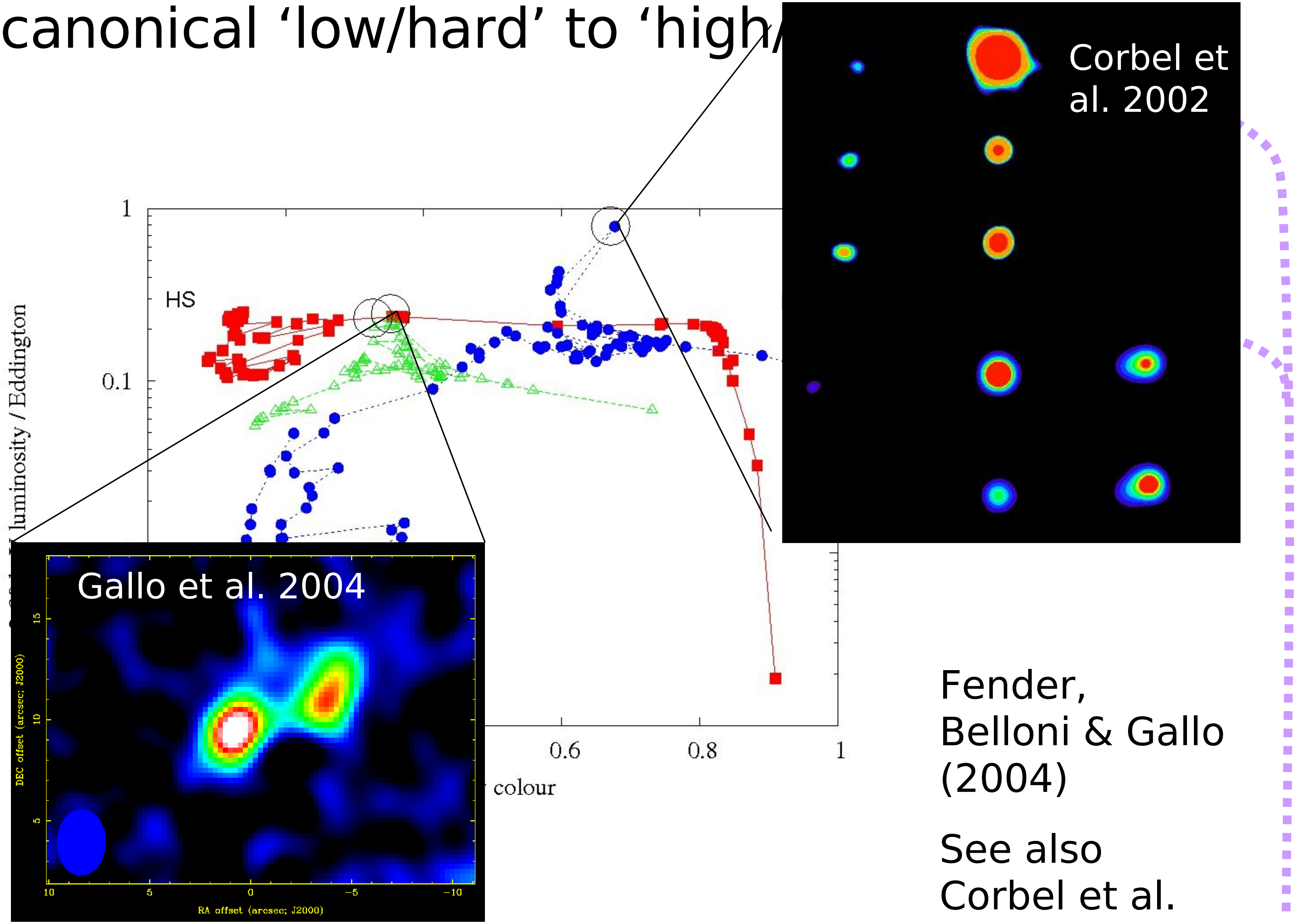
What is the relation to jet formation ?
Here we see no jet
Here we see major ejections
Here we see a steady jet
($L_R \propto L_X^{0.7}$)
Soft X-ray count rate
X-ray hardness
10000
1000
100
10
0.001
0.01
0.1
1
10

Hard state: $L_{radio} \propto L_X^{0.7}$



Gallo, Fender & Pooley (2003) Gallo, Fender et al. (2006)

Powerful jets produced in **transition** from canonical ‘low/hard’ to ‘high/

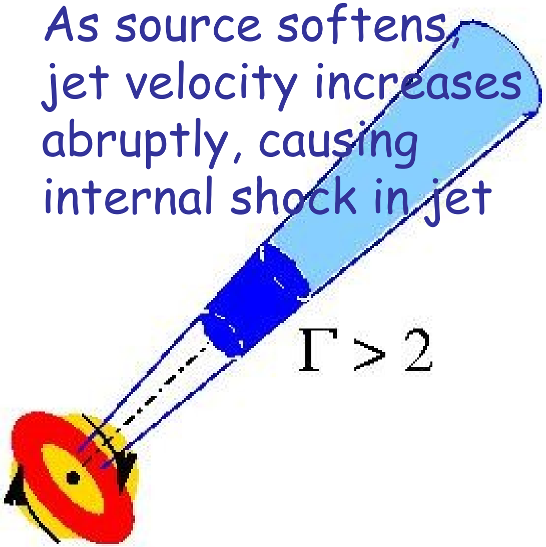


Fender, Belloni & Gallo (2004)

See also Corbel et al. (2004);

Towards a unified model…

As source softens, jet velocity increases abruptly, causing internal shock in jet



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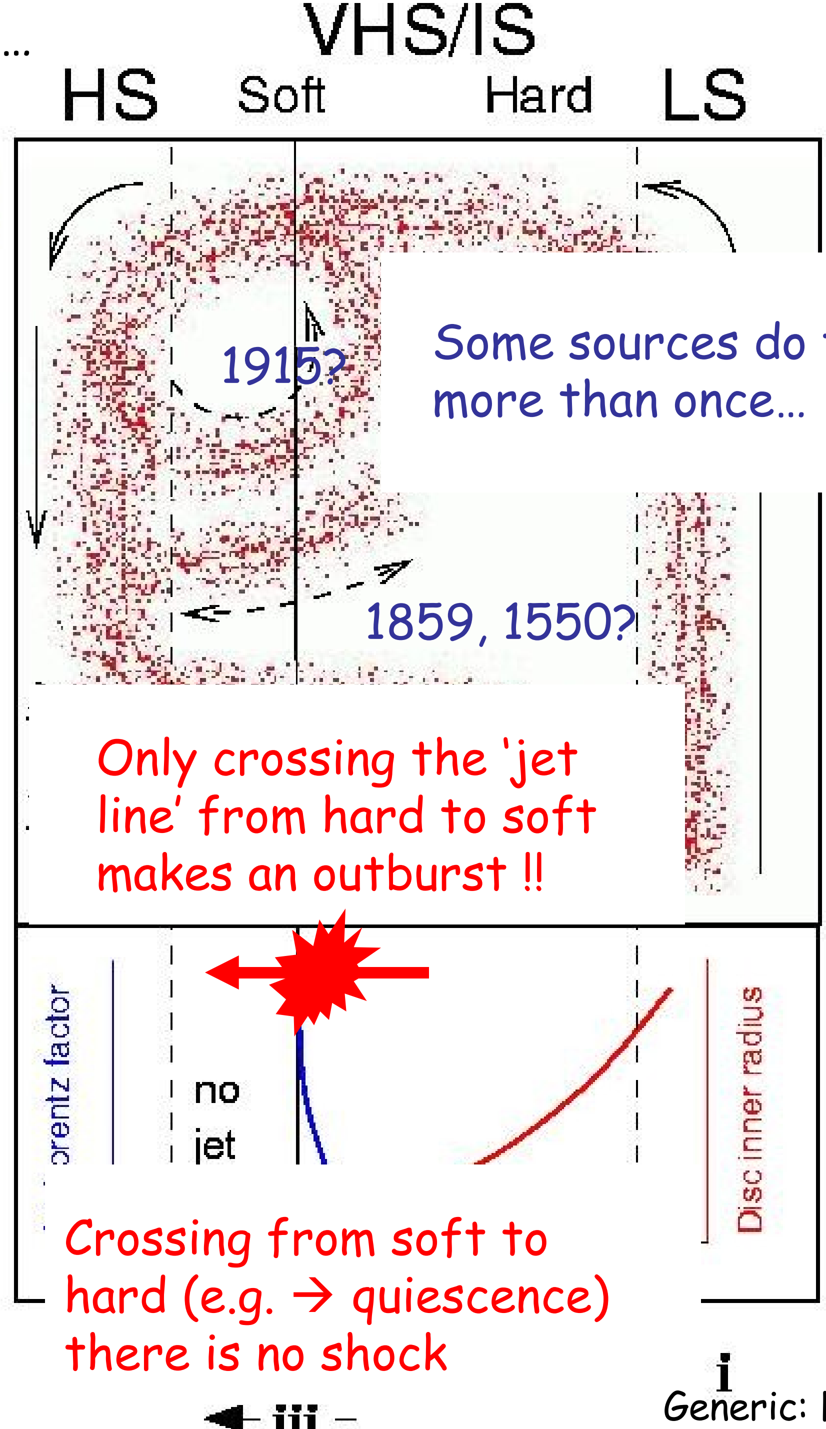
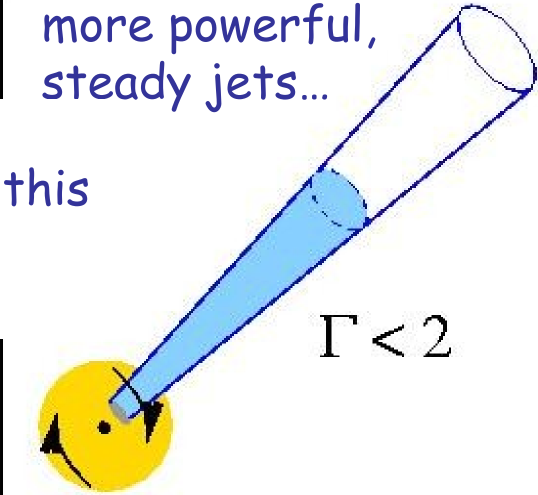


Some sources do this more than once…

Only crossing the 'jet line' from hard to soft makes an outburst !!

Crossing from soft to hard (e.g. → quiescence) there is no shock

More powerful, hard sources have more powerful, steady jets…



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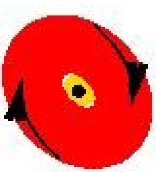
Subsequently, soft states show no jet



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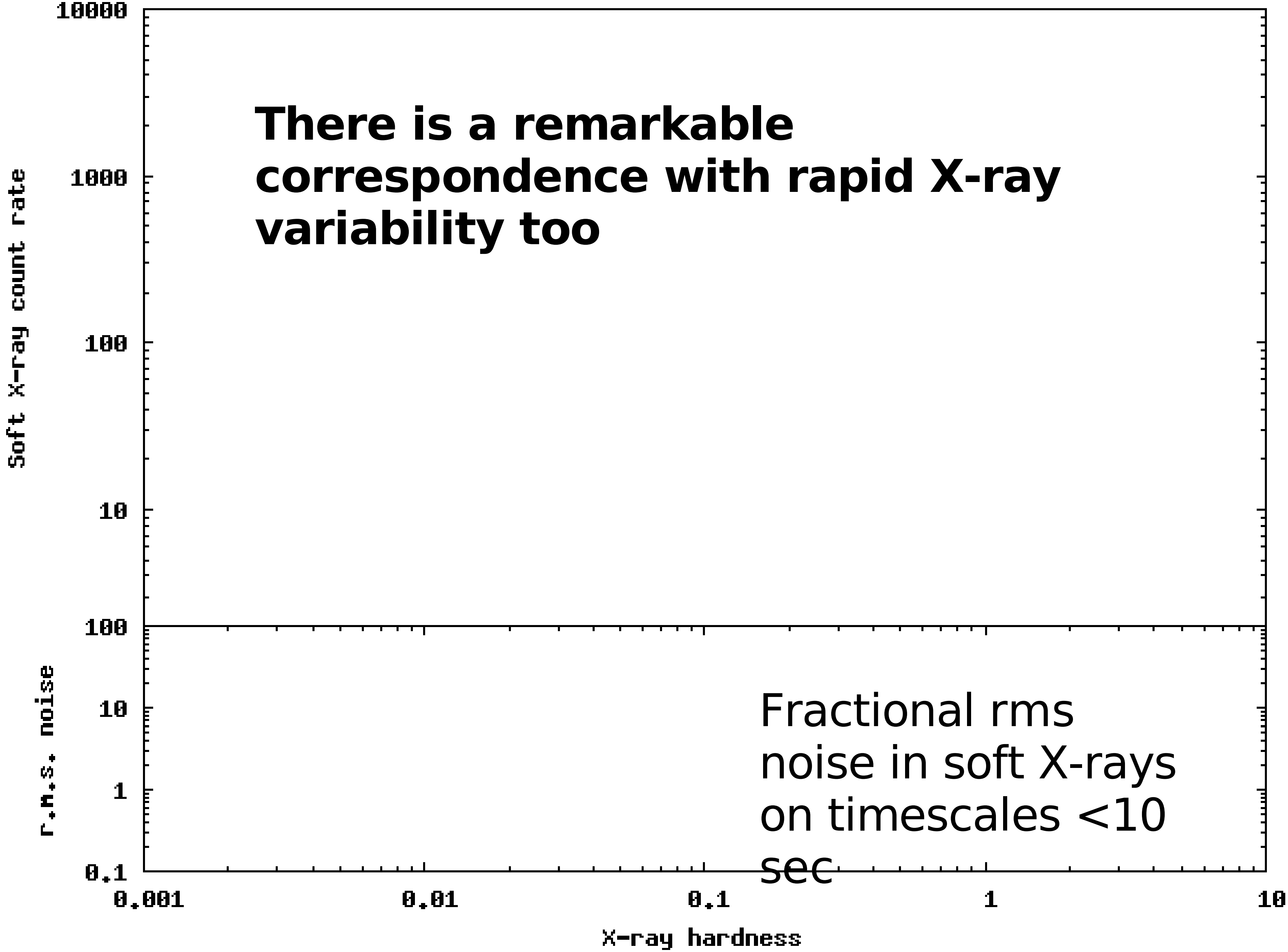
Faint, hard source have steady, Γ~1 jets

1915: Fender & Belloni (2004)

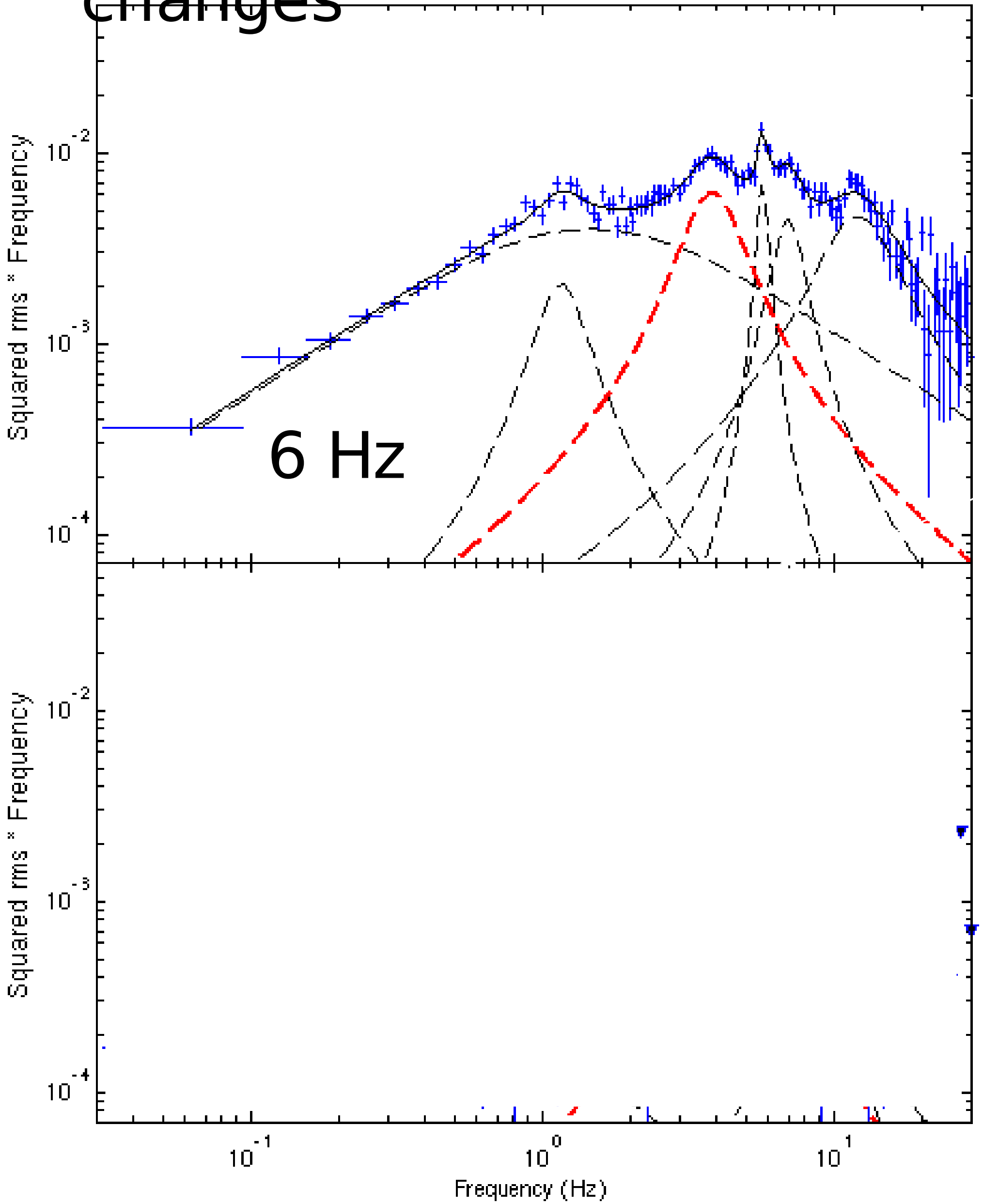
Generic: Fender, Belloni & Gallo (2004)

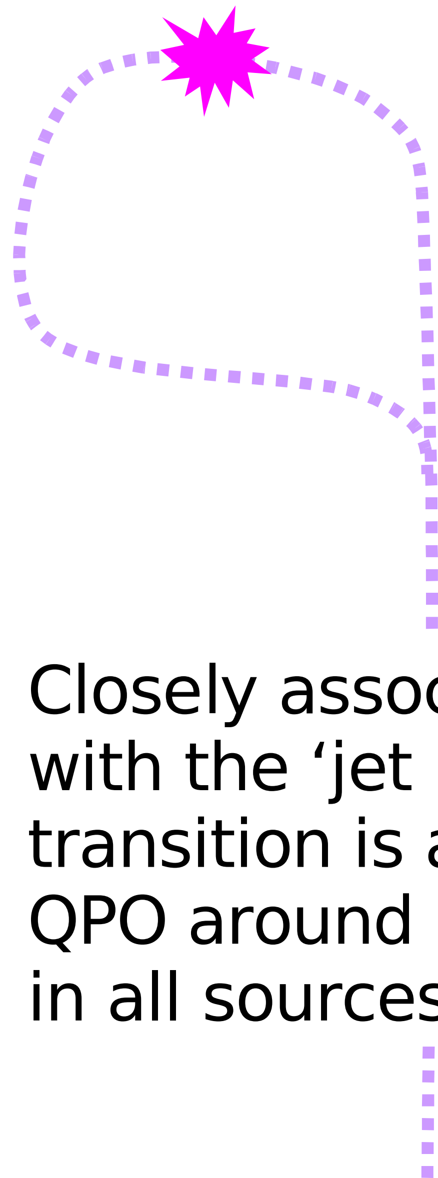
There is a remarkable correspondence with rapid X-ray variability too



Fractional rms noise in soft X-rays on timescales <10 sec

Belloni et al. (2006): not only r.m.s. but shape of PDS changes

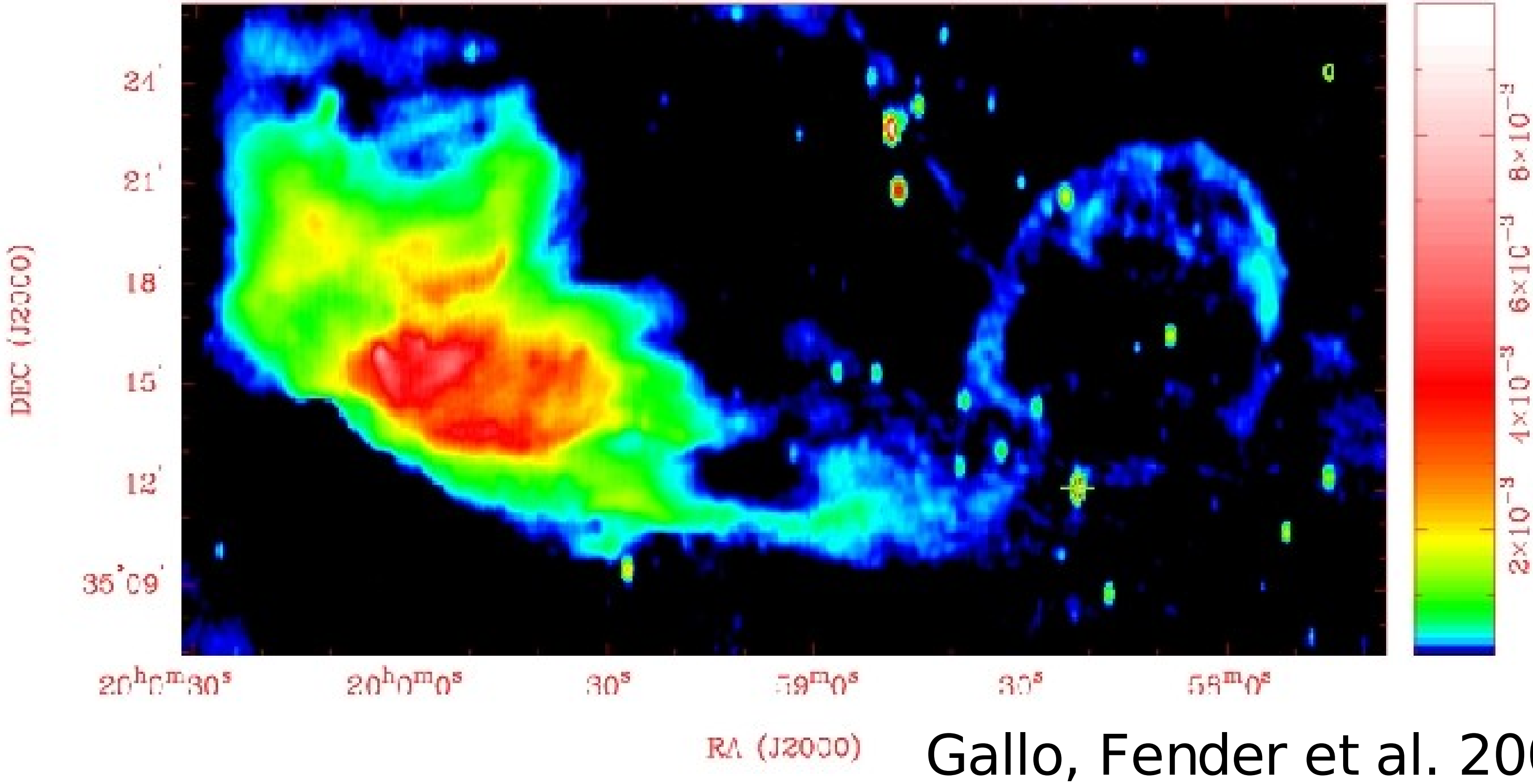




Closely associated with the ‘jet line’ transition is a strong QPO around 5-6 Hz in all sources …

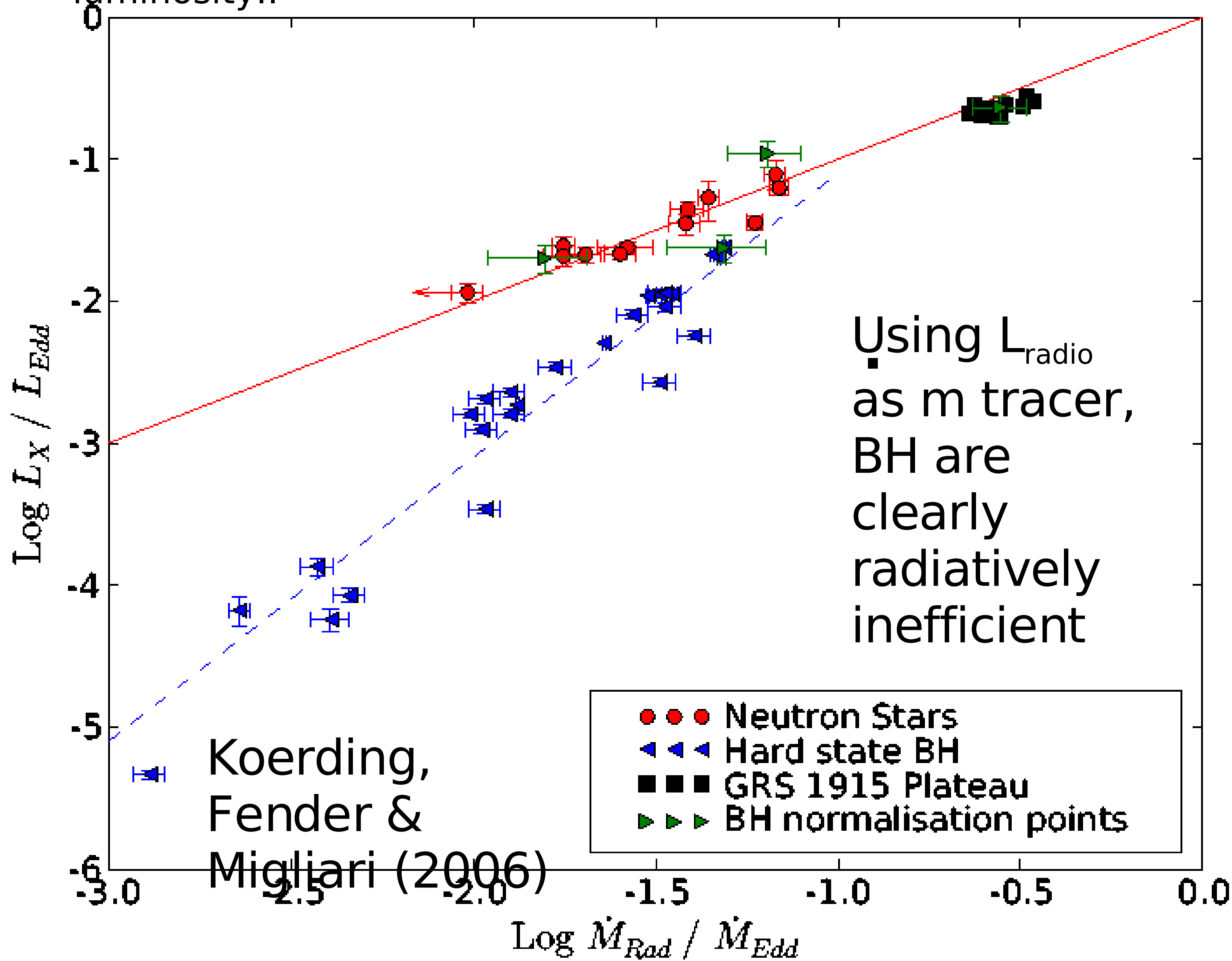
How do we estimate the power ?

$E_{min} > 10^{48}$ erg



Gallo, Fender et al. 2005

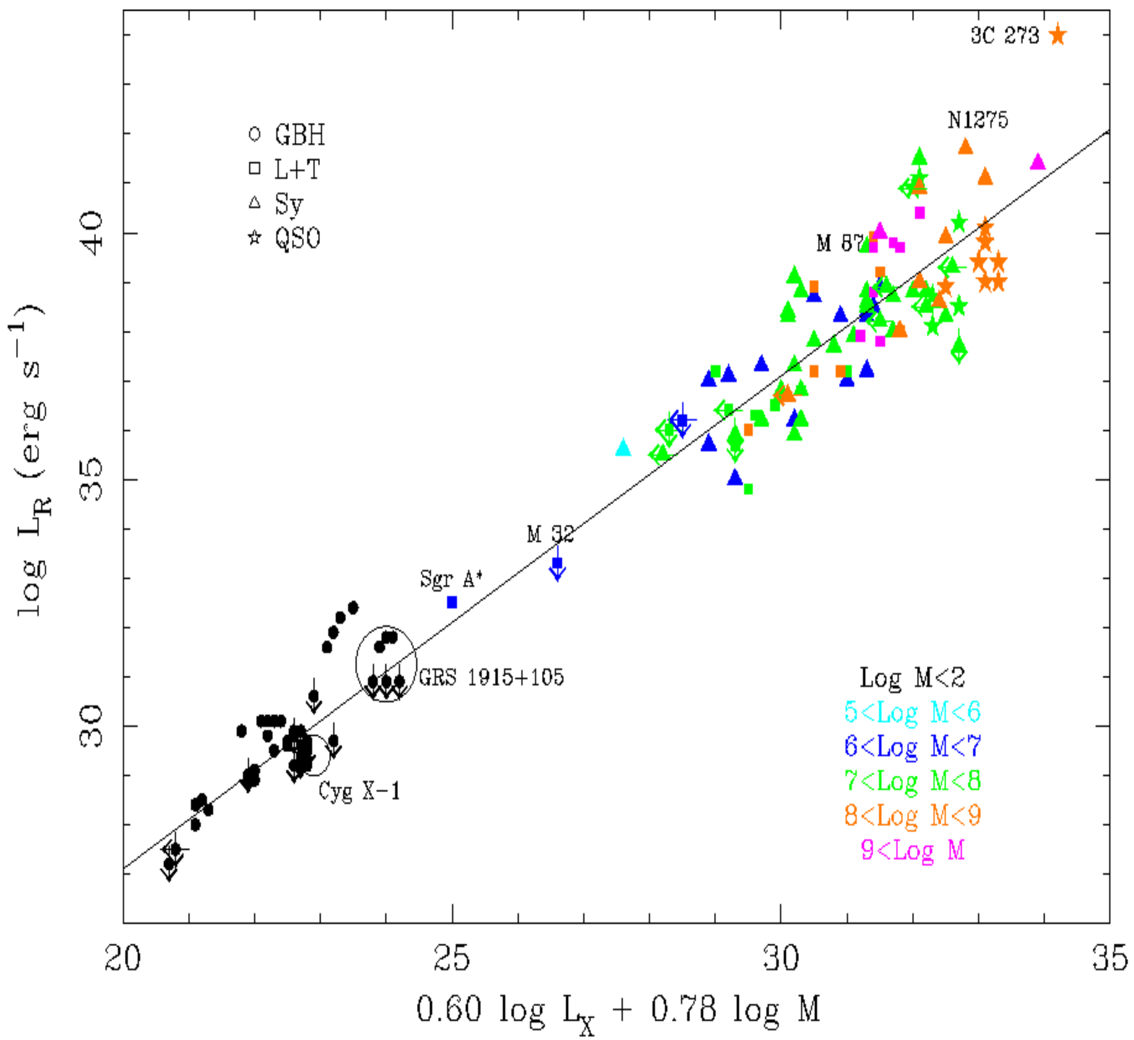
We can calibrate the relation between accretion rate and radio luminosity..



Using L_{radio} as $\dot{m}$ tracer, BH are clearly radiatively inefficient

Koerding, Fender & Migliari (2006)

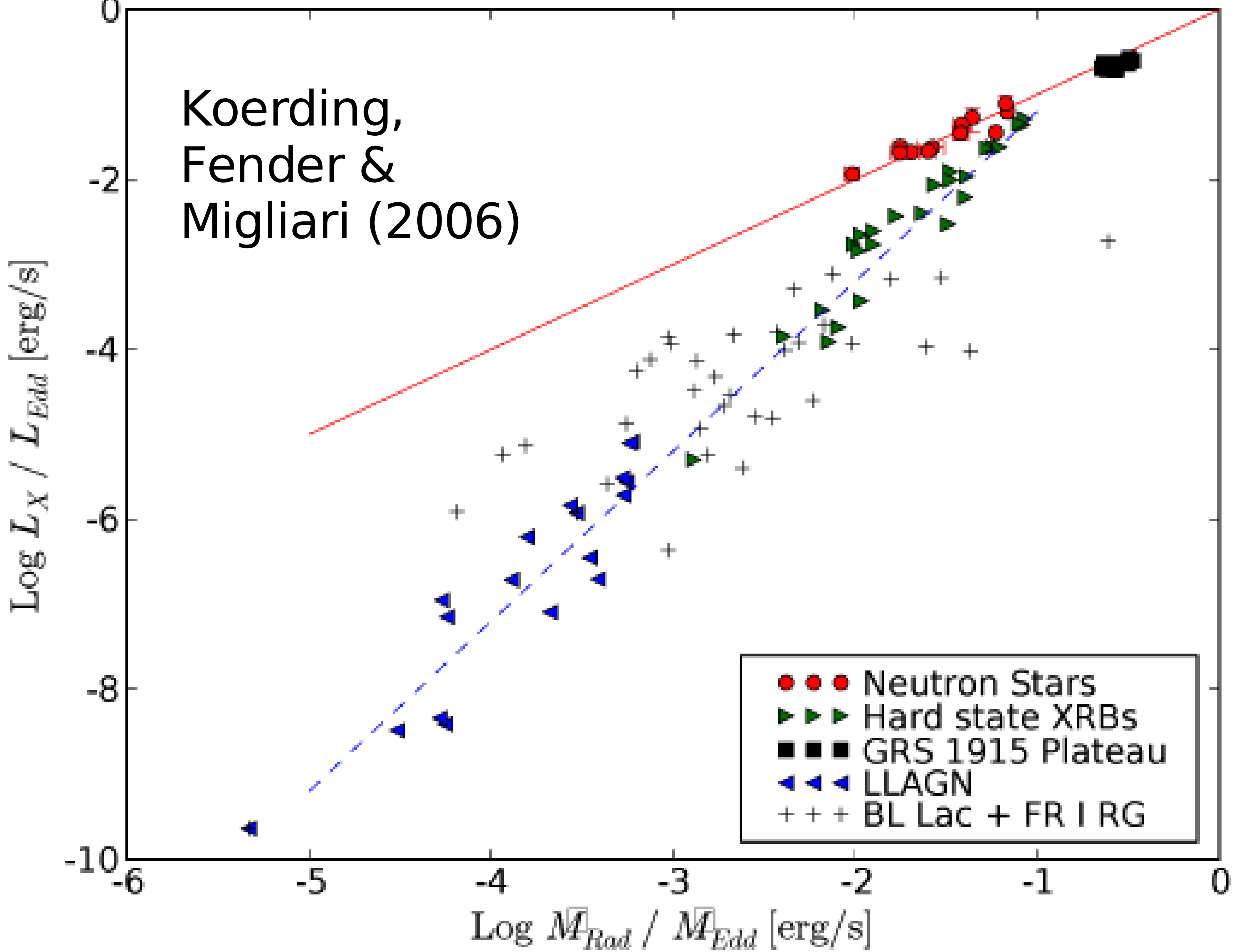
Comparison to AGN



Quantitative scaling of X-ray binaries to AGN is now a reality

Merloni, Heinz & di Matteo (2003), Falcke, Koerding & Markoff (2004)

ALL low-luminosity black holes – including AG

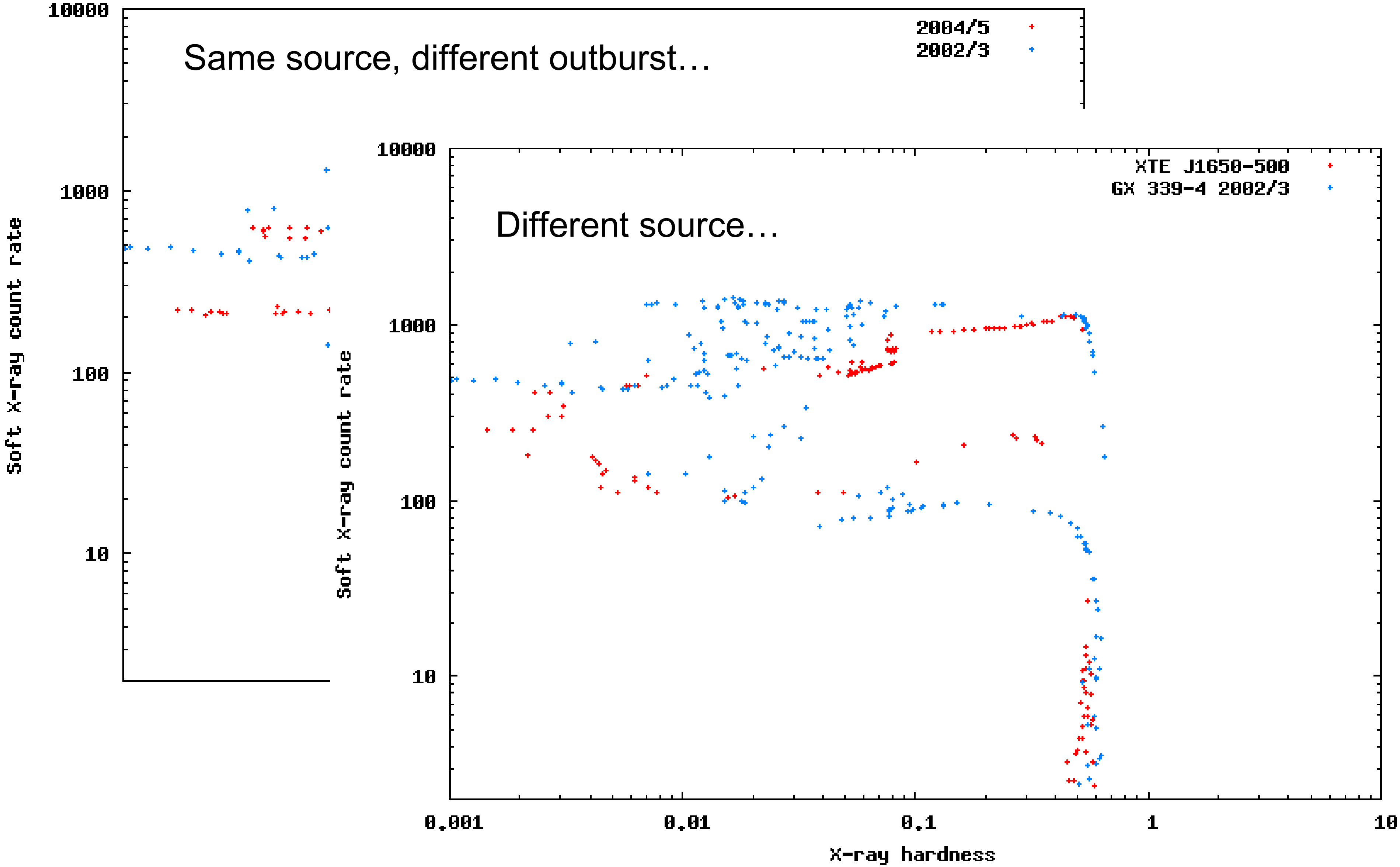


Following this approach, we can establish (=we would claim) that all hard state BH (<2% Edd), whether XRB or AGN are jet-dominated advective systems in which:

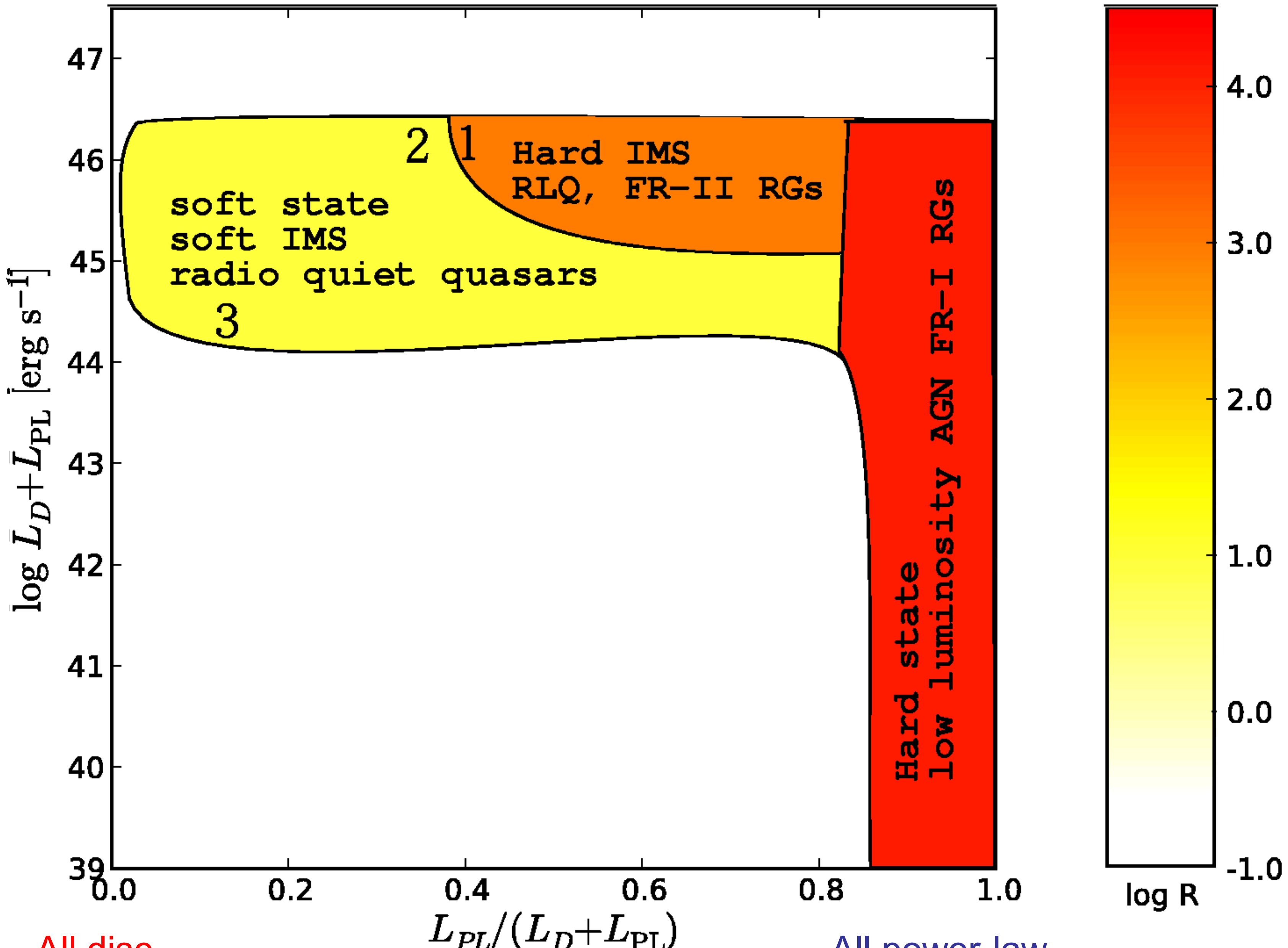
$$\mathbf{P_{jet} > L_X} \quad \text{and} \quad \mathbf{Q_{ADAF} \sim P_{jet}}$$

Furthermore, we can infer that the transition from radiatively efficient to inefficient accretion occurs at about the same Eddington ratio in all black holes

What would an ensemble of X-ray binaries look like ... ?



The Disc Fraction Luminosity Diagram(DFLD): Koerding, Jester & Fender (subm.)



All disc

All power-law

Conclusions

- From X-ray binaries we can get a very clear idea of how jet ‘modes’ relate to accretion ‘states’, characterised by spectra and timing properties of the accretion flow
- Based (initially) on X-ray binaries, we can show that in hard states (i.e. <2% Eddington) the power output is dominated by the jet and BH accretion is radiatively inefficient
- Direct comparisons with AGN are now reasonable and are all consistent with scale-free accretion physics