Relativistic jets from evolving accretion discs

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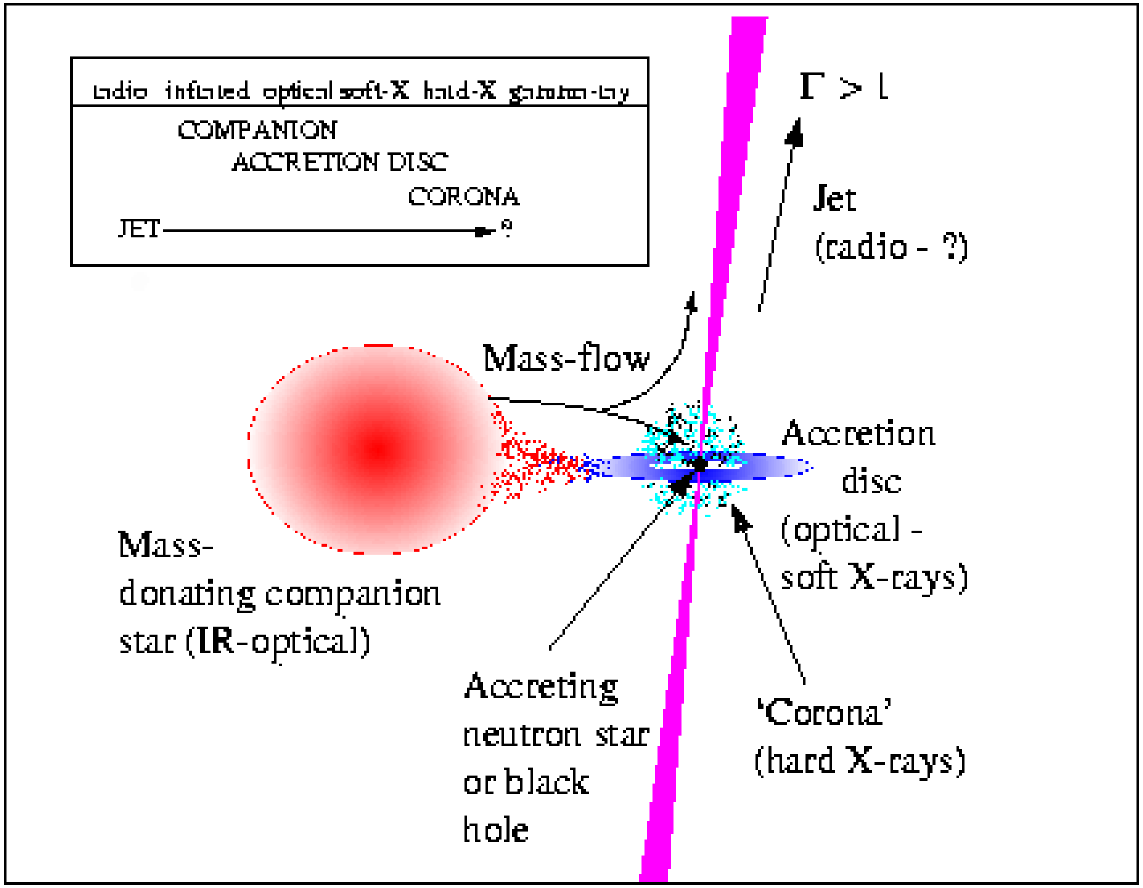
Thanks to:

Elena Gallo, Simone Migliari, Tom Maccarone (Amsterdam)
Tomaso Belloni (Brera), Stephane Corbel (Saclay),
Peter Jonker (CfA), Guy Pooley (MRAO), Ralph Spencer (Jodrell Bank)



Use X-ray binaries to study the inflow:outflow coupling around black holes

Relation to AGN ?

Timescales linearly proportional to mass

(is this really true ?

microphysics ?

environment ?)

The high-energy astrophysics occurs very close to the compact object… which means the companion star is just a distant orbiting fuel tank…

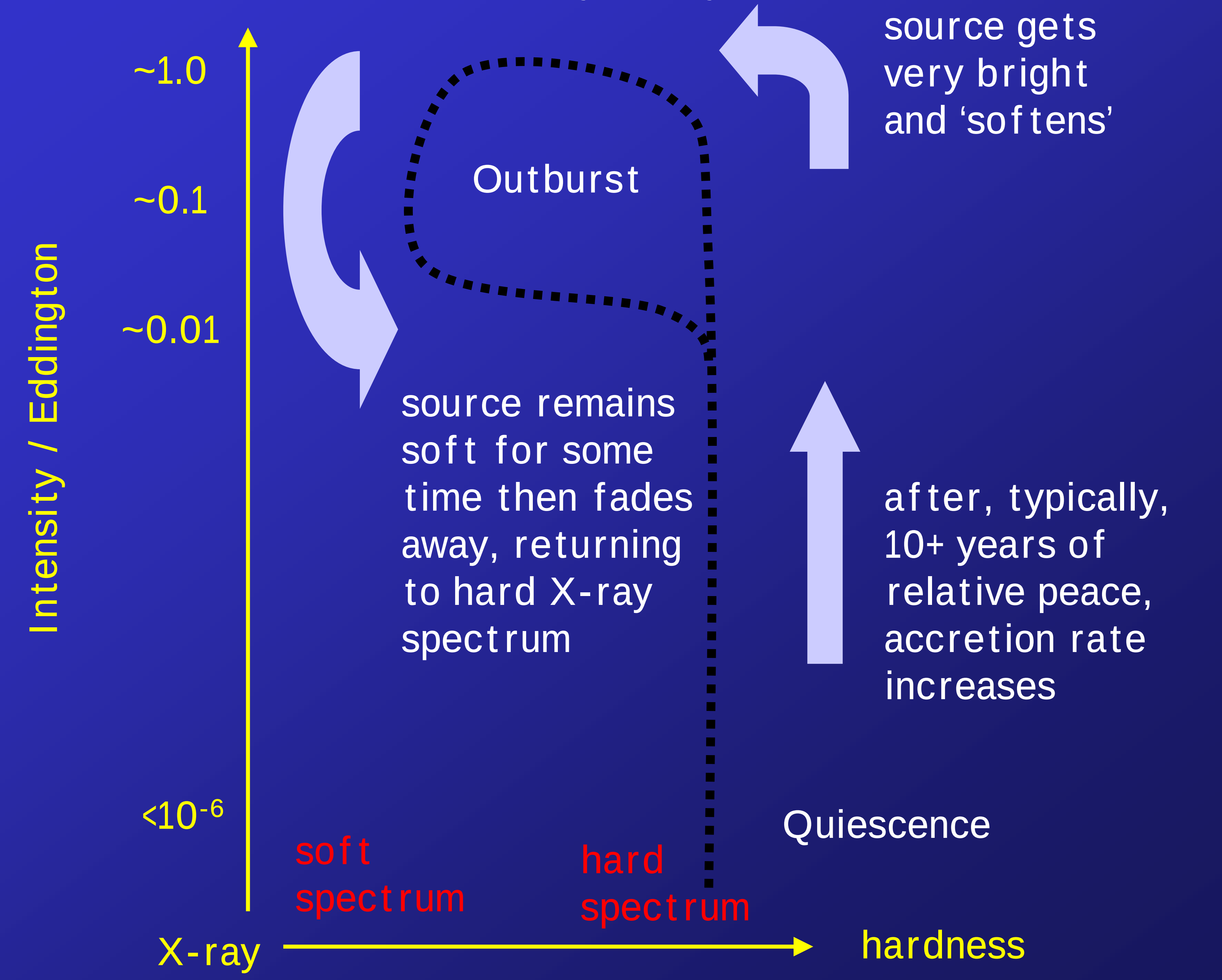
The basics:

1. Hard X-ray states (truncated accretion disc plus strong ‘corona’) make jets

2. Soft X-ray states (‘full’ accretion disc, much weaker corona) do not make jets

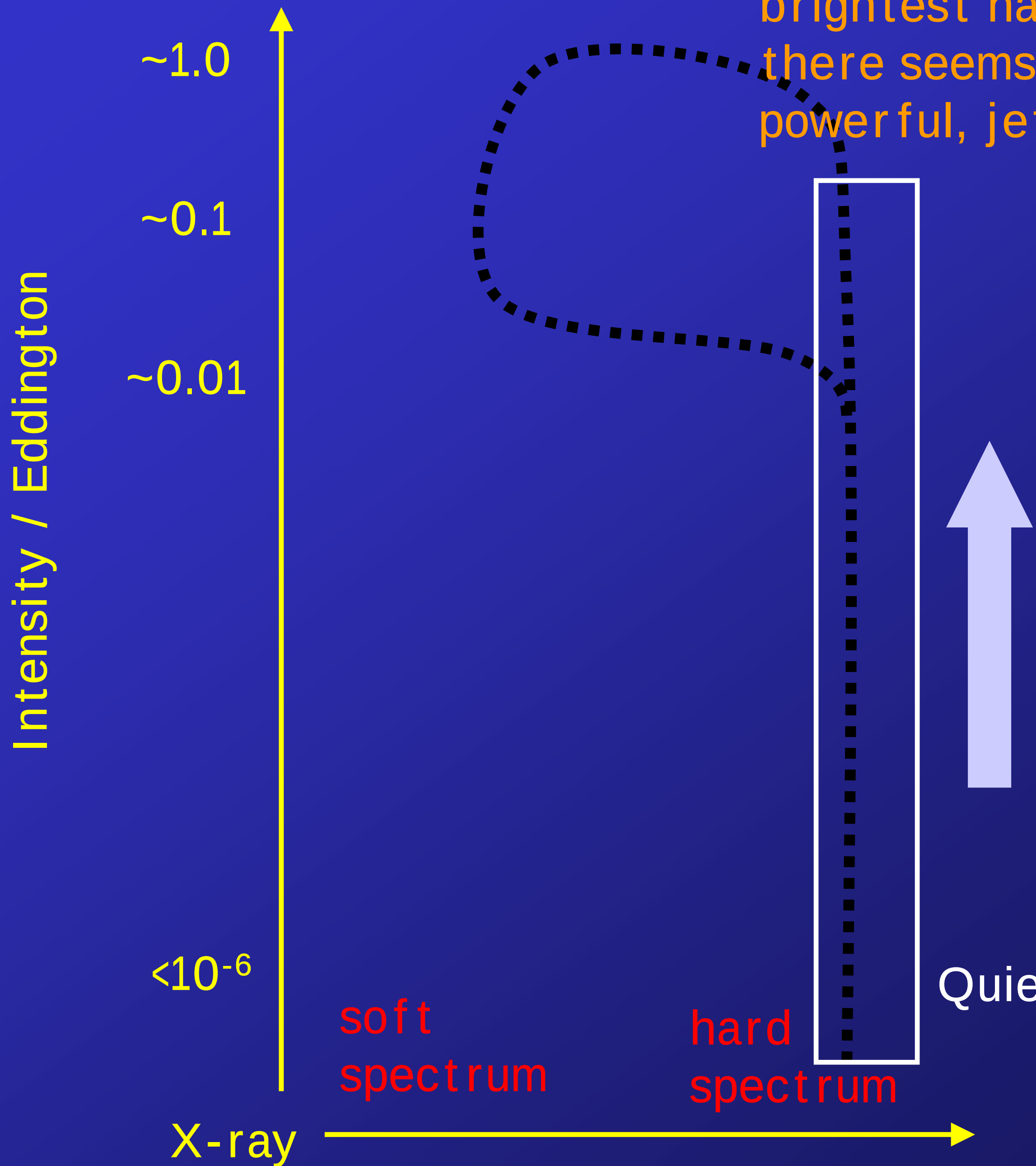
3. Transient outbursts – very rapid state changes – correspond to powerful massive ejection events

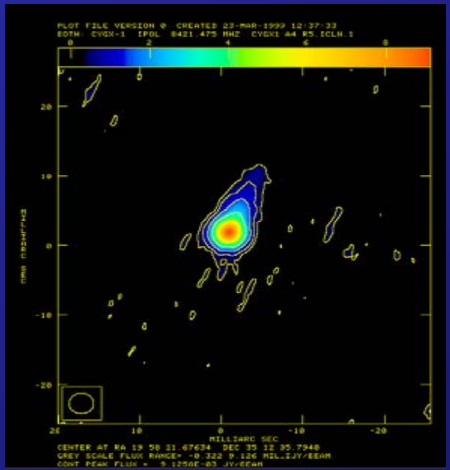
The life and times of a black hole X-ray binary...



So what is the relation to jets ?

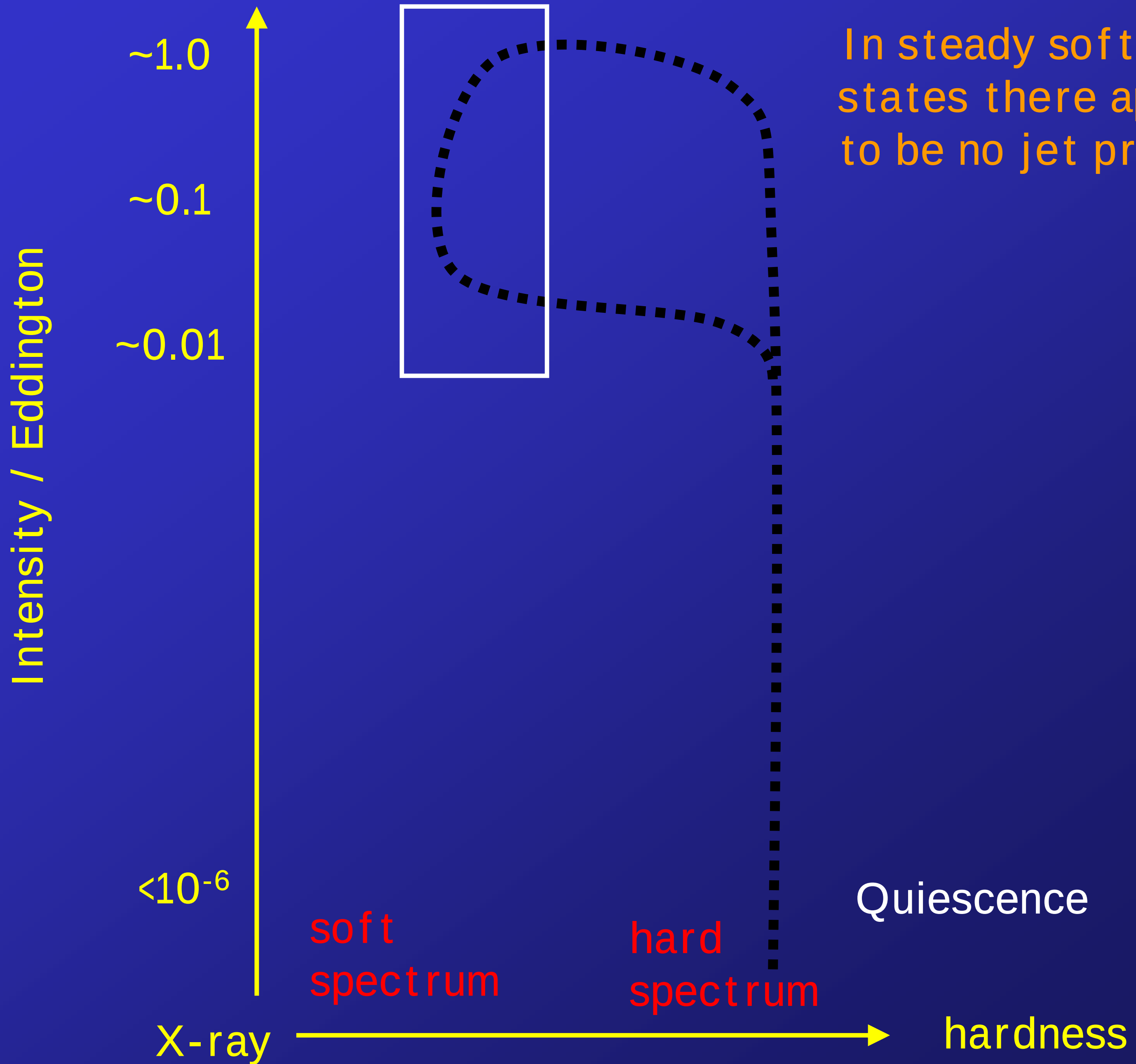
From quiescence to the brightest hard X-ray states, there seems to be a steady, powerful, jet.





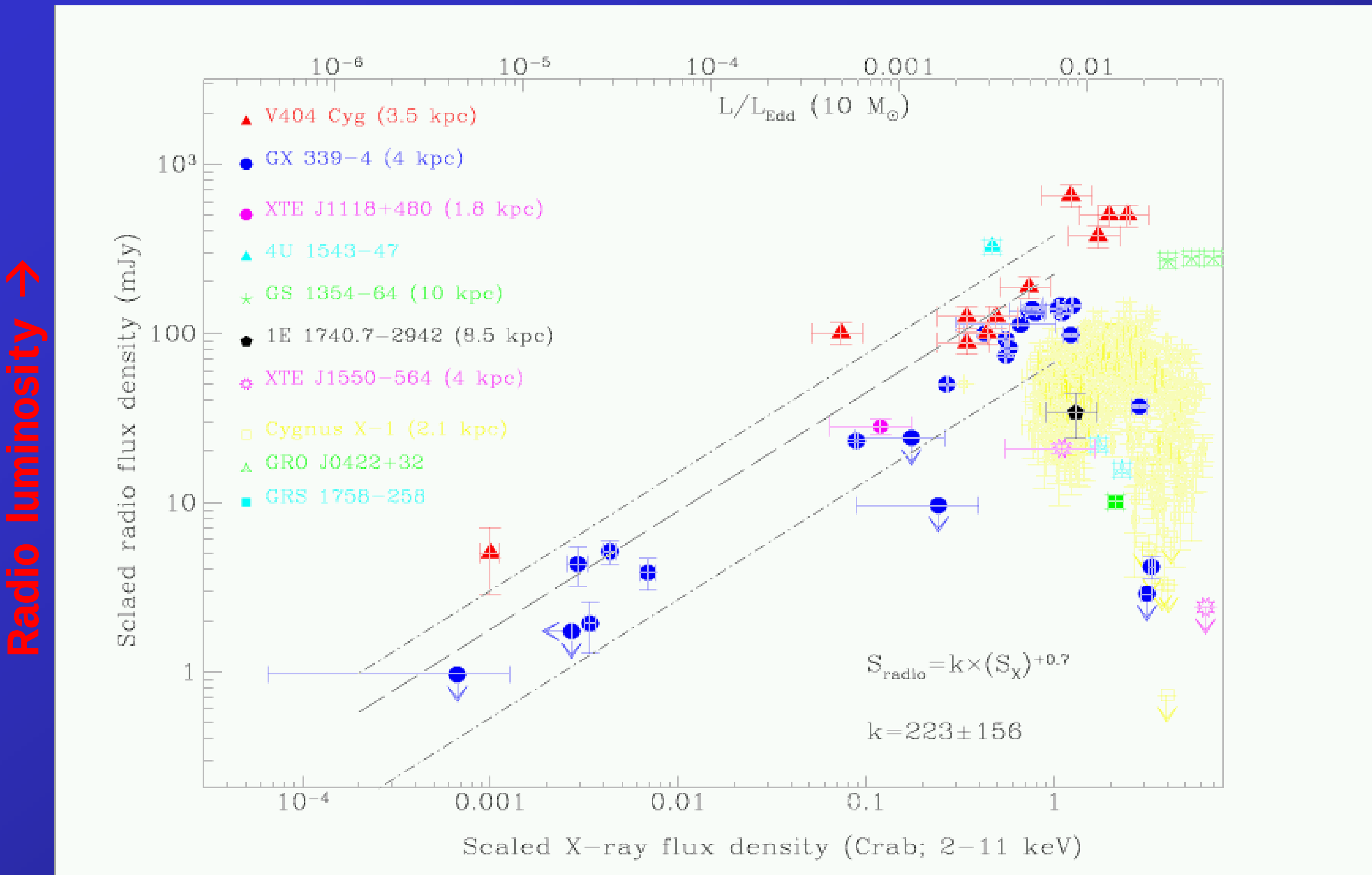
Steady jets (~10^{14} cm)

So what is the relation to jets ?



In steady soft X-ray states there appears to be no jet produced

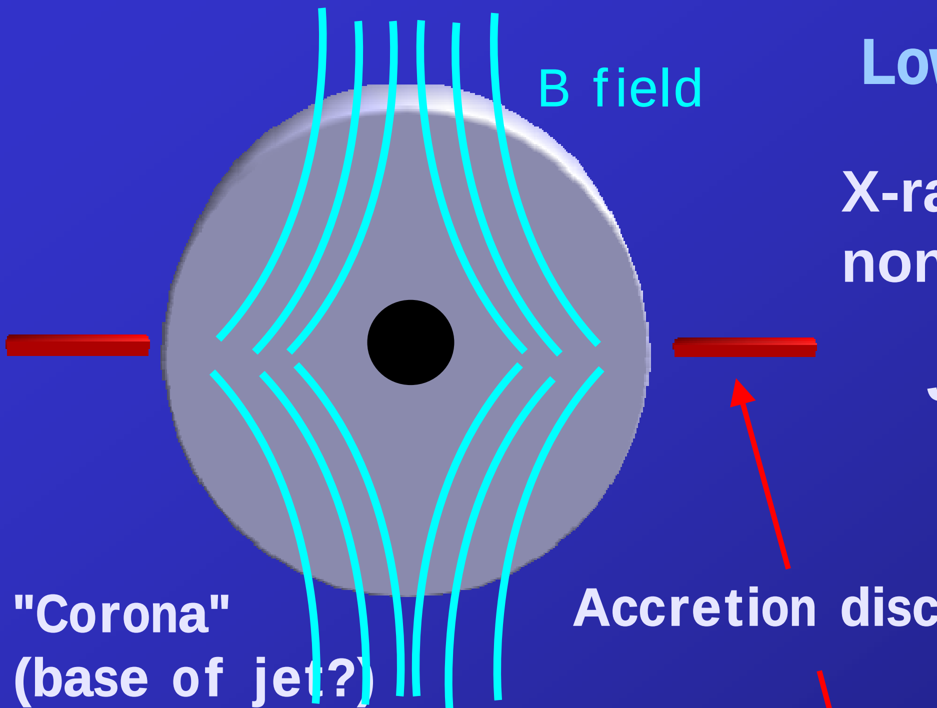
$L_{radio} \propto L_X^{0.7}$ in low/hard state (implies jet-dominated states)



X-ray luminosity →

(Corbel et al. 2003; Gallo, Fender & Pooley 2003)

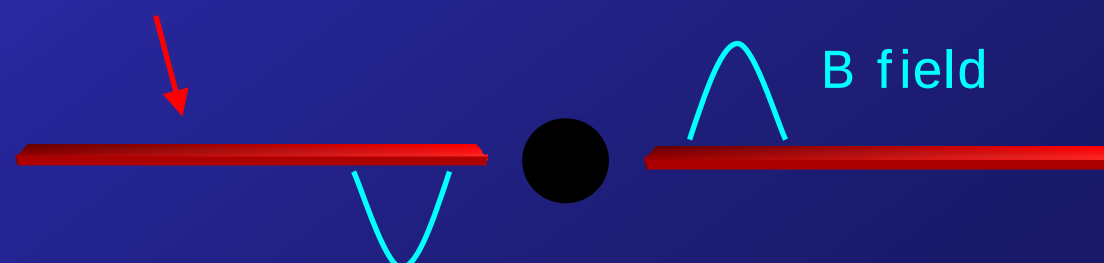
Why this relation ? MHD jets and B scale height ?



Low/hard X-ray state

X-ray spectrum dominated by non-accretion-disc emission

Jets always present

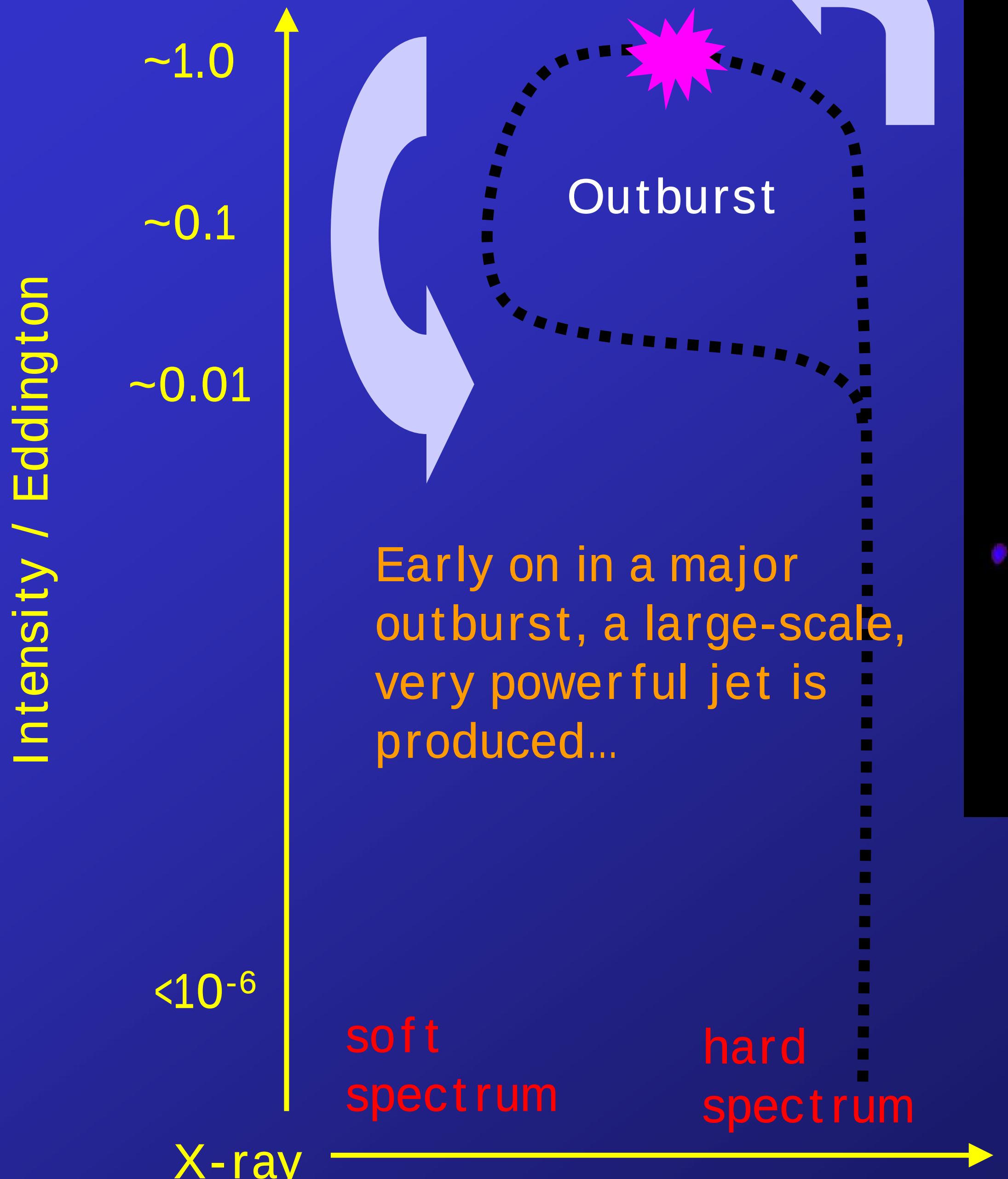


X-ray spectrum dominated by accretion disc emission

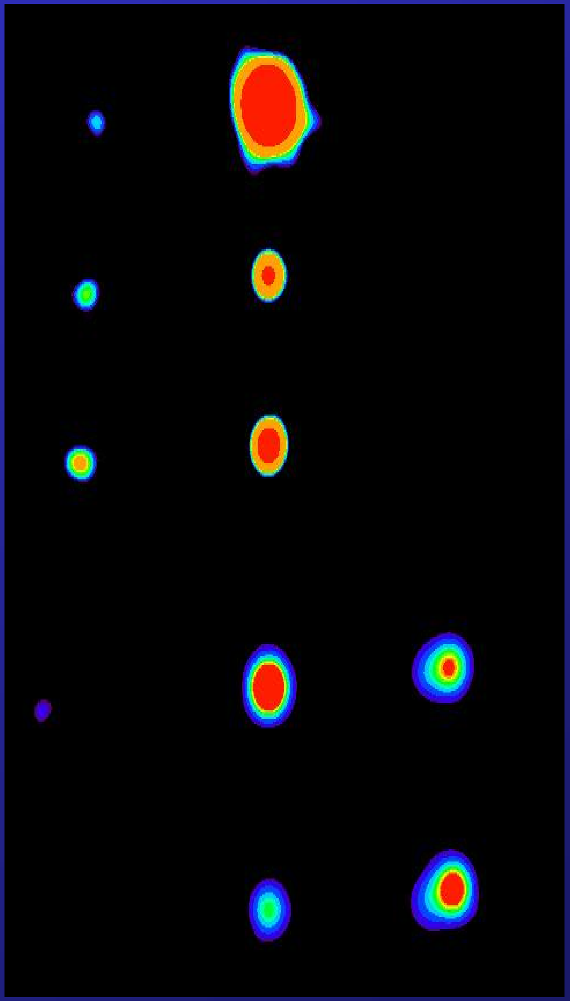
Jets never present

High/soft X-ray state

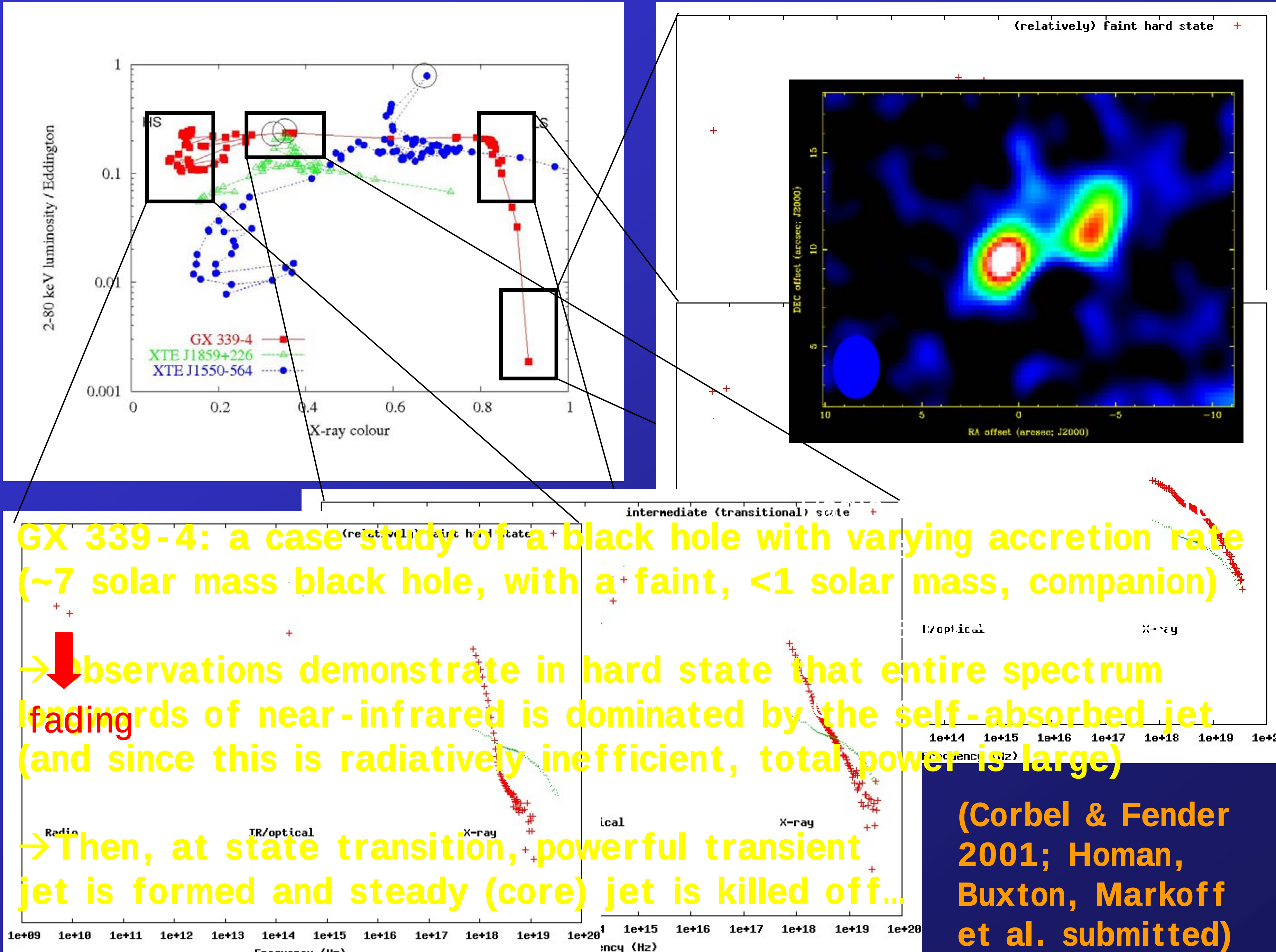
No good explanation for this... :



Early on in a major outburst, a large-scale, very powerful jet is produced...



Discrete ejections (up to parsec scales)

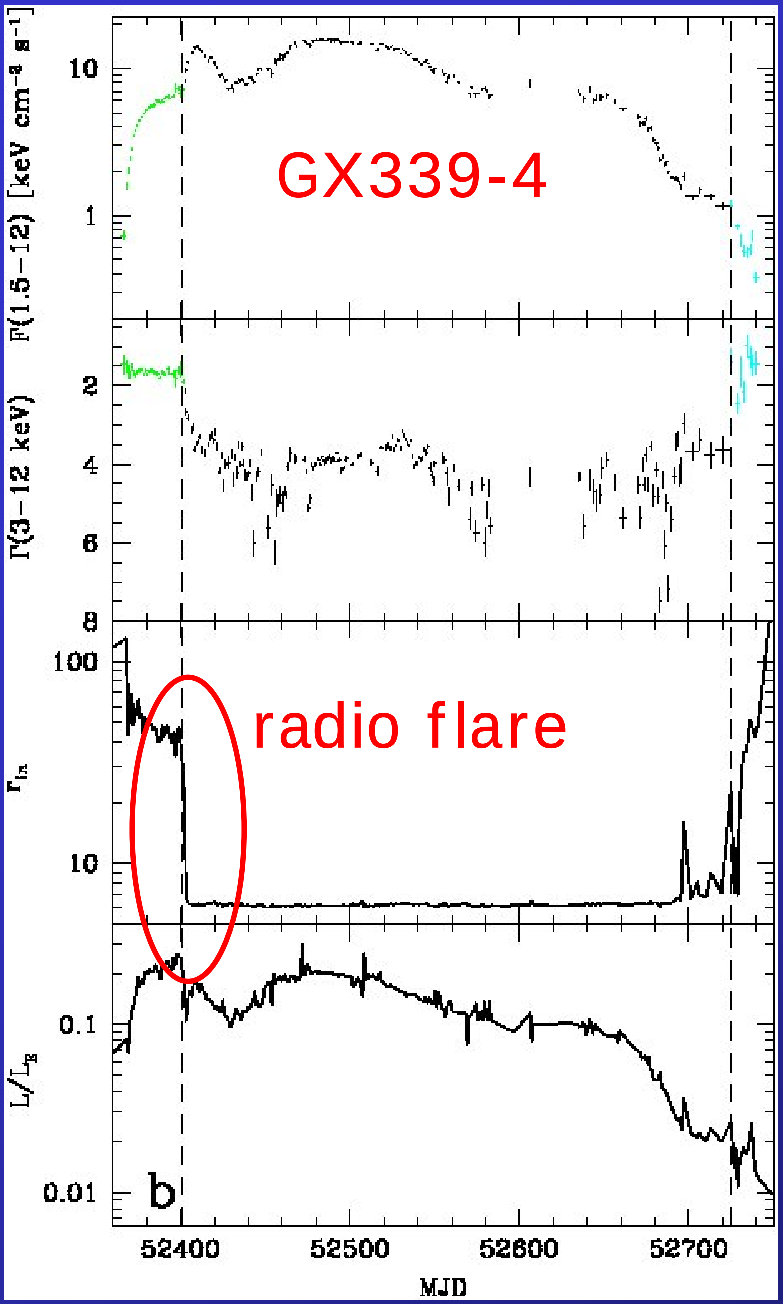


GX 339-4: a case study of a black hole with varying accretion rate
(~7 solar mass black hole, with a faint, <1 solar mass, companion)

→Observations demonstrate in hard state that entire spectrum longwards of near-infrared is dominated by the self-absorbed jet (and since this is radiatively inefficient, total power is large)

→Then, at state transition, powerful transient jet is formed and steady (core) jet is killed off…

(Corbel & Fender 2001; Homan, Buxton, Markoff et al. submitted)



The transient relativistic jet is formed at the soft peak…
What occurs at this soft peak ??

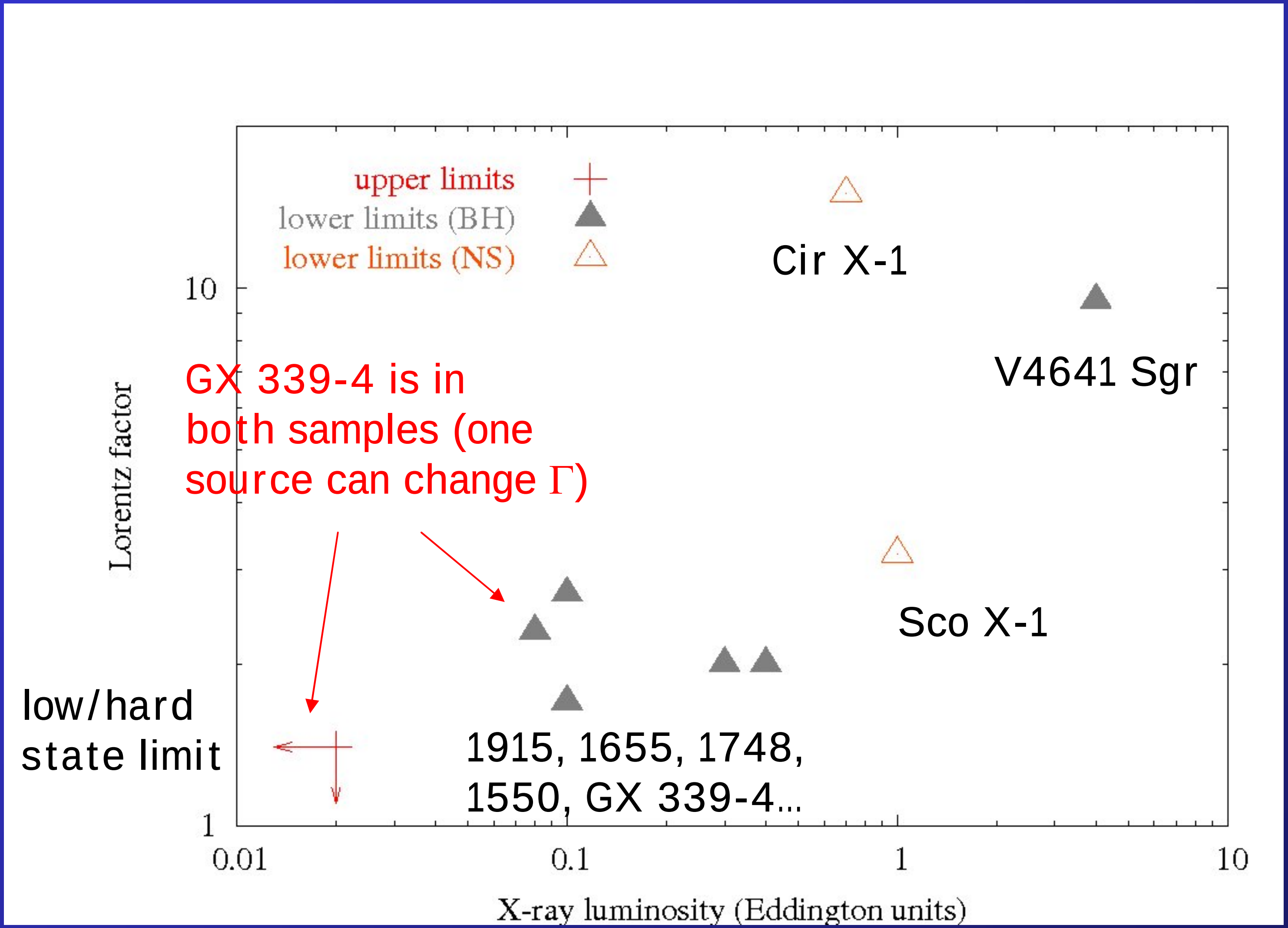
Fits to X-ray spectra (ha ha) invariably indicate that this corresponds to the point of minimum inner disc radius (which is often sustained for a period of >100 days)

→The optically thin radio flares occur around the time that the optically thick accretion disc reaches its innermost radius

… but why ? ? ?

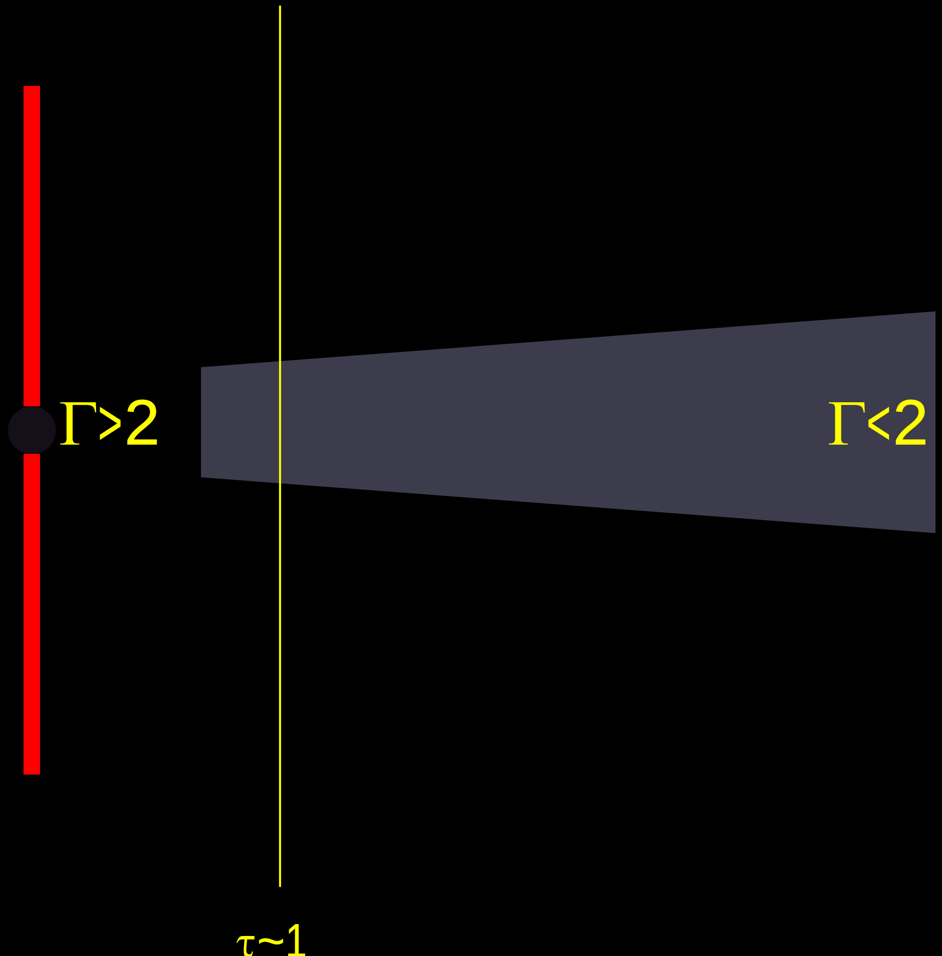
(e.g. Zdziarski et al. 2004)

jet speed variations with L_X or state?



Jet velocity increases with increasing L_X : but not clear if velocity function is a 'step' or smooth... (Fender, Belloni & Gallo 2004)

Disc moves in, Γ_{jet} increases → Internal shock



1. 'Hard' X-ray state: steady, Γ<2, self-absorbed jet

2. Disc moves in, 'softening' the X-ray spectrum. A transient, high-Γ flow collides with the slower pre-existing jet →internal shocks.

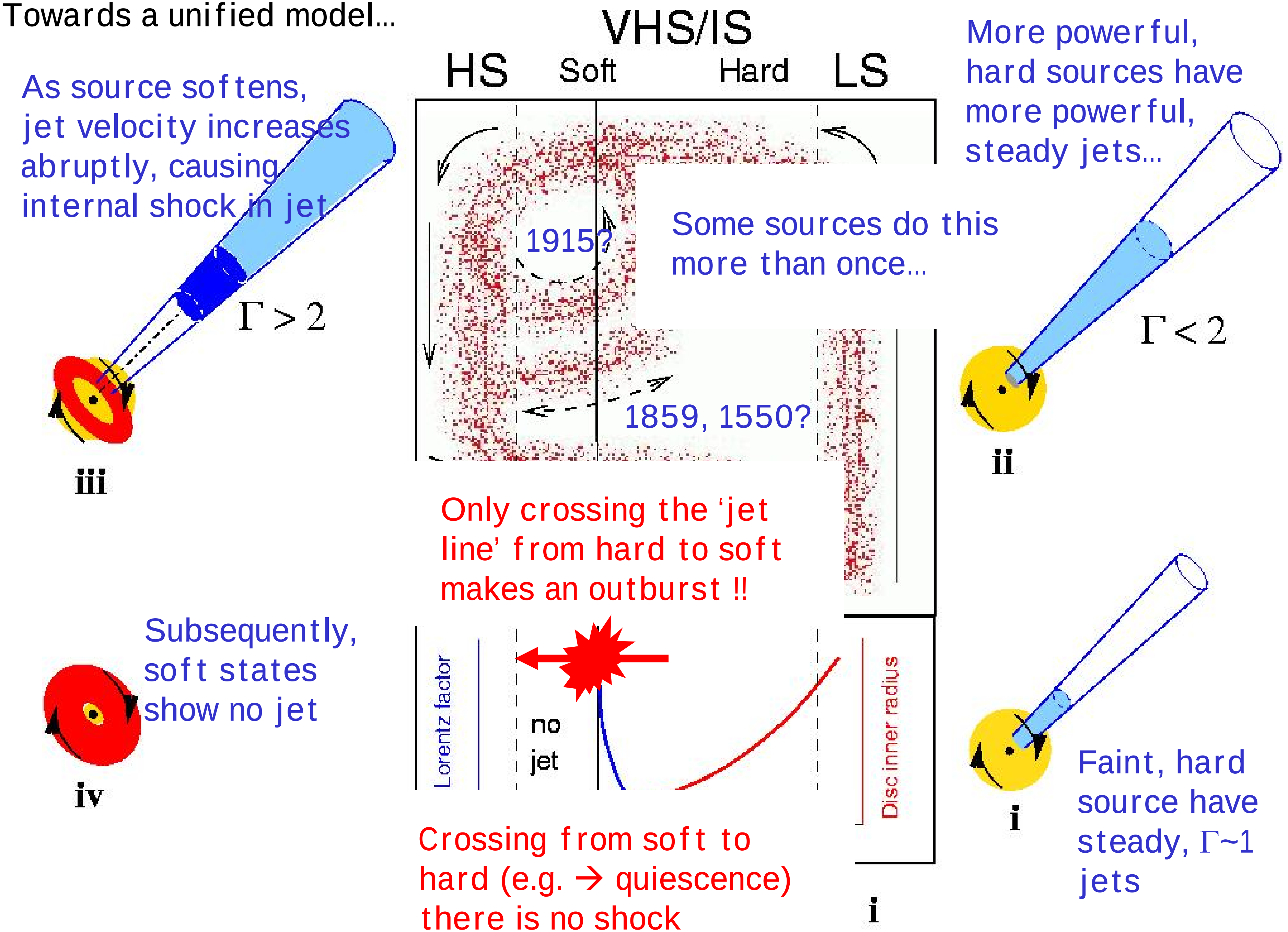
'Corona', not disc, ejected (i.e. GRS 1915+105)

Obviously you only get the shock when δΓ>0 (so only one flare per 'cycle')

(almost like an 'external' shock with steady jet as ambient medium)

(see also Kaiser, Sunyaev & Spruit 2000; Vadawale et al. 2004; Turler et al. 2004)

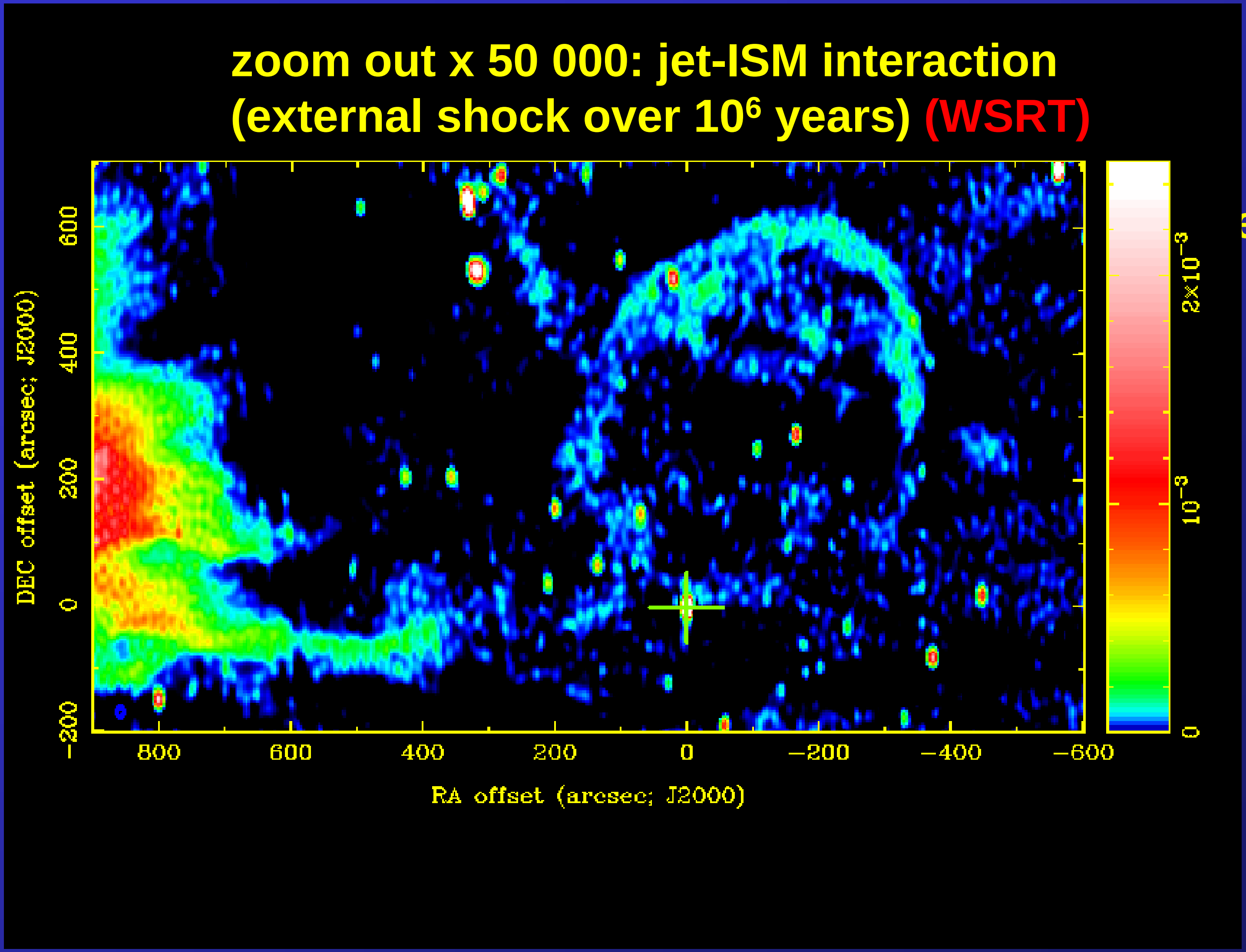
Towards a unified model...



1915: Fender & Belloni (2004)

Generic: Fender, Belloni & Gallo (2004)

Cygnus X-1: three phases of jet from black hole to ISM



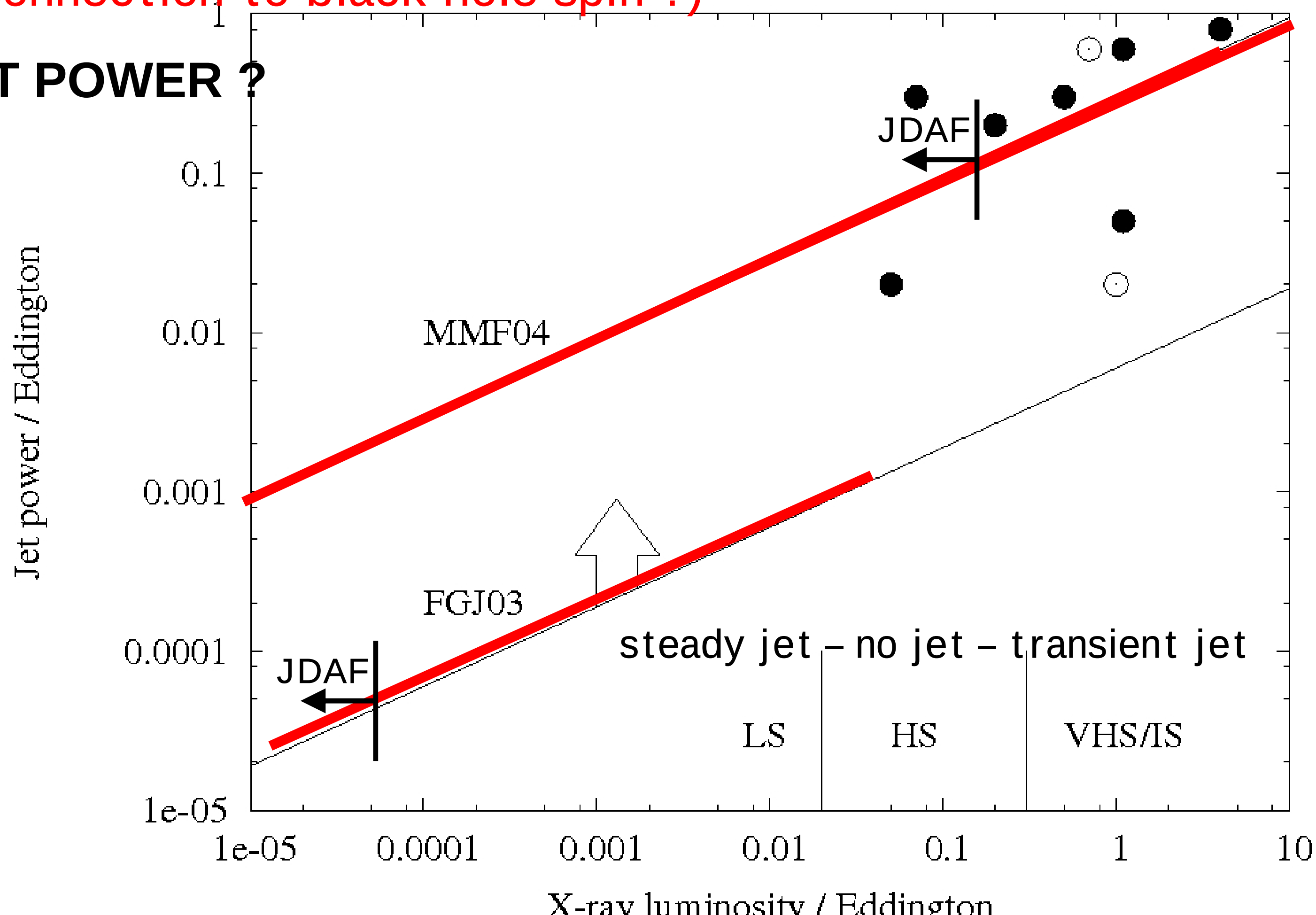
(Stirling et al. 2001; Stirling, Fender in prep; Gallo et al. in prep)

Or, there may be a step up to a more powerful mode

A single function may fit steady/transient jets

(connection to black hole spin ?)

JET POWER ?



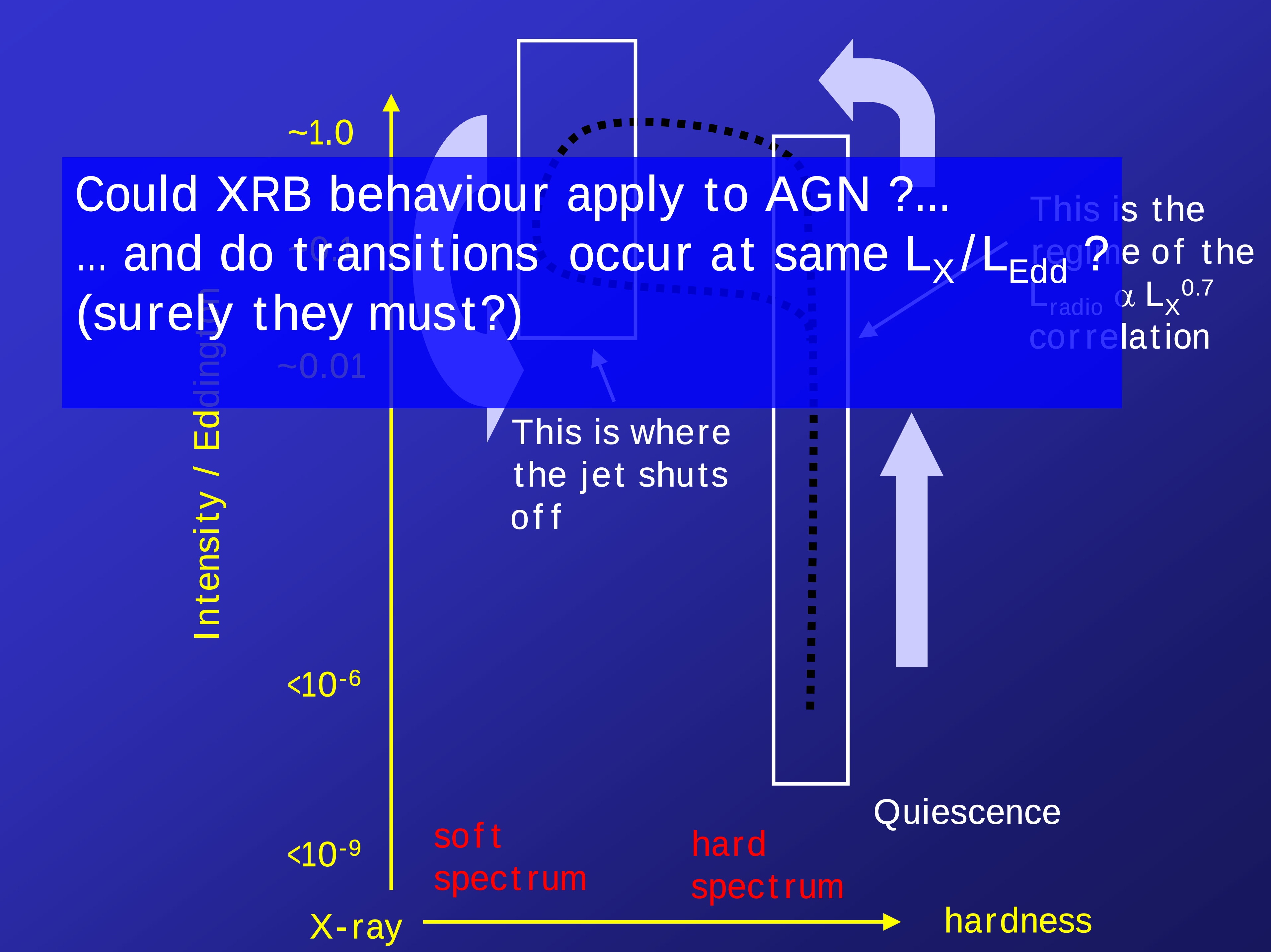
(Fender, Gallo & Jonker 2003

Malzac, Merloni & Fabian 2004

Fender, Belloni & Gallo 2004)

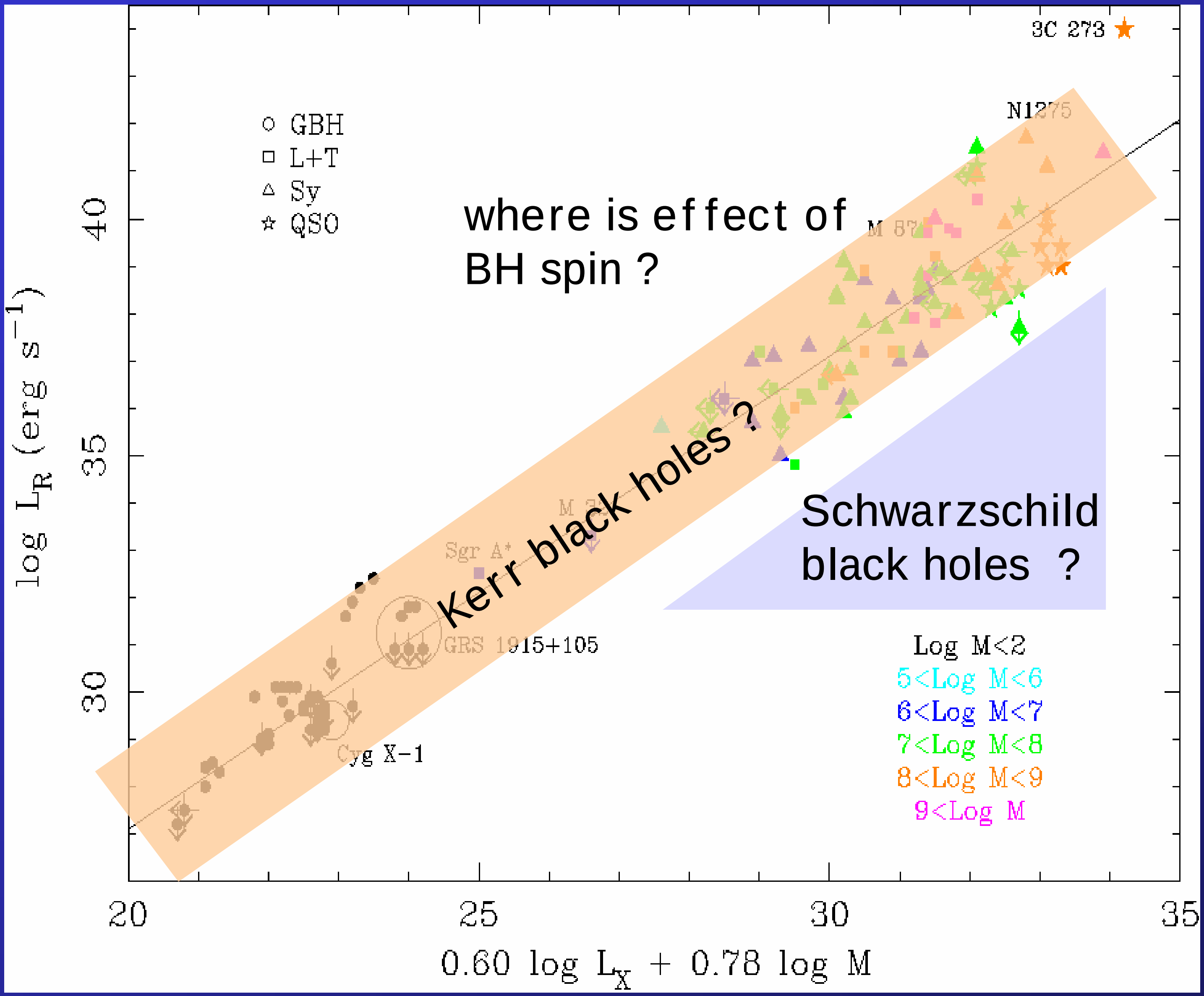
$L_{jet} \propto L_X^{0.5}$ → **Jet dominated states**

(for MMF04 estimate, <u>all hard states are jet-dominated</u>)



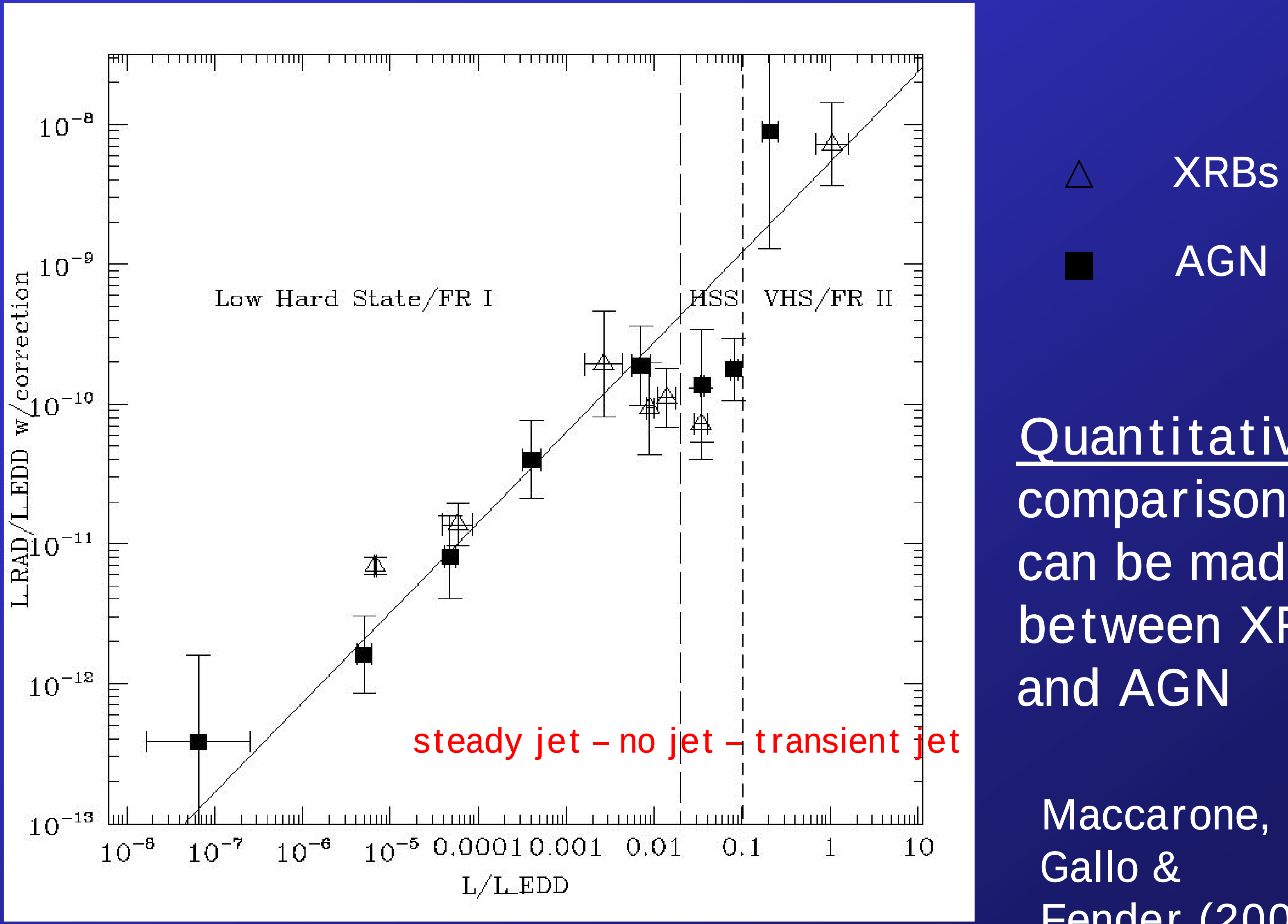
Could XRB behaviour apply to AGN ?...
... and do transitions occur at same L_X/L_{Edd} ?
(surely they must?)
~1.0
~0.01
<10^-6
<10^-9
Intensity / Eddington
This is the regime of the L_{radio} α $L_X^{0.7}$ correlation
This is where the jet shuts off
Quiescence
soft spectrum
hard spectrum
X-ray
hardness

Extending the L_R:L_x correlation to AGN – add a mass term?



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

‘Quenching’ of radio emission in the same (Eddington fraction) luminosity range as the XRB soft state… ?

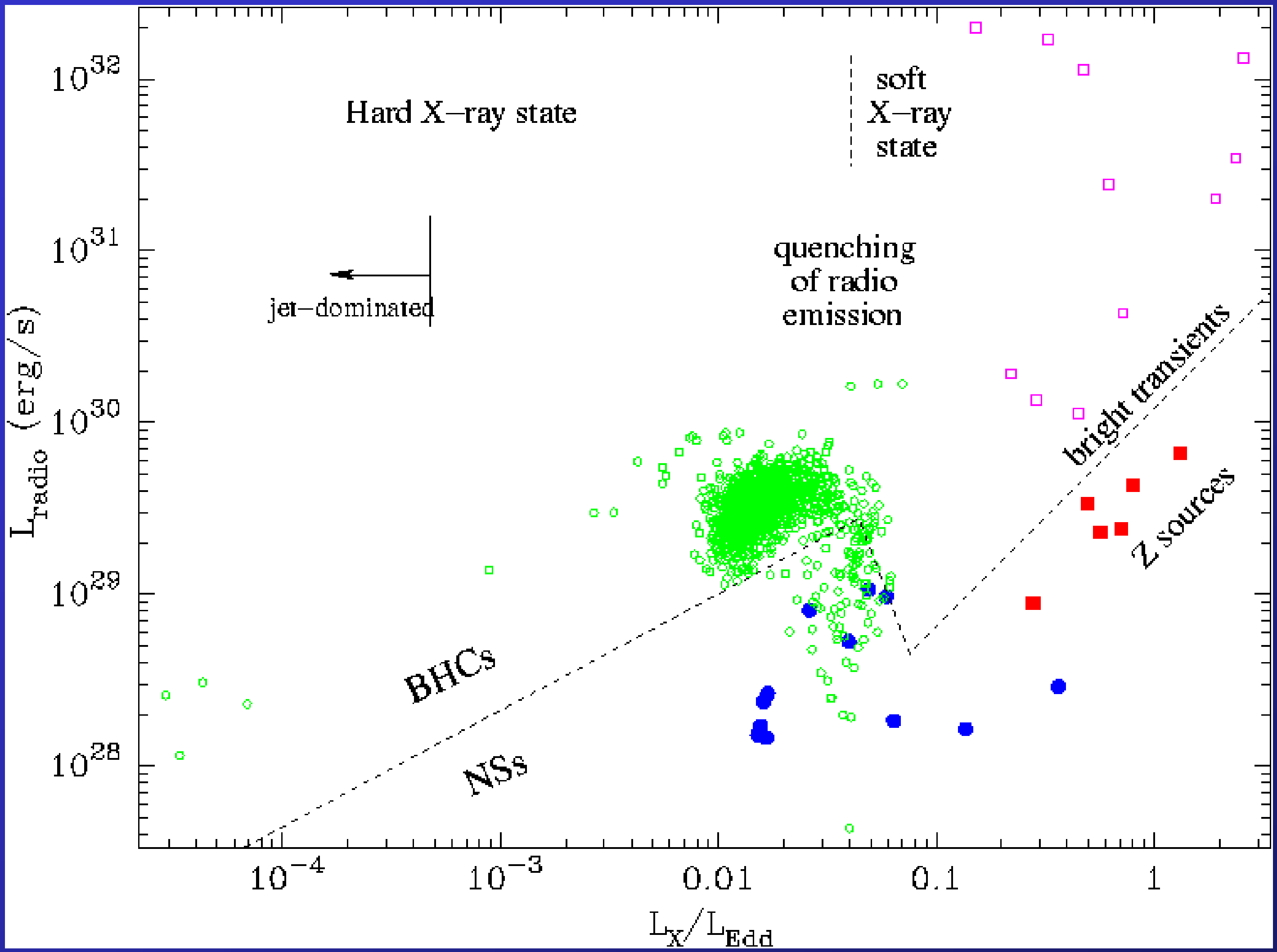


<u>Quantitative</u> comparisons can be made between XRBs and AGN

Maccarone, Gallo & Fender (2003)

Is the fact that the central object is a black hole important … ?

Neutron stars can act as a control sample.



Neutron stars behave qualitatively the same but quantitatively differently to black holes

(same patterns but are less 'radio loud' for a given L_X)

(Migliari et al. 2003, 04, 05)

Conclusions and speculations…

1. Accretion flow state and behaviour of jet strongly coupled. <u>Jets do not like thin discs</u>. <u>Every 'ADAF' case has a jet.</u>

2. There is a common pattern of behaviour in outbursts, which might be explained by an internal shock as jet velocity increases just before it is 'quenched' by disc…

3. These patterns may actually apply qualitatively and (!) quantitatively to AGN

4. Acting as a control sample, neutron stars show that 'type' of jet relates to disc only, not nature of accretor… BUT black holes seem to be more 'radio loud'…

The end