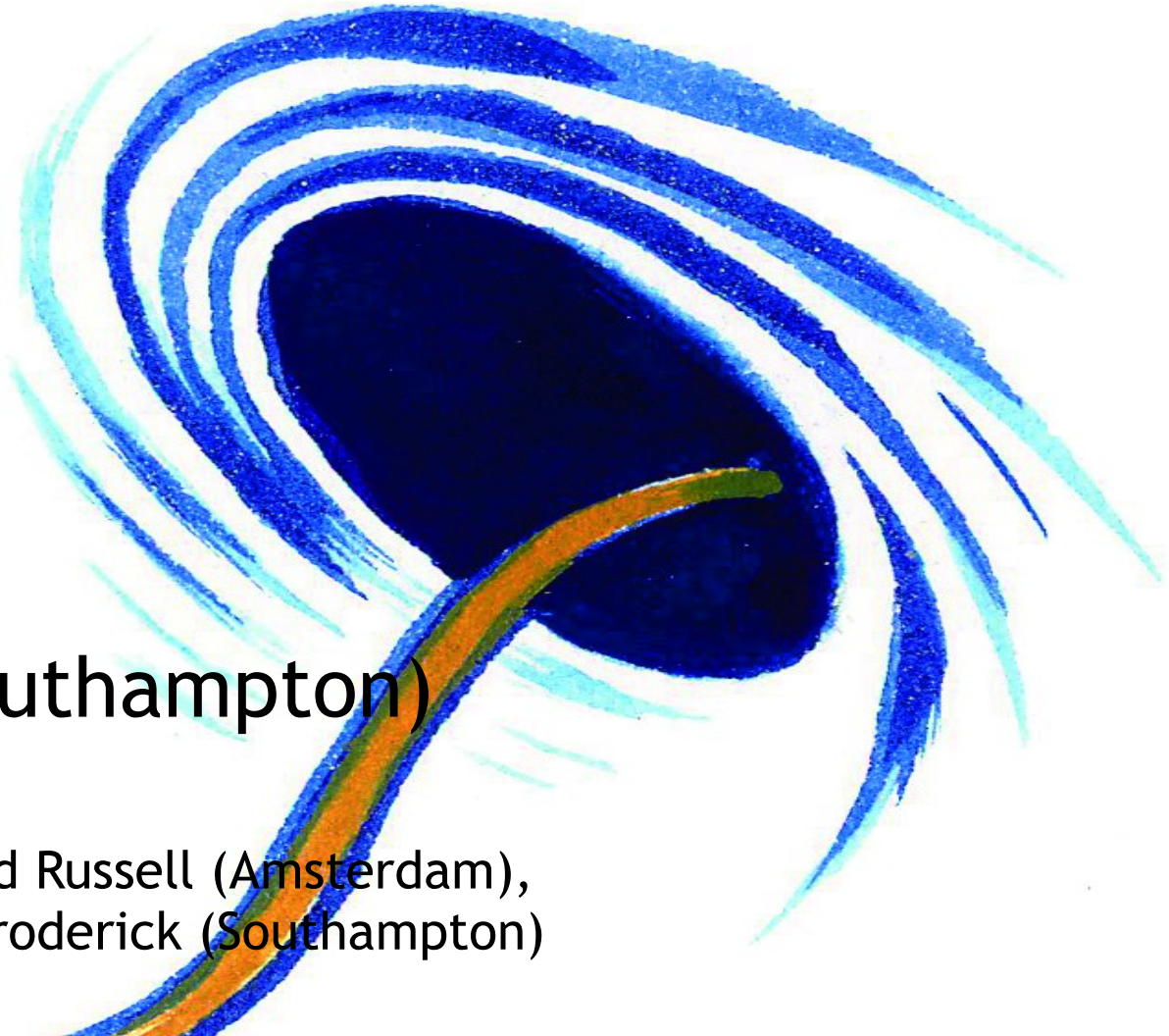
Is there really any evidence for spin-powering of jets from black holes

(and, is there really a radio loud : radio quiet dichotomy in AGN ?)

(and some forewords
on disc-jet coupling)



Rob Fender (Southampton)

Elena Gallo (MIT), David Russell (Amsterdam),
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University of Glasgow

University of Hertfordshire

University of Kent

University of Leicester

Liverpool John Moores University

Manchester 1824

Newcastle University

The University of Nottingham

The Open University

University of Oxford

University of Portsmouth

Queen Mary University of London

RAL Space

The University Of Sheffield.

University of Southampton

University of Sussex

UCL

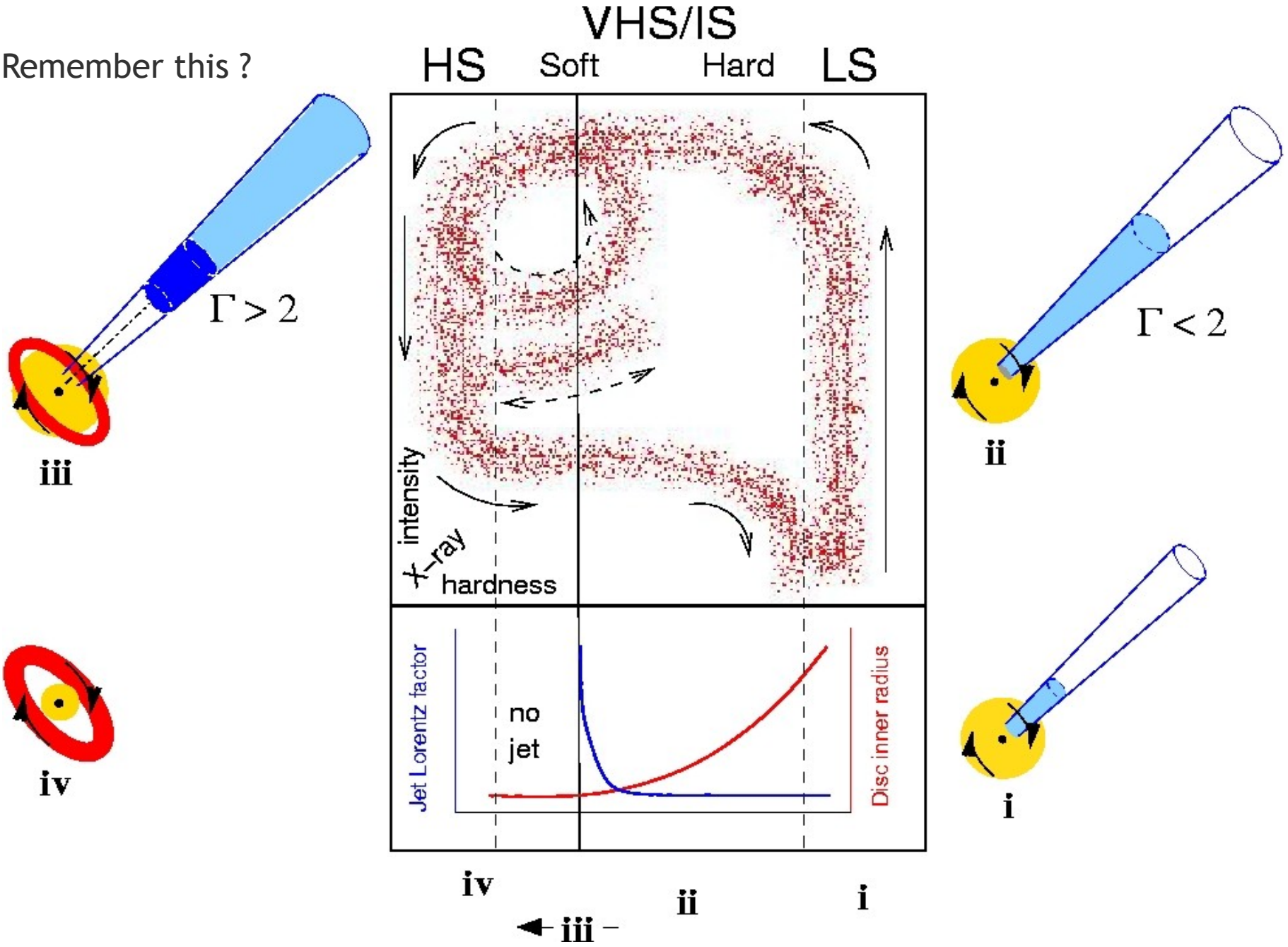
Science & Technology Facilities Council
UK Astronomy Technology Centre

Science & Technology Facilities Council

SEPnet
South East Physics Network

Asides on stellar mass black holes and accretion states

1. Remember this ?

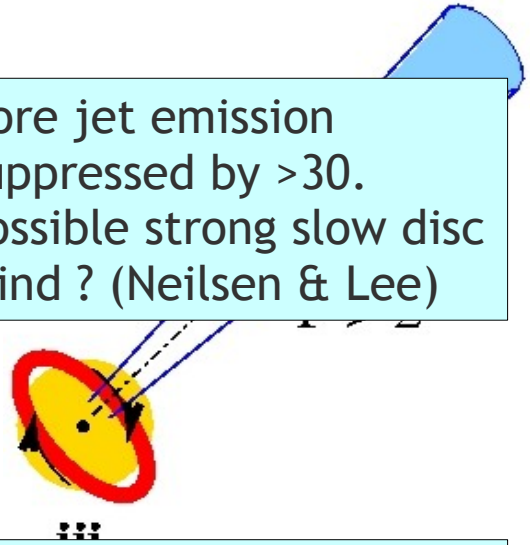


Fender, Belloni & Gallo (2004)

Asides on stellar mass black holes and accretion states

1. Remember this ?

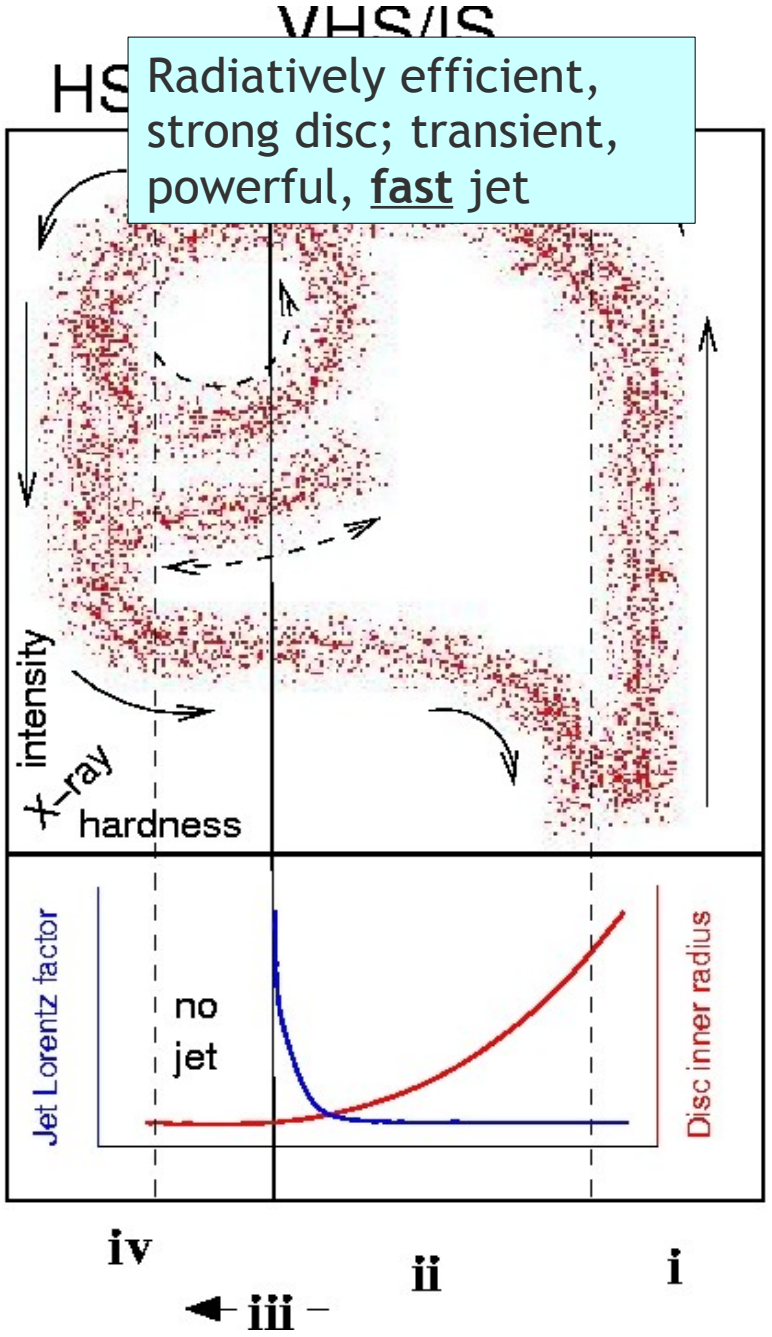
Core jet emission suppressed by >30. Possible strong slow disc wind ? (Neilsen & Lee)



No clear 'switch' at any Eddington ratio. Remember this:

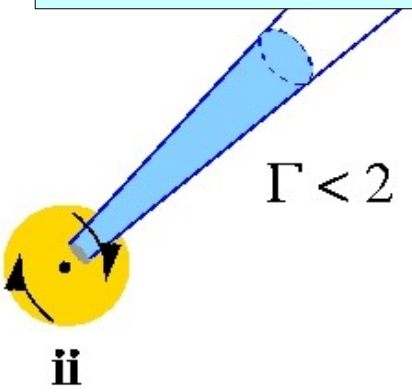
1. Below ~1% Eddington, jet-dominated hard states

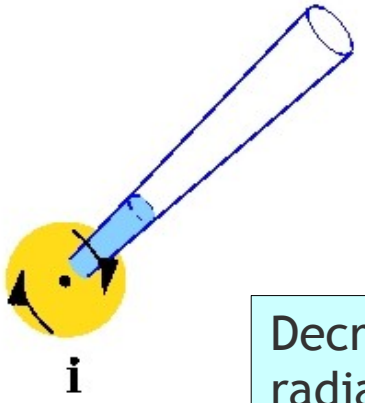
2. Above 1% Eddington, mix of strong- and weak-jet states



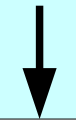
Radiatively efficient, strong disc; transient, powerful, **fast** jet

Radiatively efficient hard state **with** relatively slow [?] powerful jet





Decreasing radiative efficiency



Fender, Belloni & Gallo (2004)

In Fender, Belloni & Gallo (2004) we presented a 'unified' model for the disc-jet coupling in black hole X-ray binaries

Six years later..

Empirical couplings demonstrated to be correct in much larger sample:
- Jet always on in hard state
- Jet off or [fading and optically thin] in soft state
- Major outbursts associated with hard → soft state transitions
- Reactivation of jet during return to hard state not well observed

Attempt to extend this to timing properties
- Clearly jets are stronger when variability is stronger
- Approximate but imprecise connection between rapid drops in variability power and major ejection events

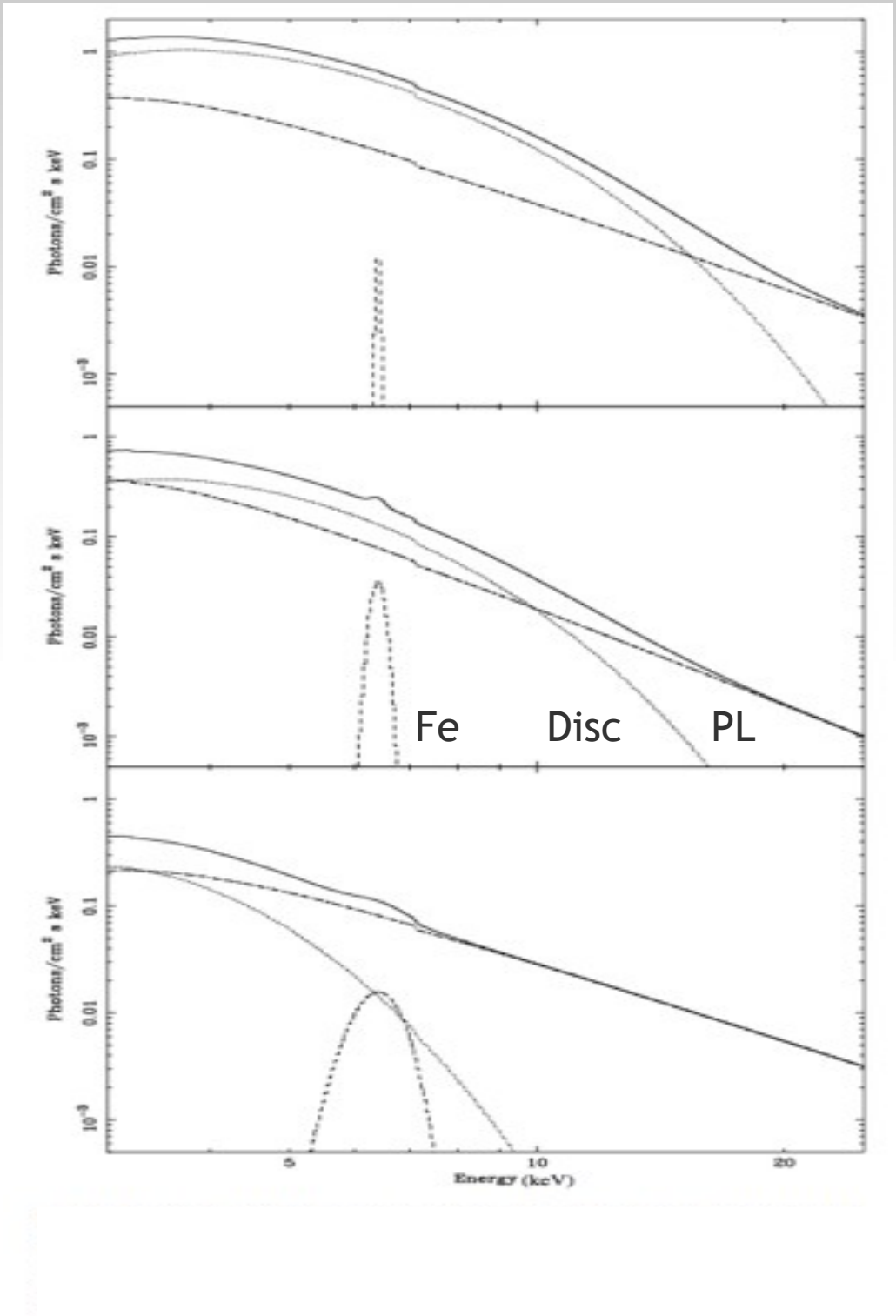
Theoretical interpretation
- Disc radius changes at high Eddington ratios remain controversial – disc could be varying over small (~10 R_G) range (or not). Below about 1% Eddington disc does seem to recede to larger radii
- Internal shocks model for major outbursts consistent but untested. We need a measurement of the hard state jet speed.

Fender, Homan & Belloni (2009)

2. A specific point – you **do** get states which are radiatively bright and have a powerful jet

Q: Which one makes the powerful jet and which one doesn't ?

Migliari & Belloni (2003)



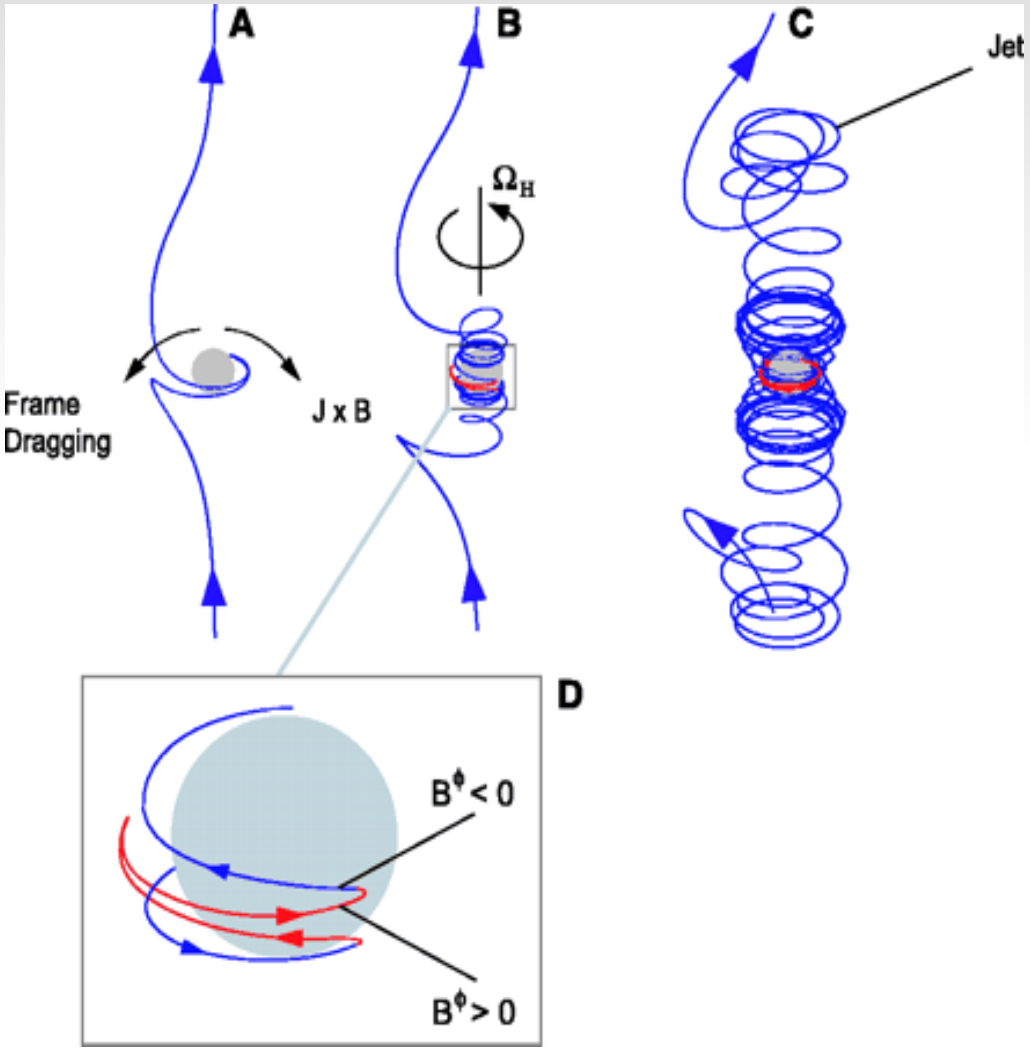
Black hole spin powering of jets: a very attractive idea

- Penrose (69), Christodolou (70) showed that you can extract up to ~30% of the mass-energy of a maximally rotating black hole

- Blandford & Znajek (77) … McKinney (05++) showed how a disc could allow this energy to be extracted and to drive a powerful relativistic jet, as observed from black holes of all masses (10 to 10 billion solar masses)

- Livio, Ogilvie & Pringle argue that the power extracted from the spin has been overestimated and can never exceed the power from the accretion disc. McKinney et al. claim this is not correct in astrophysical environment and spin should be important

- Essentially **all** current GRMHD simulations of relativistic jet formation focus on a rotating black hole to produce the most relativistic jets



Radio loud and radio quiet AGN: a brief history

• Early radio surveys at (relatively) low frequencies and angular resolutions → appeared to show two separate populations of '**radio loud**' and '**radio quiet**' AGN (recall masses not well know then). This dichotomy becomes part of the received wisdom for AGN, is stated without many caveats in textbooks, etc. This in turn drives much study into the origin of this difference, usually tying it to the evolution of black hole spin via the merger history etc. Big business.

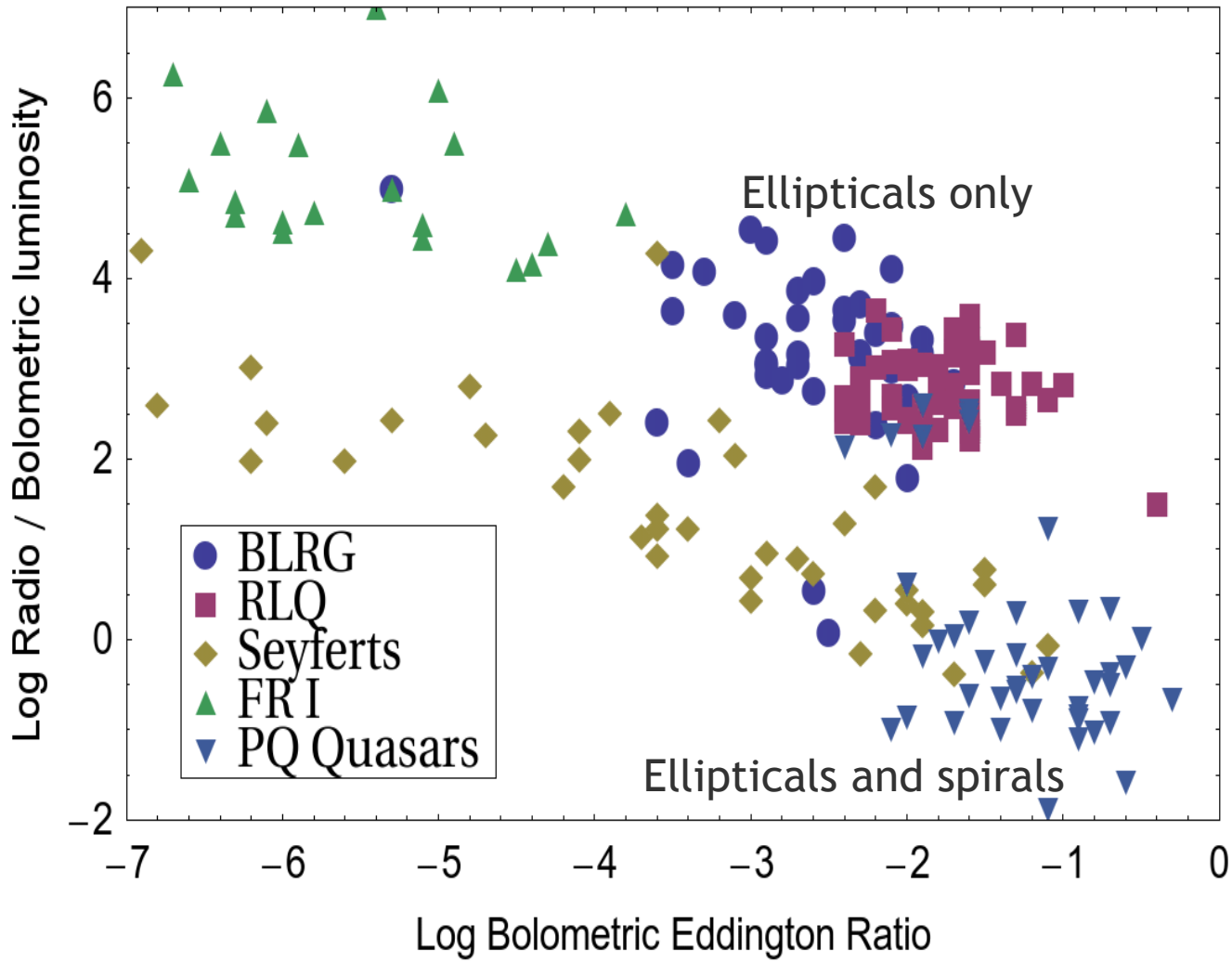
• In the 2000s, several surveys (e.g. FIRST) start to show **no dichotomy**. Several of these surveys only measure the core.

• The 'fundamental plane' (L_x, L_r, M) relations of Merloni et al. (2003) and Falcke et al. (2004) do not find any evidence for any dichotomy. They also only use core luminosities.

• Sikora et al. (2007) revive the discussion using recently estimated black hole masses to plot radio loudness as a function of Eddington ratio... using extended radio emission.

Sikora, Stawarz & Lasota (2007):

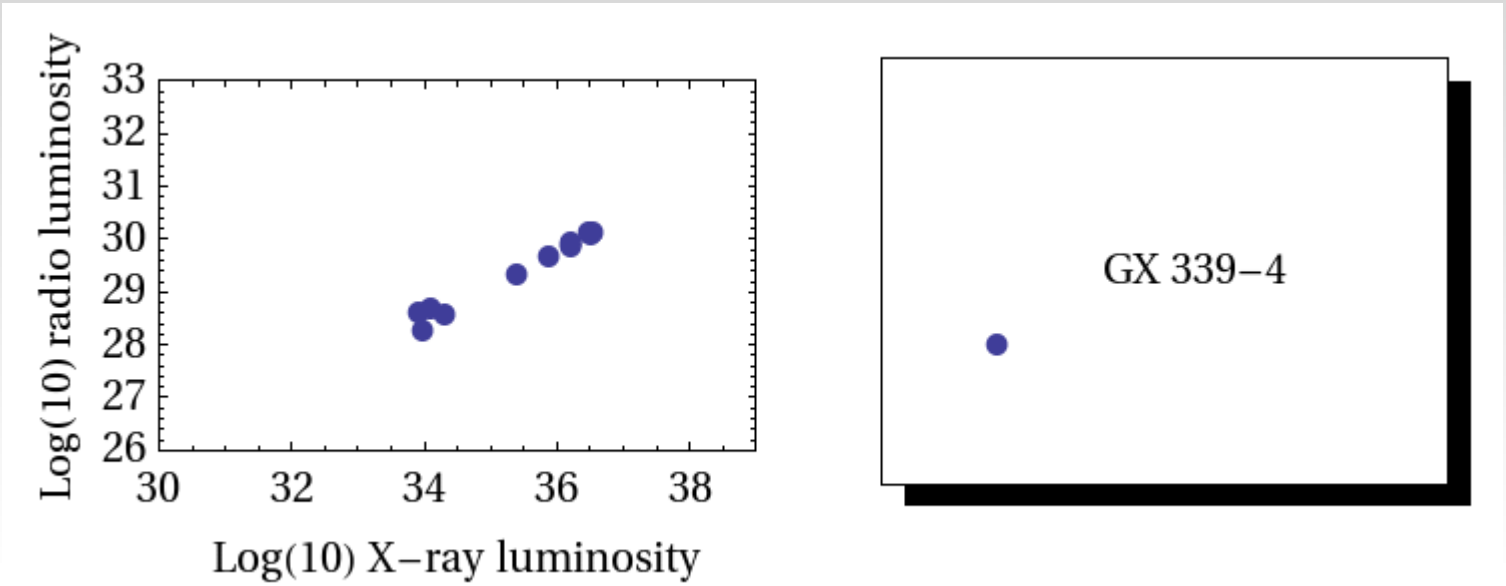
At low Eddington ratios there appear to be two tracks



At high Eddington ratios there is some mixing

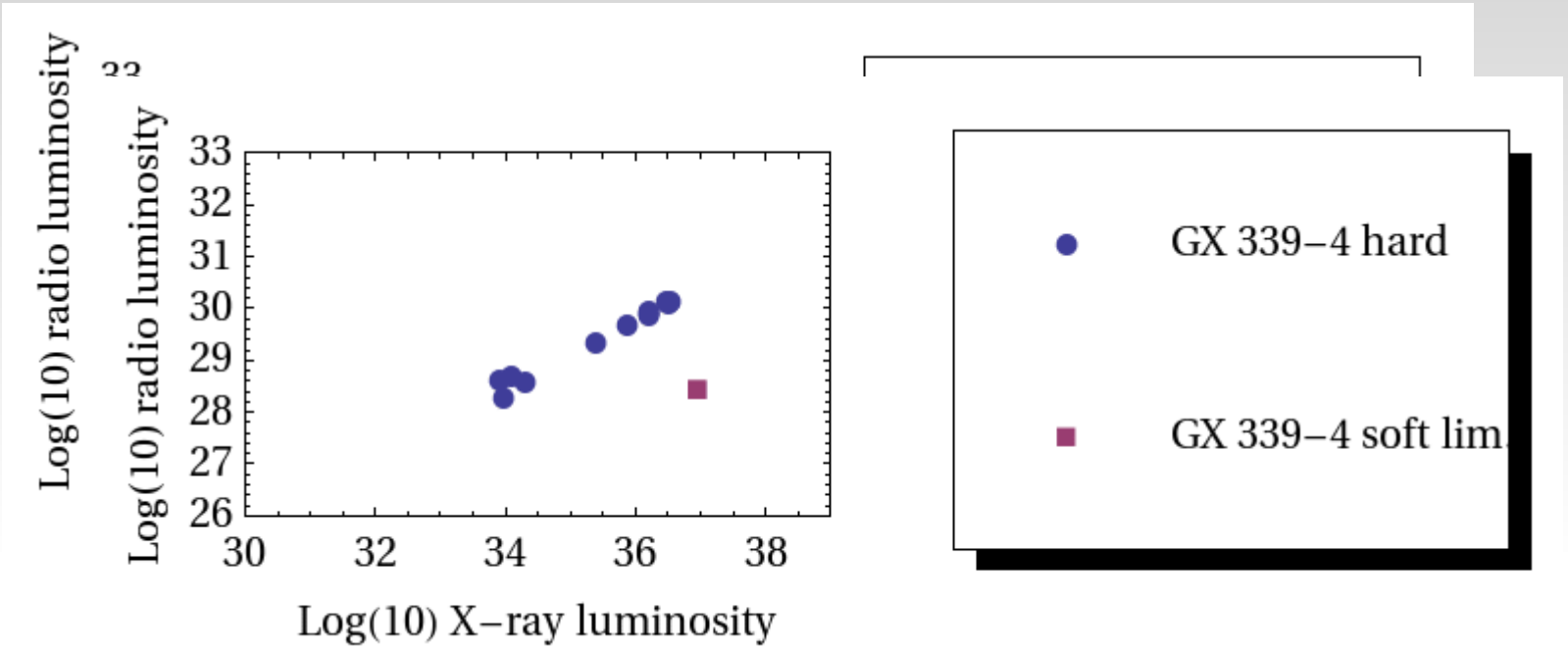
The interpretation presented is that **spin affects the radio loudness** – higher spin = more powerful jets, but **at high Eddington ratios there are also state changes** (like XRBs)

Learning about varying core radio loudness from black hole binaries



Most of the time (hard state) radio and X-rays nicely correlated

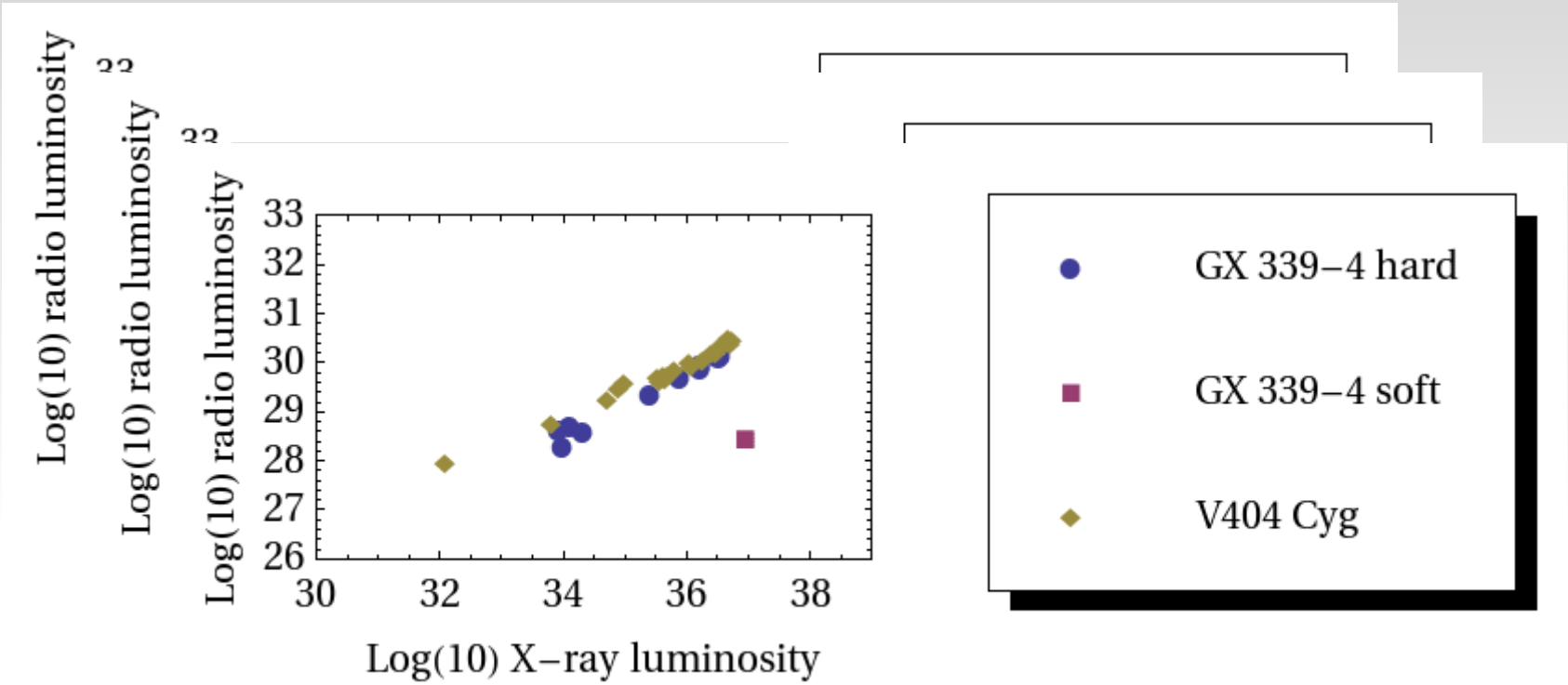
Jets in hard state black holes: many ways of changing radio loudness



Most of the time (hard state) radio and X-rays nicely correlated

In soft state however jet is suppressed dramatically at ~same luminosity

Jets in hard state black holes: many ways of changing radio loudness



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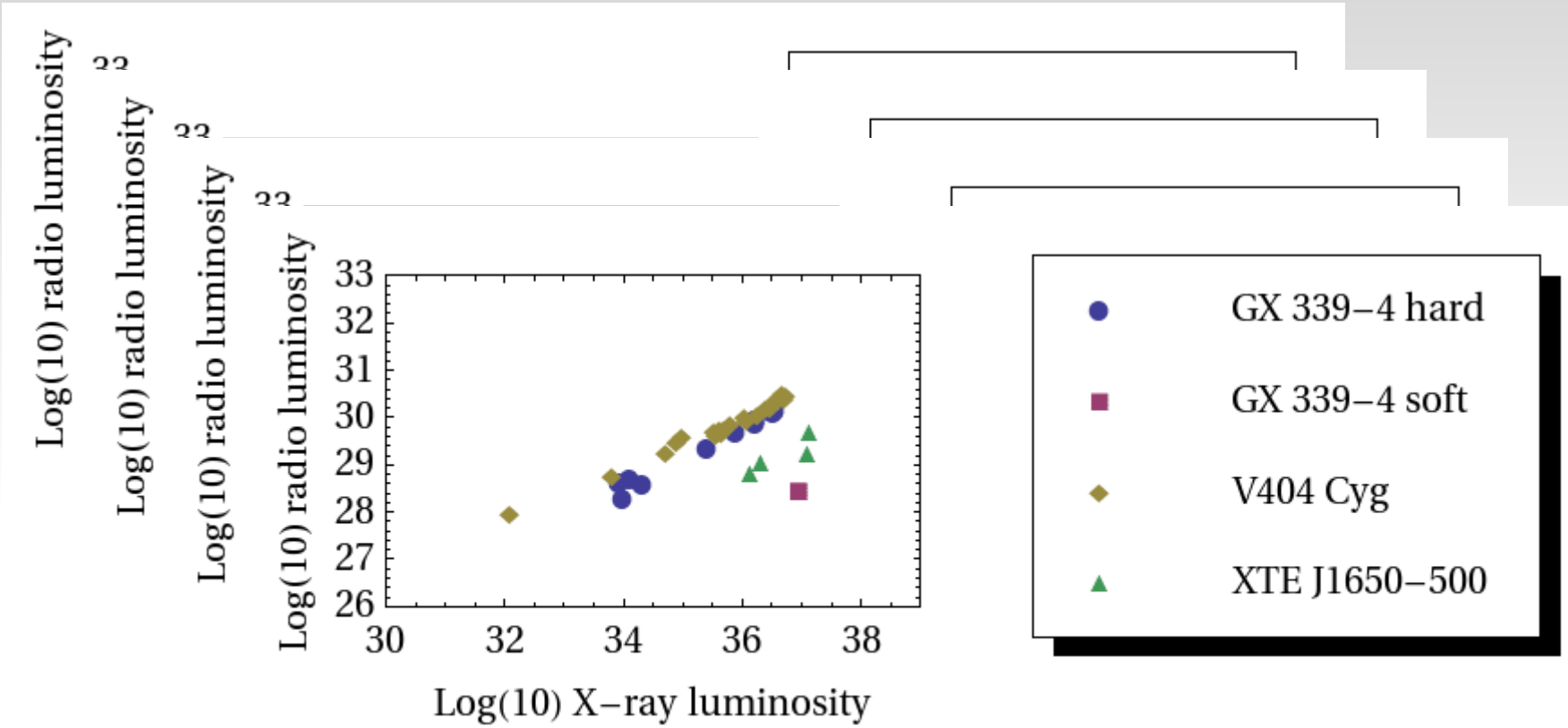

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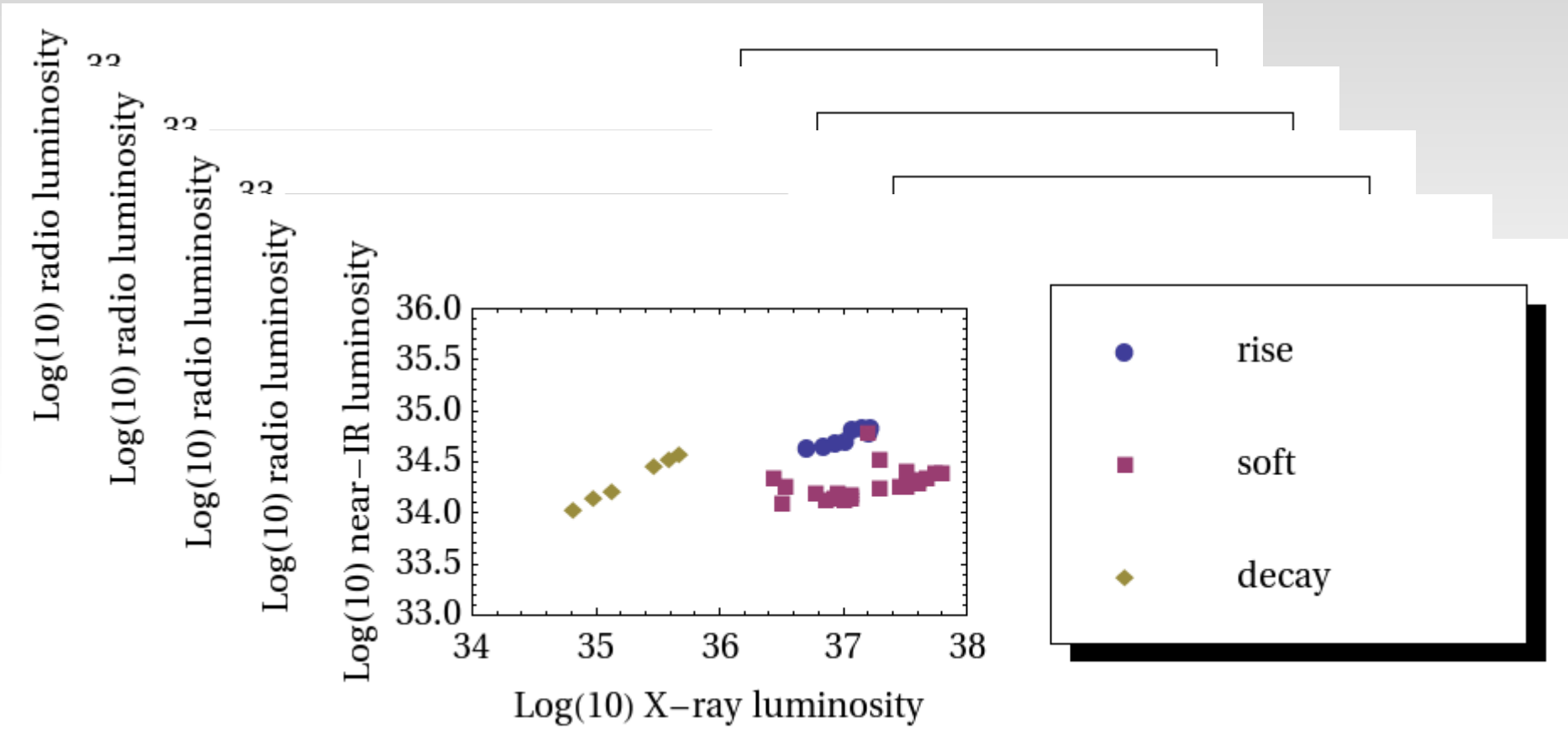
Some sources show parallel behaviour but are more 'radio quiet'

Jets in hard state black holes: many ways of changing radio loudness



Most of the time (hard state) radio and X-rays nicely correlated

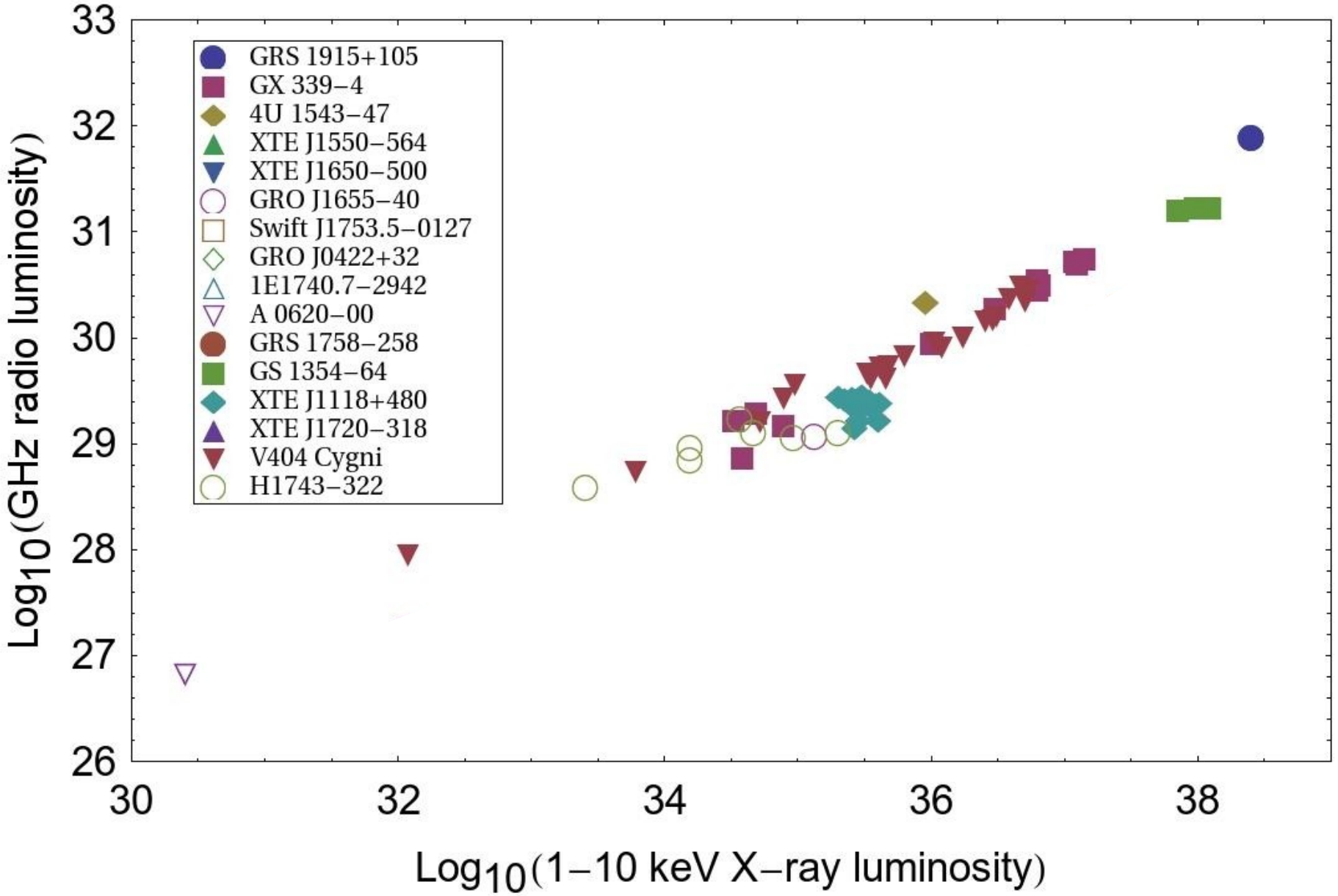
In soft state however jet is suppressed dramatically at ~same luminosity

Almost exactly the same hard state correlation seen in other source(s)

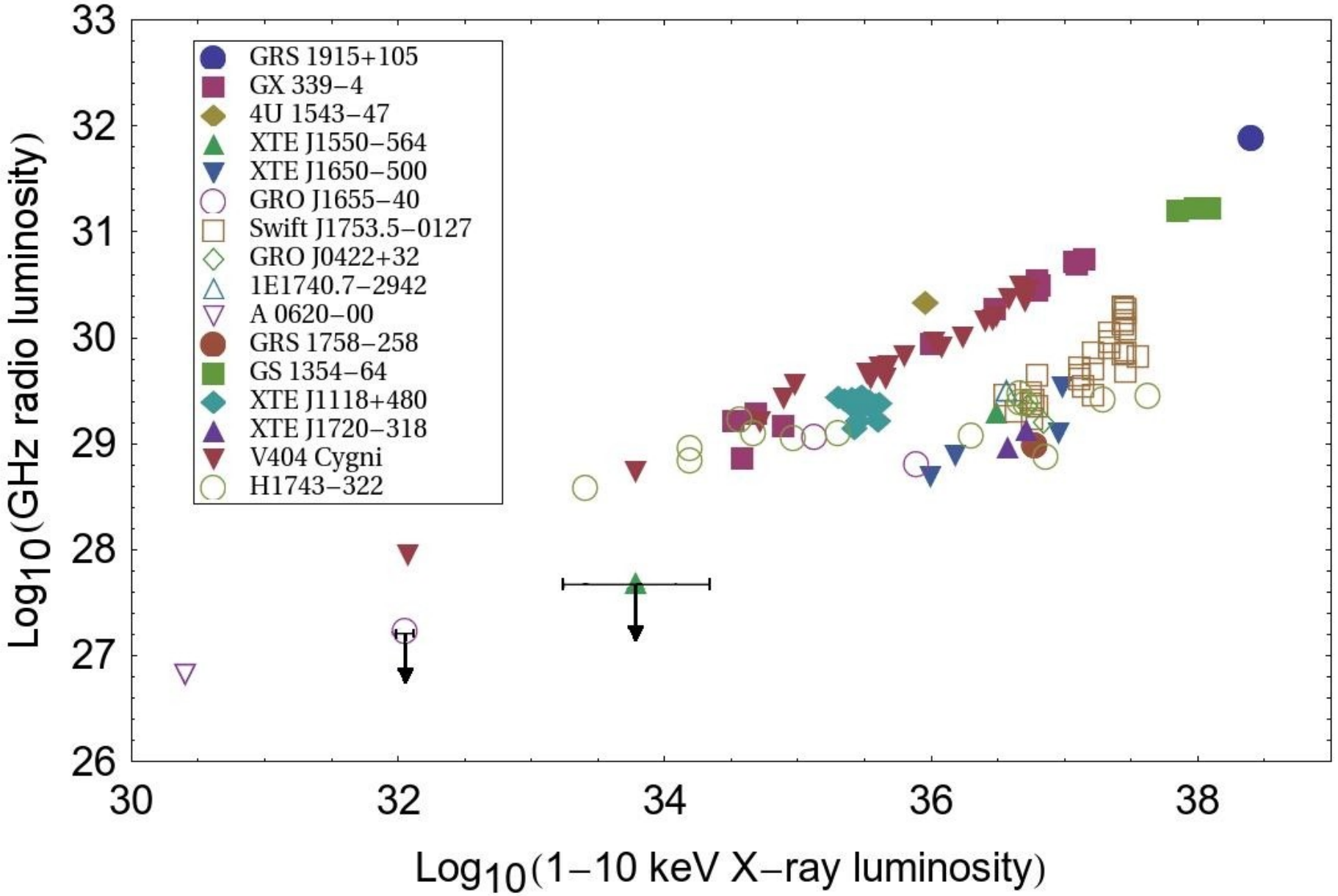
Some sources show parallel behaviour but are more 'radio quiet'

Same source, same state, same luminosity, different jet power ...

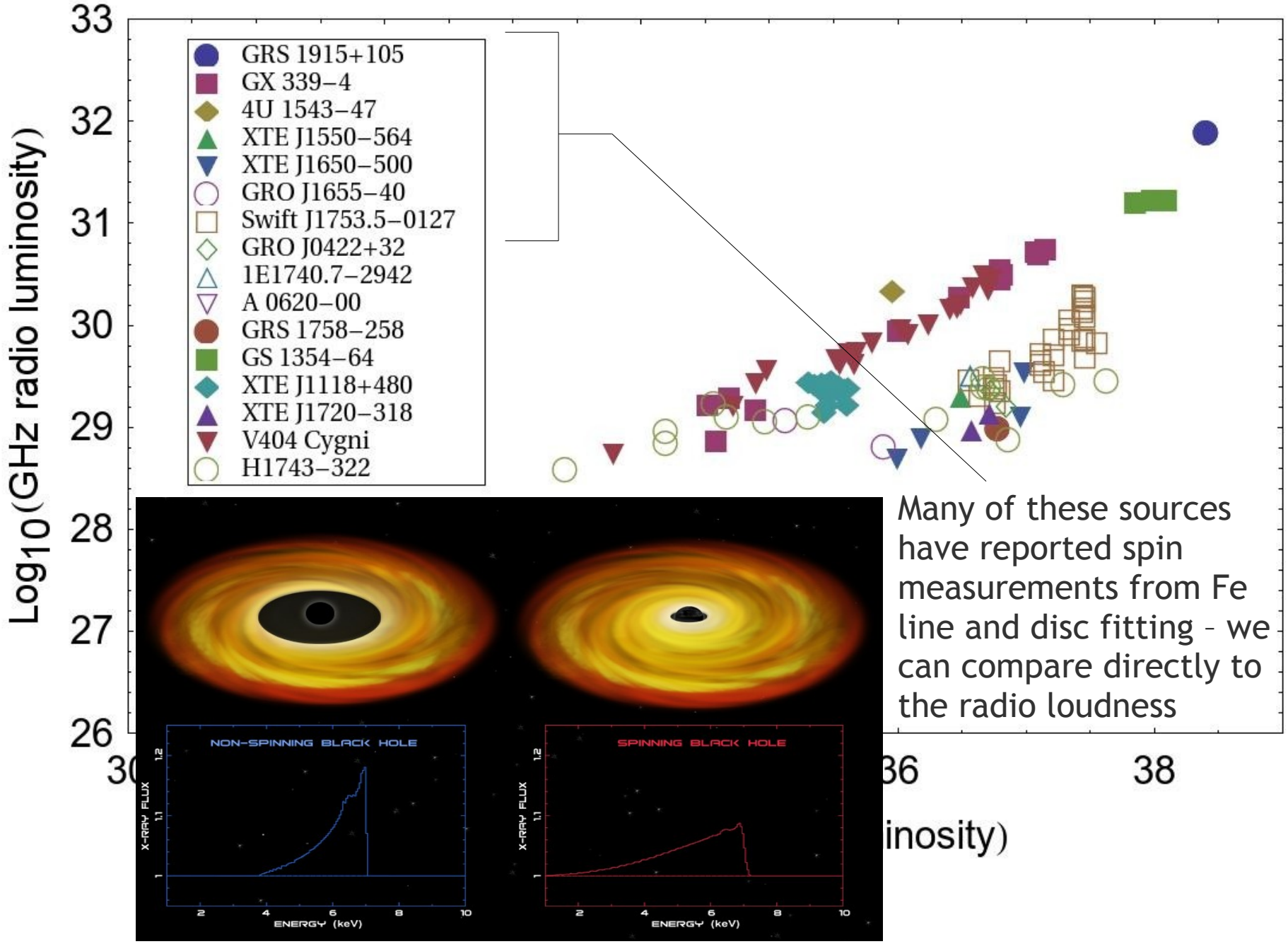
The X-ray : radio correlation – we thought it was like this
(e.g. Gallo, Fender & Pooley 2003)



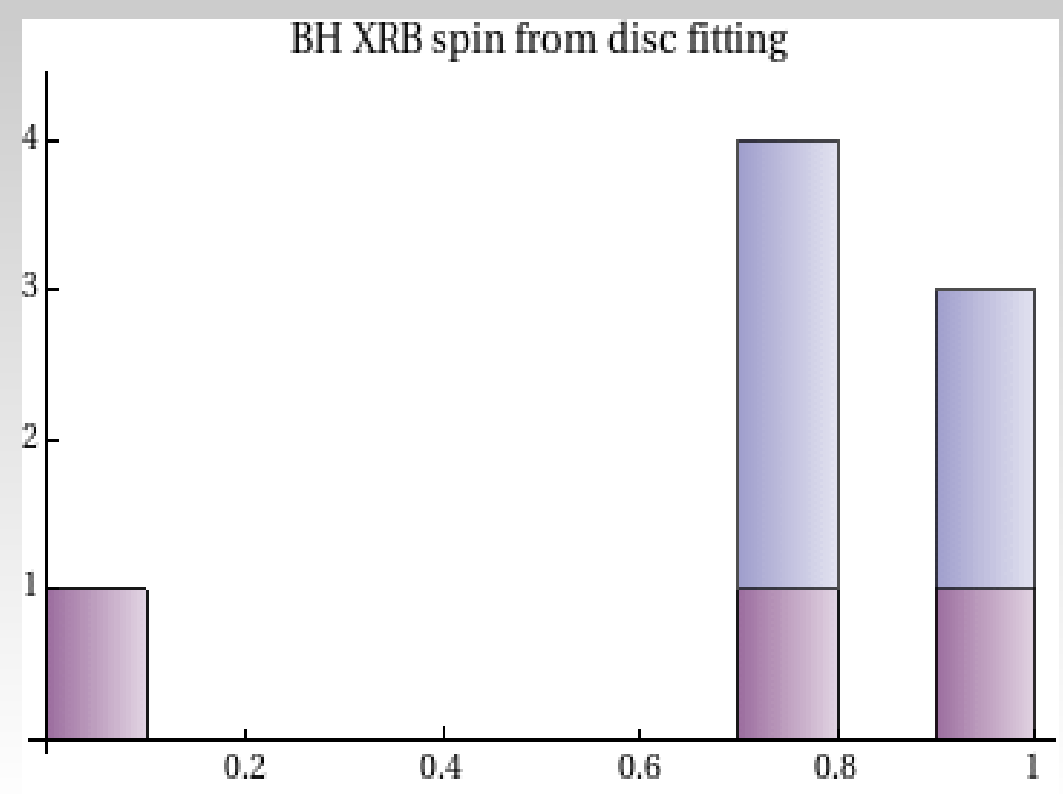
But in fact it is like this (minus Cygnus X-1): **Two tracks ?**
(Calvelo et al. 2010)

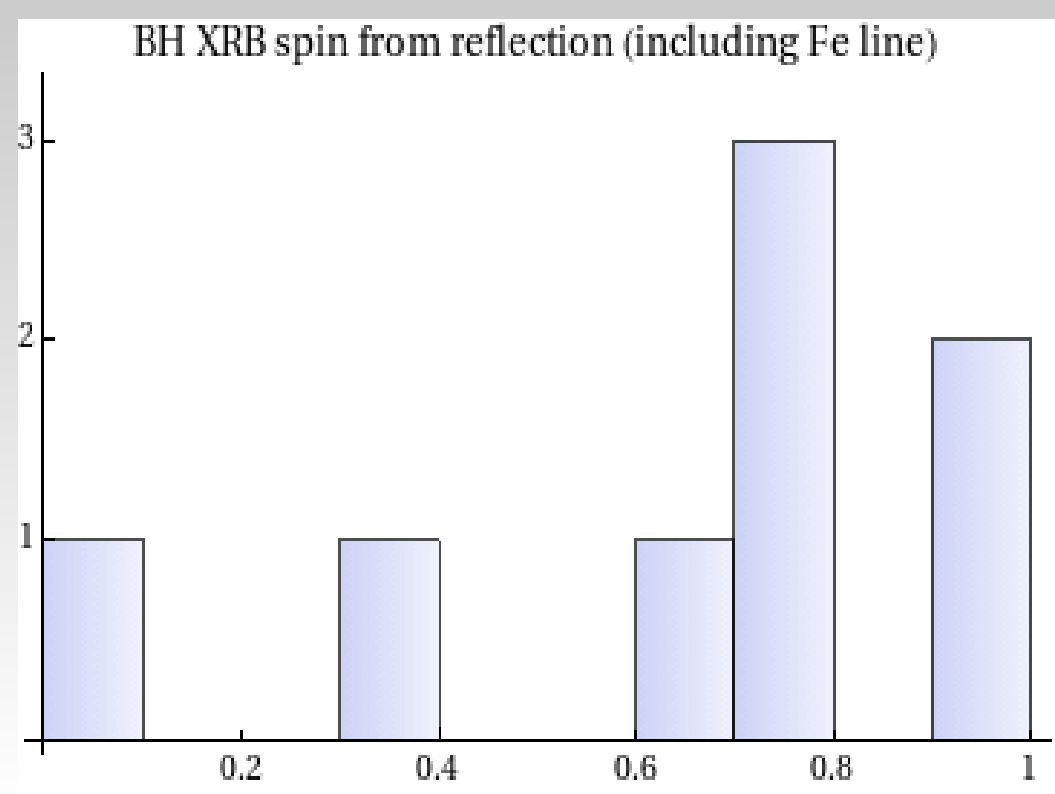


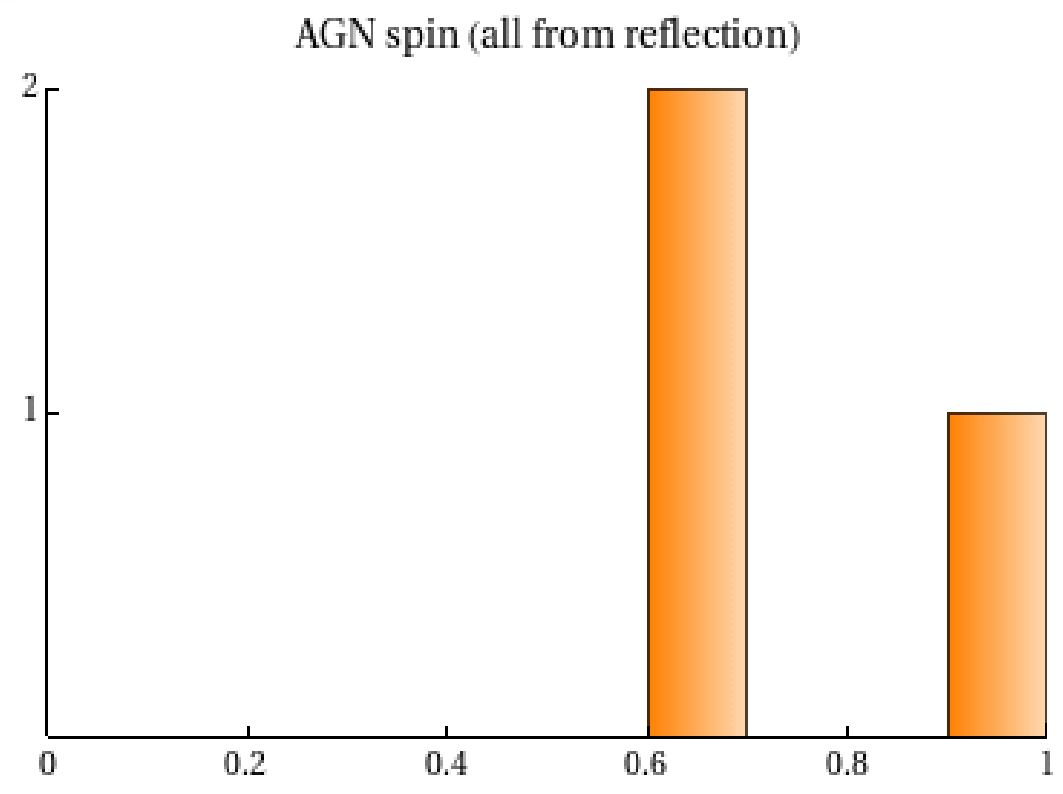
Unlike in AGN there are a set of reported spin measurements for these source

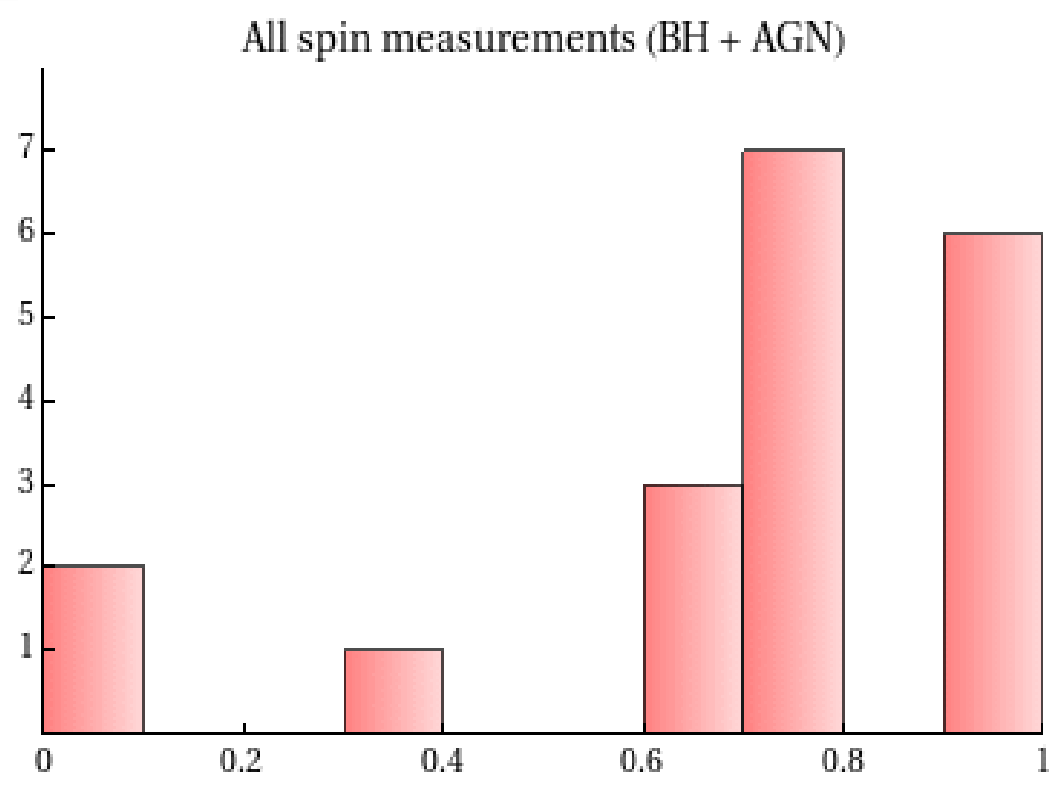


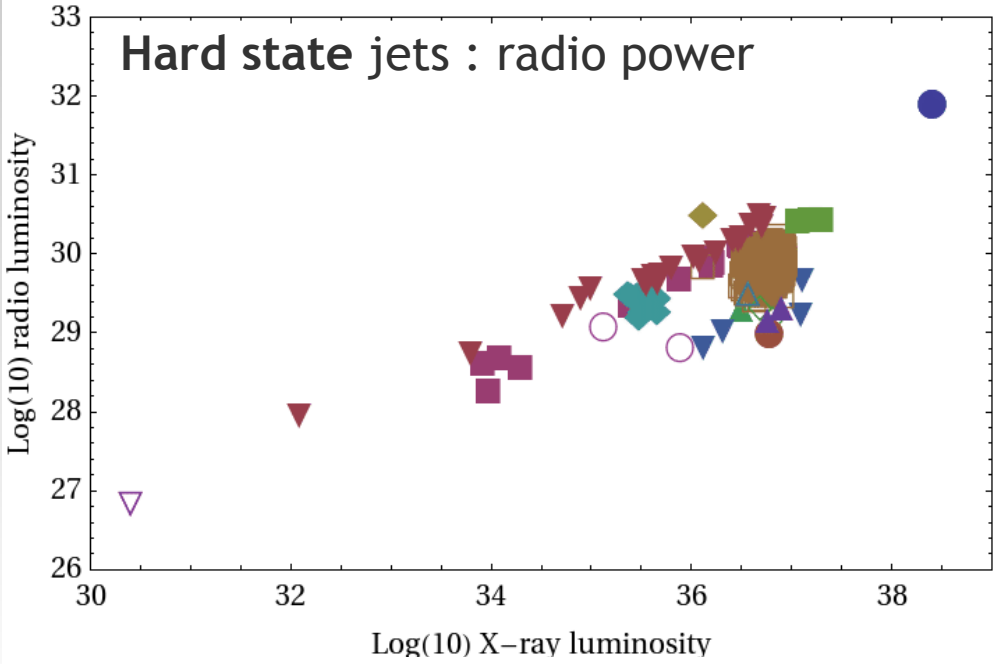
Many of these sources have reported spin measurements from Fe line and disc fitting – we can compare directly to the radio loudness

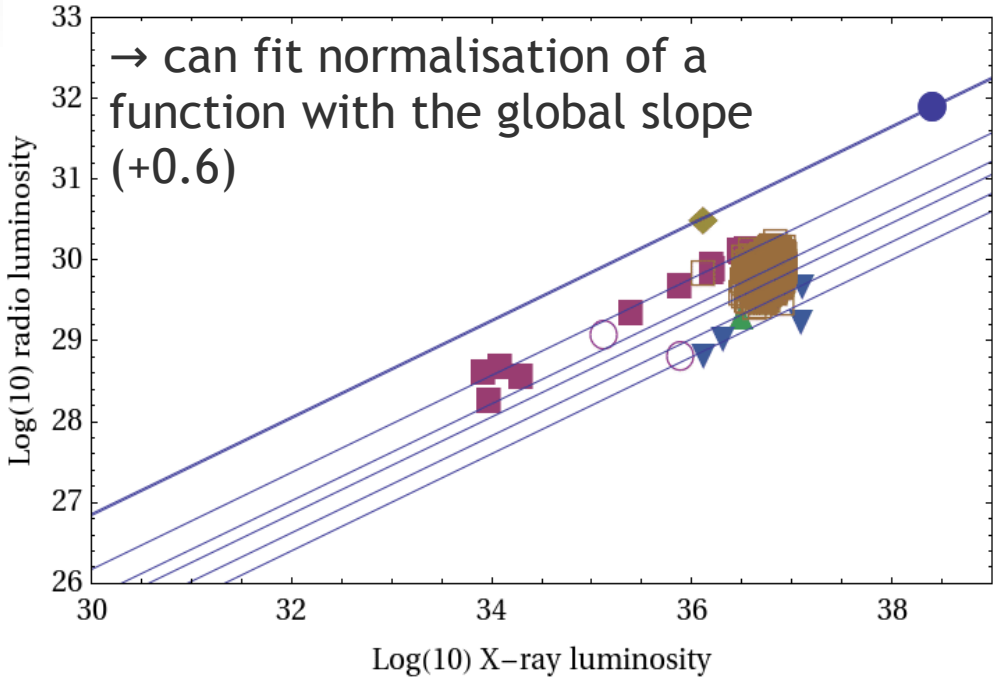

BH XRB spin from disc fitting
4
3
2
1
0.2
0.4
0.6
0.8
1


BH XRB spin from reflection (including Fe line)
3
2
1
0.2
0.4
0.6
0.8
1


AGN spin (all from reflection)
2
1
0
0.2
0.4
0.6
0.8
1

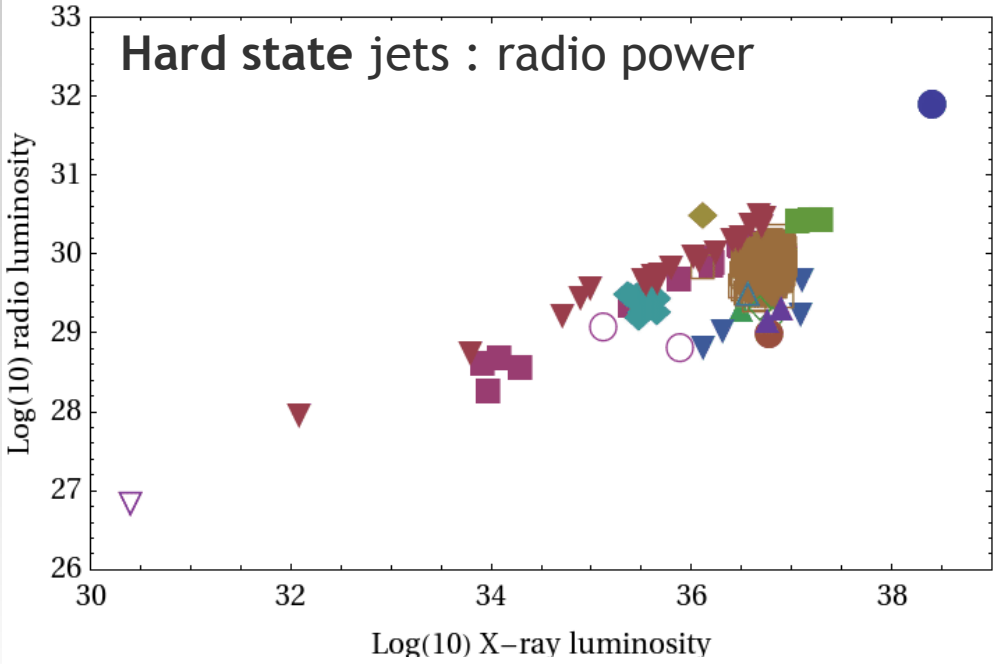

All spin measurements (BH + AGN)
7
6
5
4
3
2
1
0
0.2
0.4
0.6
0.8
1

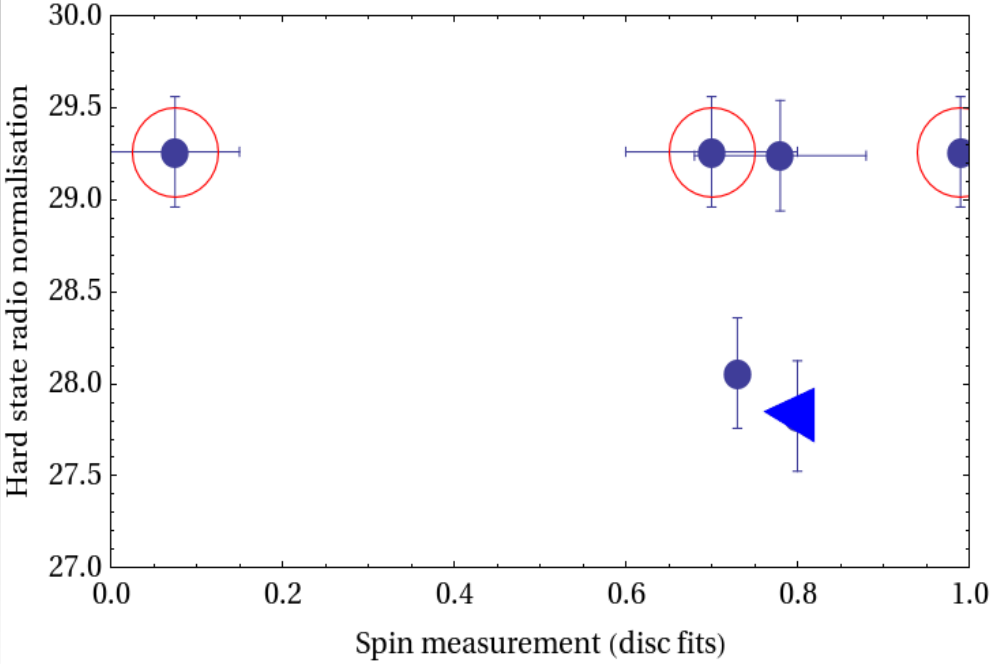


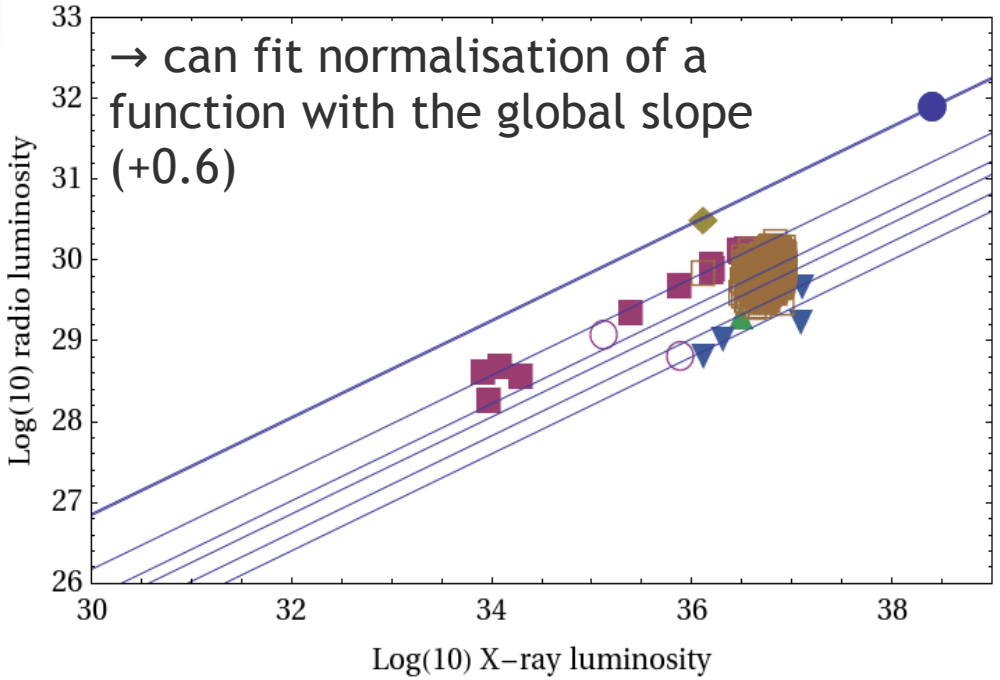


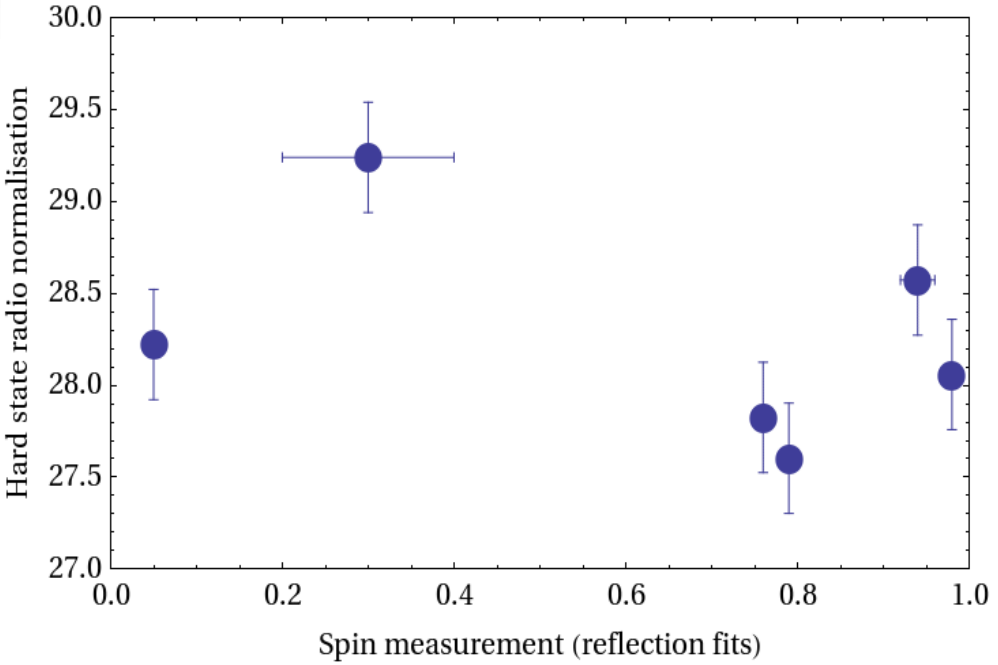
Fender, Gallo & Russell (2010)

We can take take these estimates of the radio power and compare them directly with reported spin measurements from X-rays...









Fender, Gallo & Russell (2010)

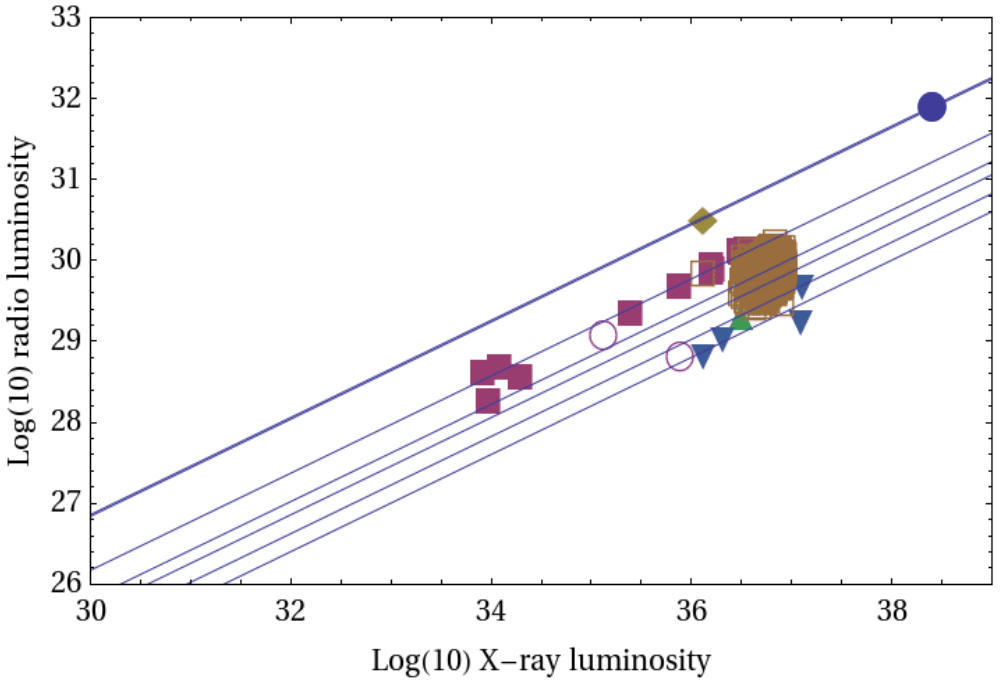
There is no correlation of any of the jet parameters (radio power, speed) with

- **Reported spin measurements**

- **Any other known binary parameter (binary separation, inclination, disc size)**

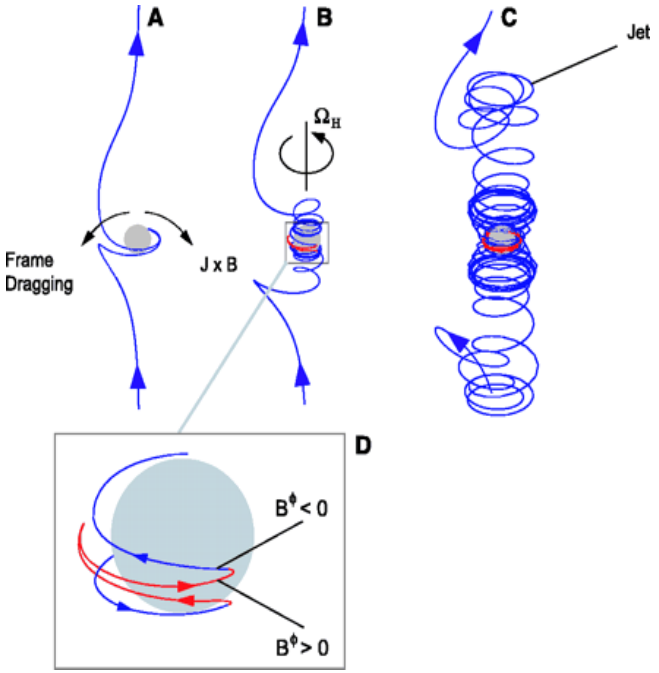
- **Furthermore, the radio-quiet BH are not really distinguishable from neutron star systems in the radio:X-ray plane**

Fender, Gallo & Russell (2010)
Soleri & Fender (submitted)

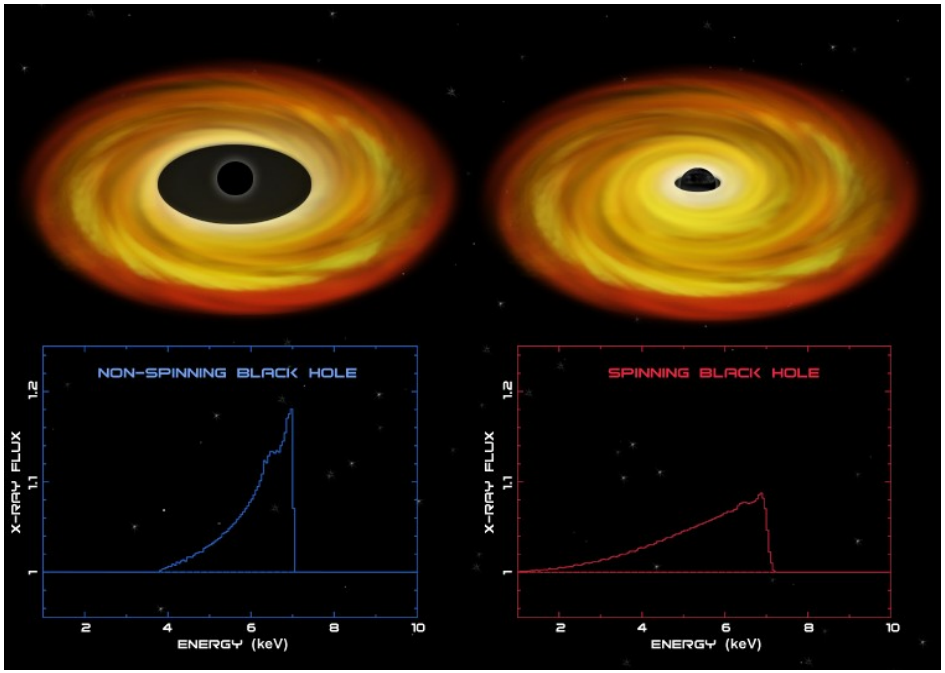


So one or more of these statements is true for black hole binaries

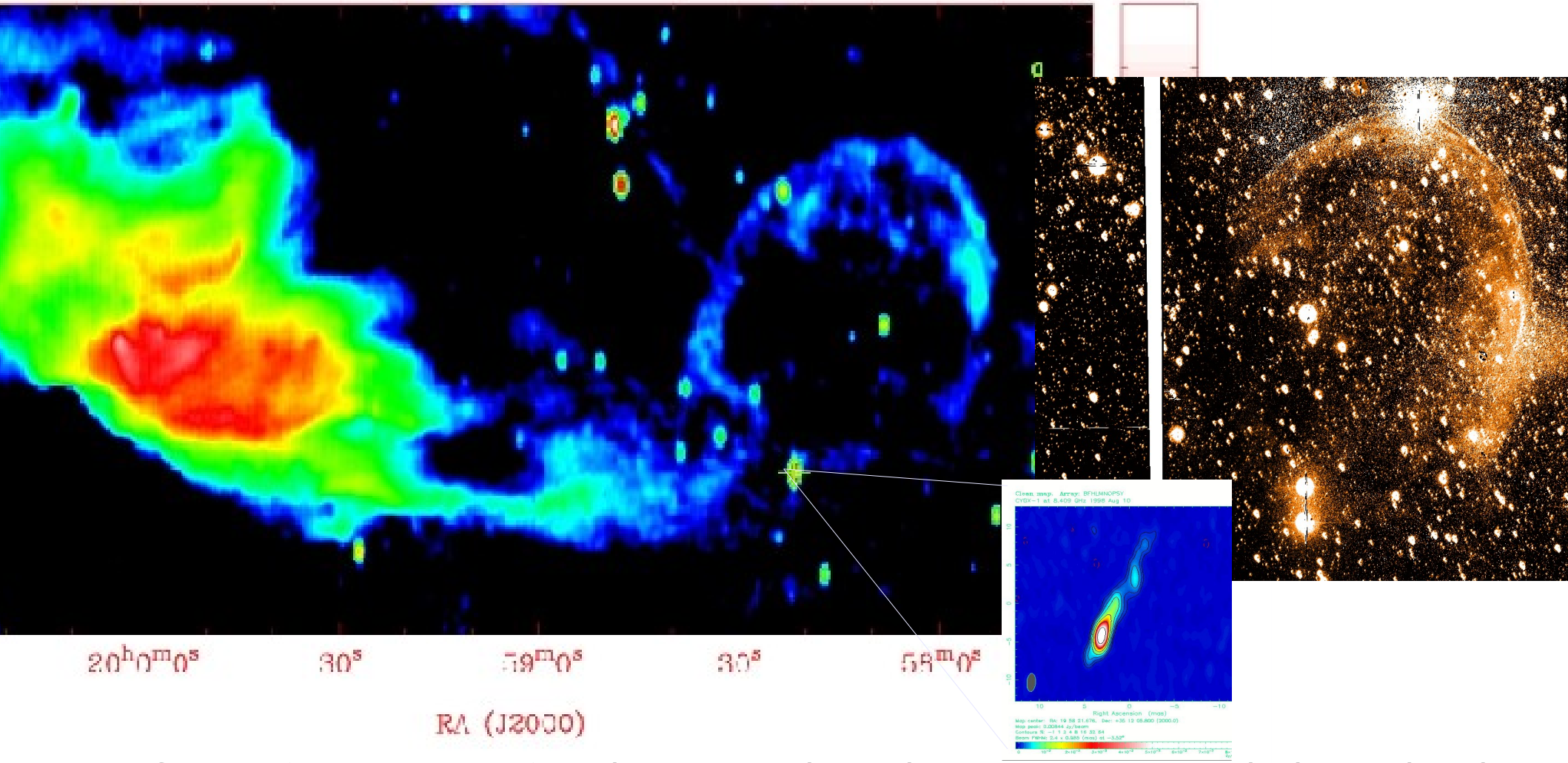
- The jet power estimates are wrong
- The spin measurements are wrong
- Spin is not important for jet power (i.e. Blanford-Znajek not important)



?



The lowest reported spin has a strong jet (Gallo et al., Russell et al.)



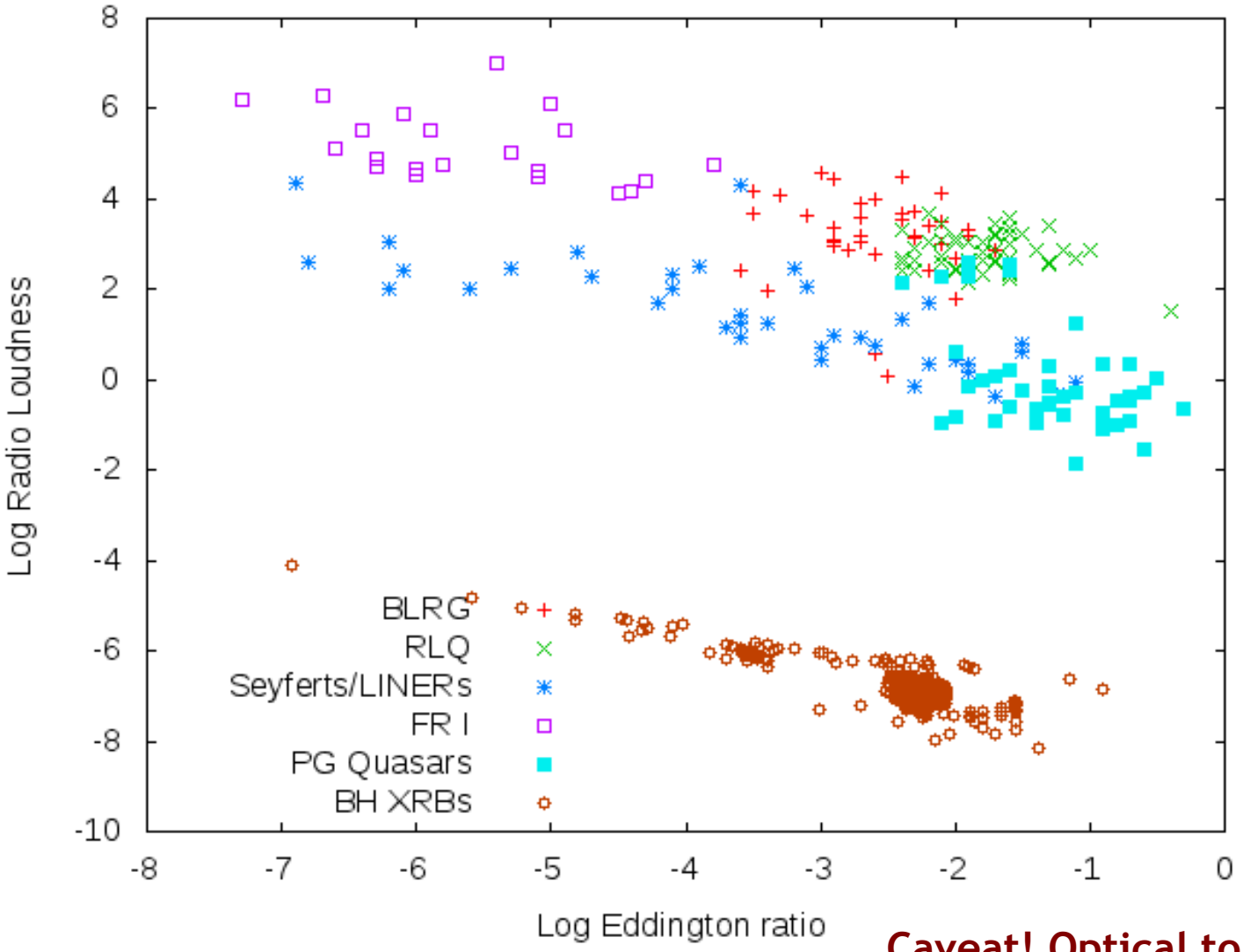
For Cyg X-1 **(a=0.05+/-0.01)** we have strong lower limits on jet power which are already comparable to the X-ray luminosity **and to the (mass normalized) jet power of (LL)AGN** (see also Heinz 2006; Malzac et al. 2009 .. lots of work on this jet)

McKinney (priv. comm.) – ***if*** *the spin measurement of Cyg X-1 is correct,* ***and*** *you observe a highly relativistic jet from it, then our current models and theories are wrong*

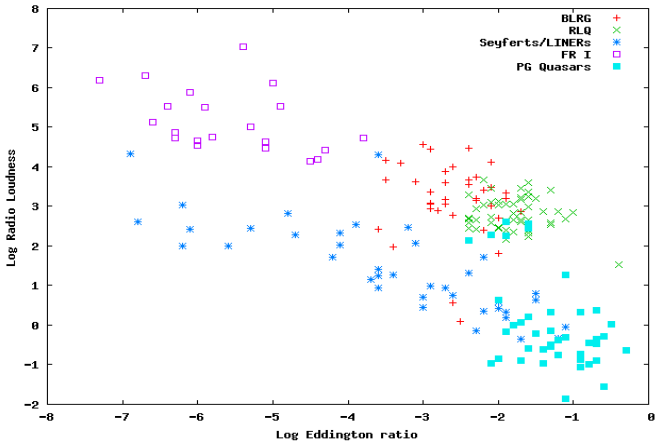
So what's going on with the Sikora et al. result ? We attempt to make two corrections

1. Mass term : $L_{radio} / L_x \sim M^{0.8} L_x^{-0.4}$

Predicted by Heinz & Sunyaev(2003) – larger mass = lower optical depth in the jet
Observationally established by Merloni et al. (2003), Falcke et al. (2004)

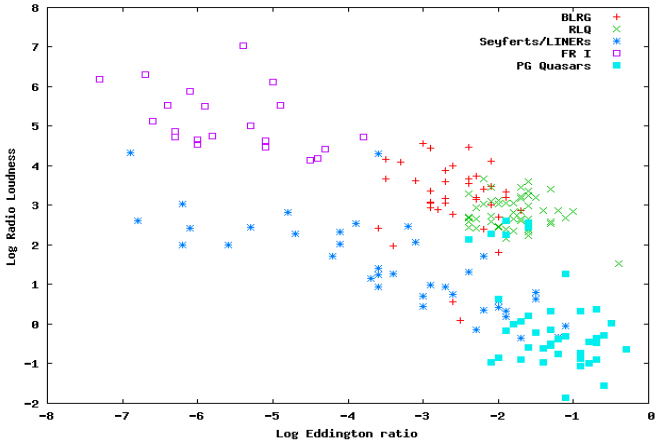


Caveat! Optical to X-ray conversion



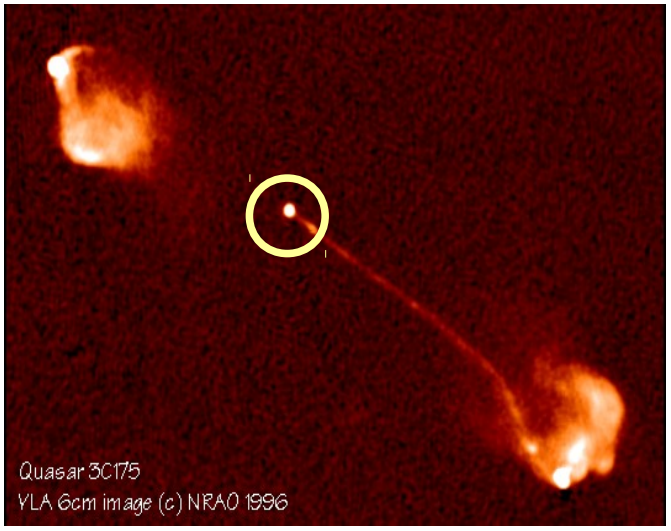
Sikora et al. data **with the mass correction (dividing by $M^{0.8}$)**

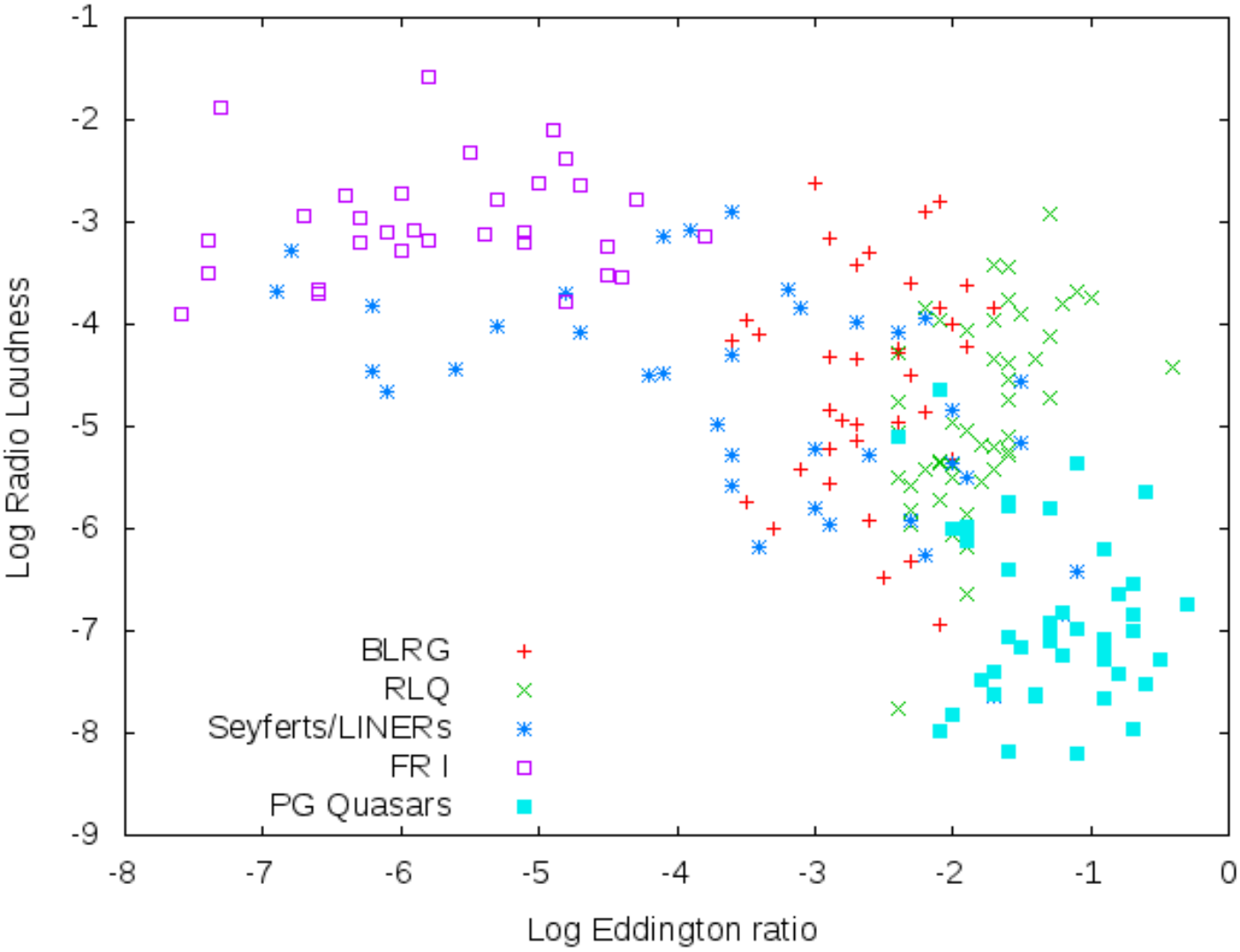
The gap between the two tracks is closed considerably, but not totally

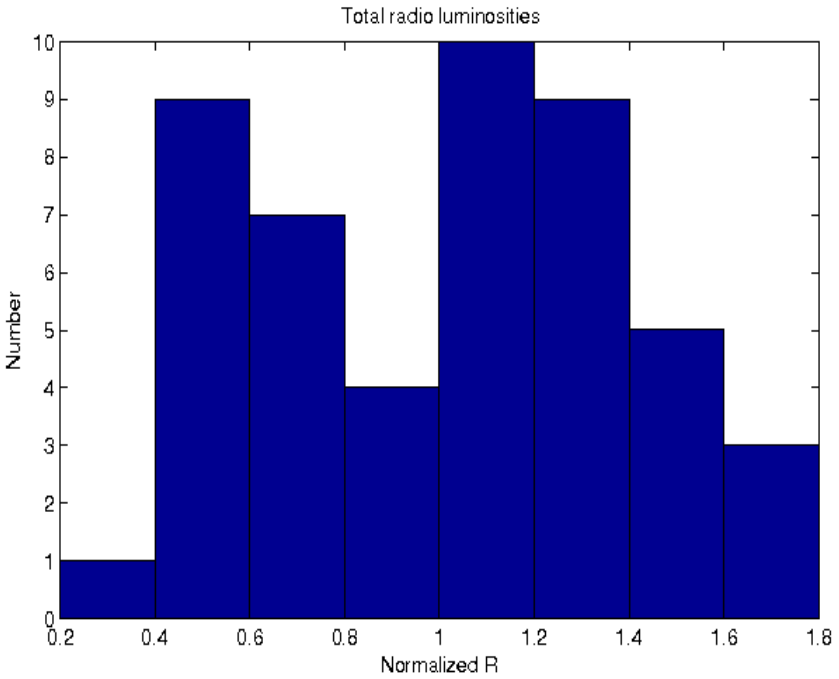


2. A further correction – the use of **only core radio luminosities** – collapses the 'dichotomy' almost completely (in fact there remains a statistically significant difference at the level of a few in jet power – not orders of magnitude) Broderick & Fender (in prep)

The tracks nearly merge and are ~indistinguishable when only core radio luminosities are used

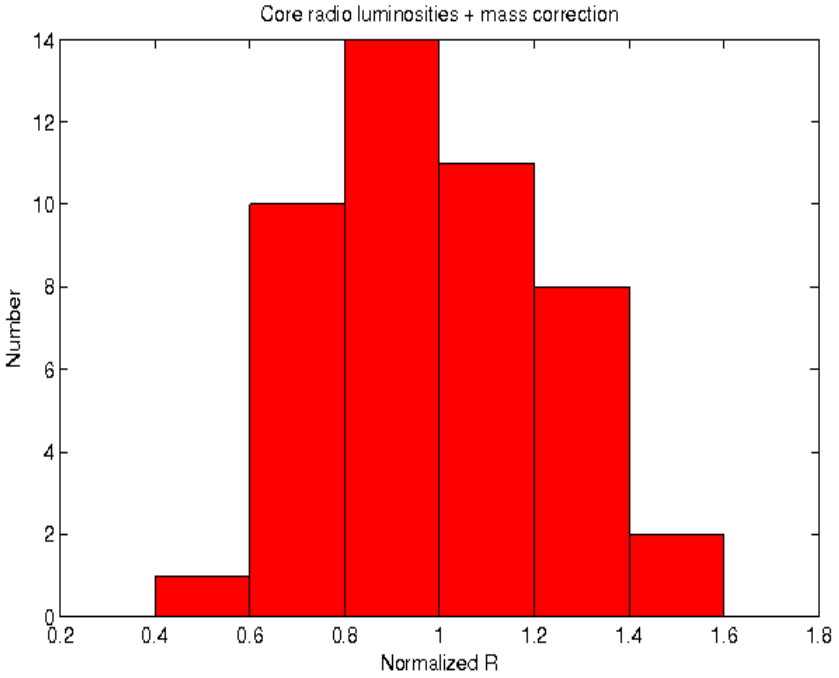






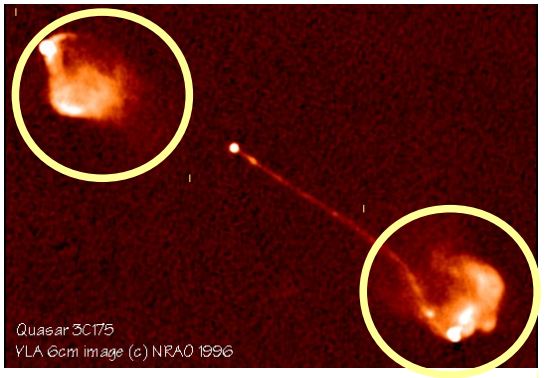
Distribution perpendicular to correlation

Sikora et al.



Broderick & Fender
(mass correction, core only)

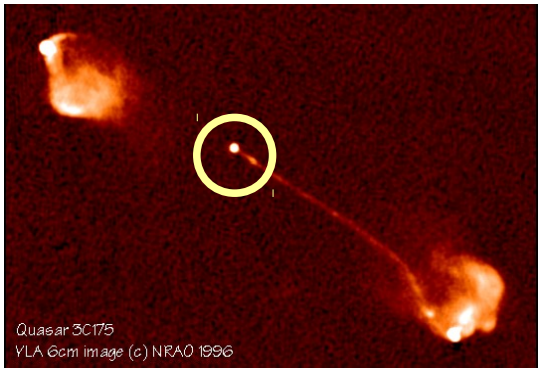
Should we use core or extended emission ?



Extended emission (=bimodality)

• **Pros:** unbeamed

• **Cons:** must be affected by environment (jets in a dense environment are brighter than jets in a vacuum). Time-averaged, but compared with instantaneous core optical, X-ray etc measurements.



Core emission (=no bimodality)

• **Pros**: Instantaneous measurement – good for comparing to X-ray, optical, etc. Not affected by large-scale environment. The only relevant measurement for comparison to X-ray binaries.

• **Cons:** could be beamed (but seems unlikely that beaming alone could remove and collapse a real intrinsic bimodality). Doesn't really (yet) explain why only ellipticals on upper track.

Summary

X-ray binaries have shown us that 'radio loudness' can change dramatically in the same source on short timescales → on its own it is not a measure of spin

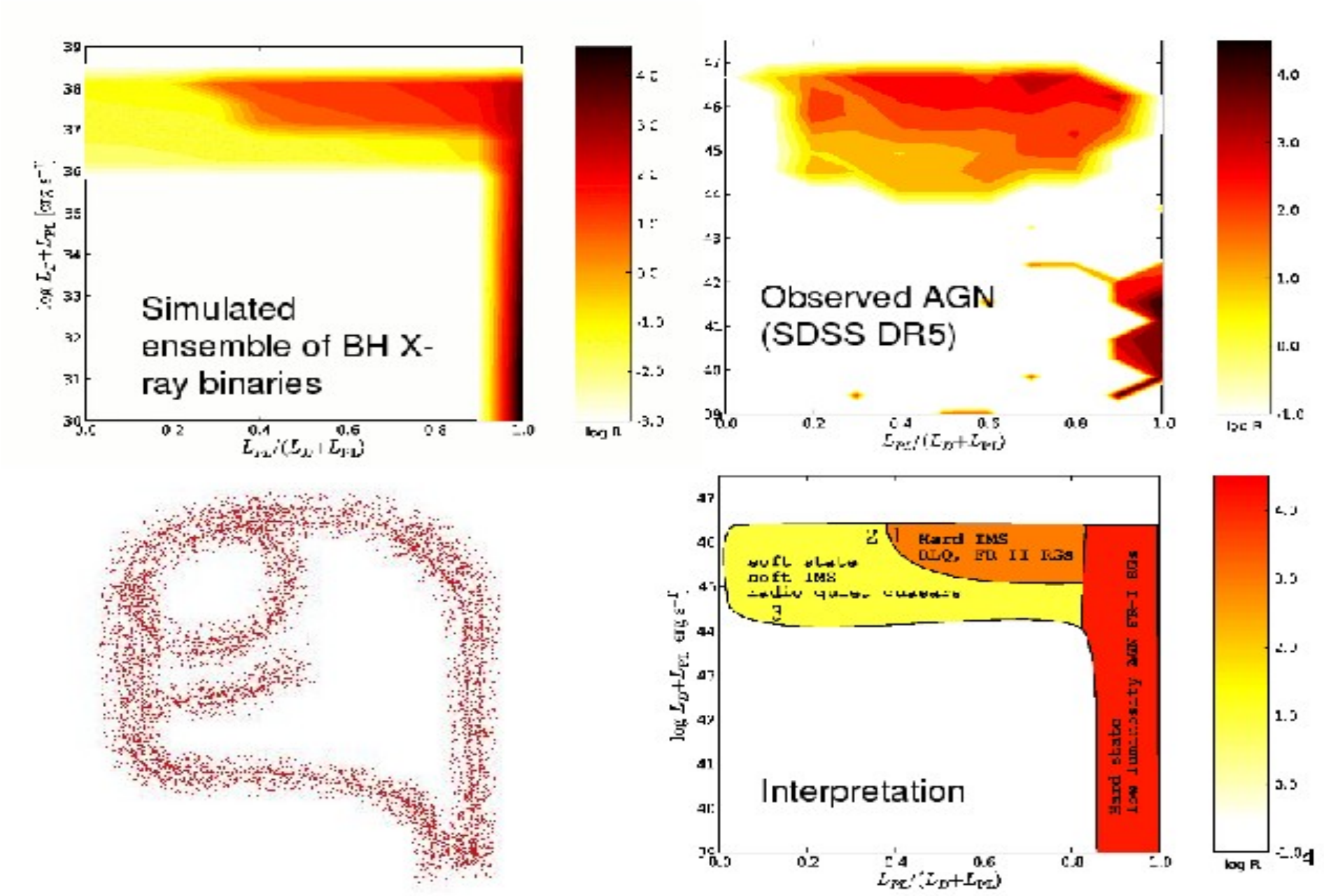
There is no correlation between reported spins and jet in binaries. This means that one of the following is correct:

(I) radio measurement are wrong / it is not a good measure of jet power
and/or (i) spin measurements are wrong
and/or (ii) spin doesn not power jets from black holes

Revisiting the radio-loud:radio-quiet 'dichotomy' in AGN, we find that it **is not there** (to any great extent) when **mass corrections are applied** and **only core radio emissions is used.** This is not a surprise in the context of the history of 'radio loudness' in AGN.

→ **If** spin is responsible for the Sikora et al. Dichotomy then it only affects extended and not core emission. Odd. Surely environment and age are equally plausible ? Might screw up useful comparisons with XRBs (but they work..)

Conclusion: T**here is at present essentially no strong evidence for spin-powering of jets from black holes of any mass, AGN or X-ray binary.**



Koerding, Jester & Fender (2006)
[also Marscher et al., Merloni et al., Falcke et al.]

Perhaps spin really has nothing to do with the tracks..
BH binary H1743-322 appears to 'change tracks' during decline