Observational characteristics of black hole accretion

The Blandfords
(Jet models / Flat spectra / Connection of jets to spin)

The Blandfords

Three important papers of relevance to jets

1. Blandford-Payne (1982)

'Bead on a wire' production of jets by accretion discs

2. Blandford-Konigl (1979)

Production of flat radio spectra by stratified jets

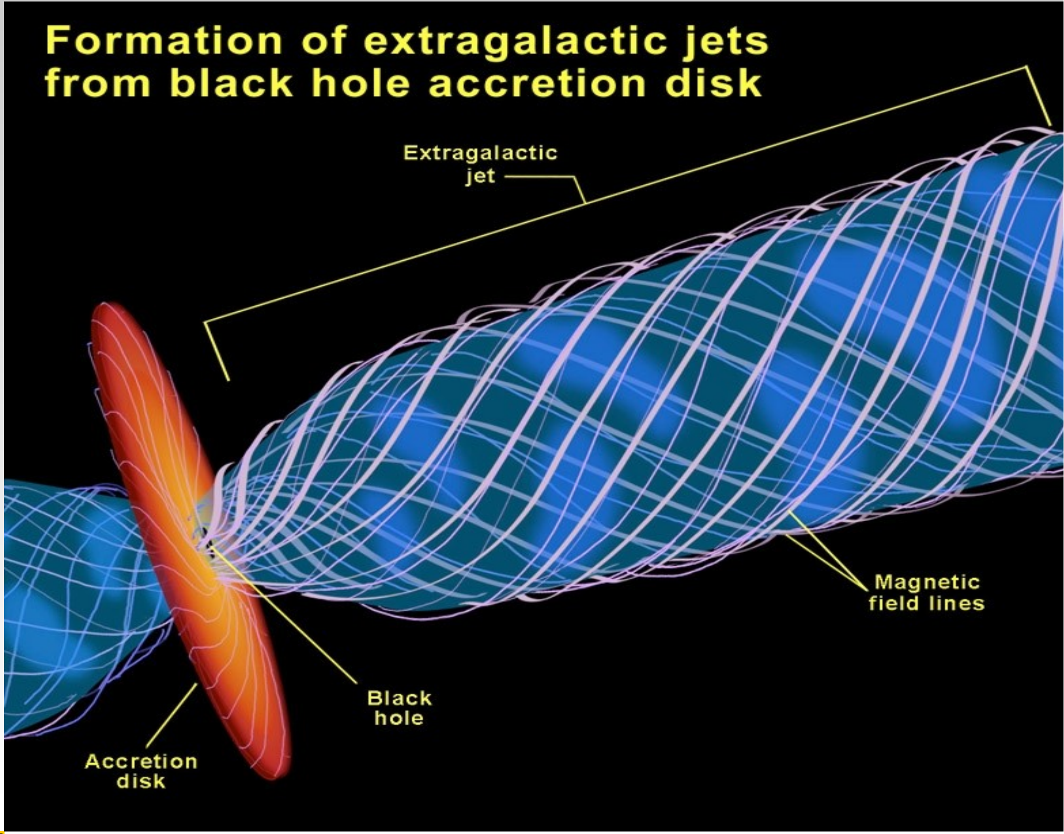
3. Blandford-Znajek (1977)

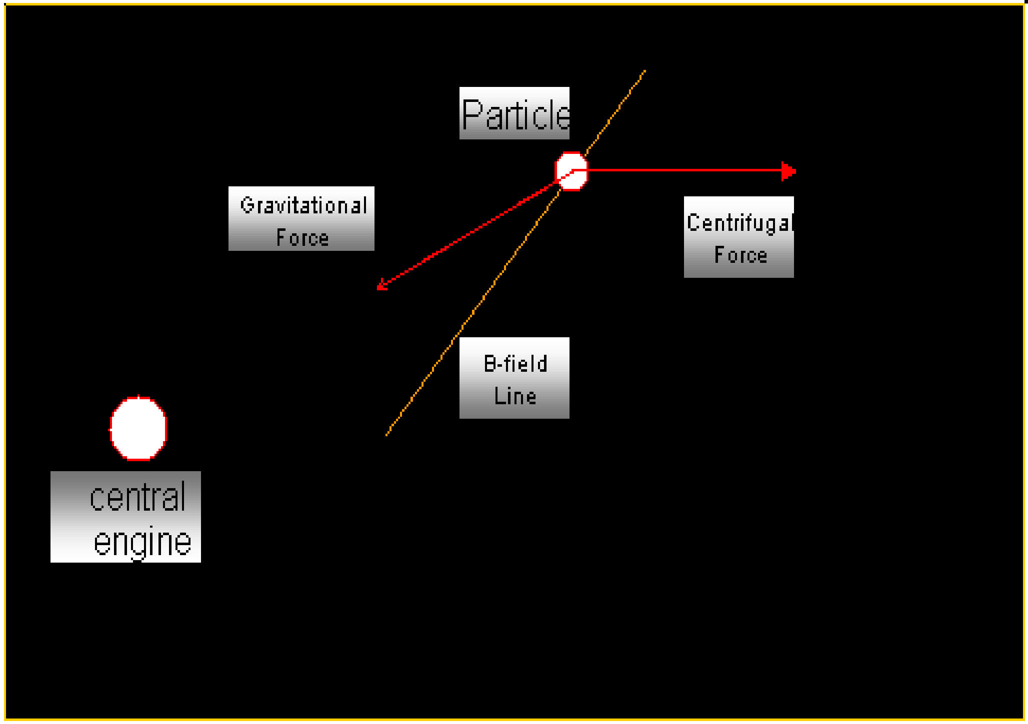
Powering of jets by black hole spin

(and of course there are many many more Blandford works of relevance...)

Blandford & Payne (1982)

Hydromagnetic flows from accretion discs and the production of radio jets





All models of relativistic jet formation require magnetic fields

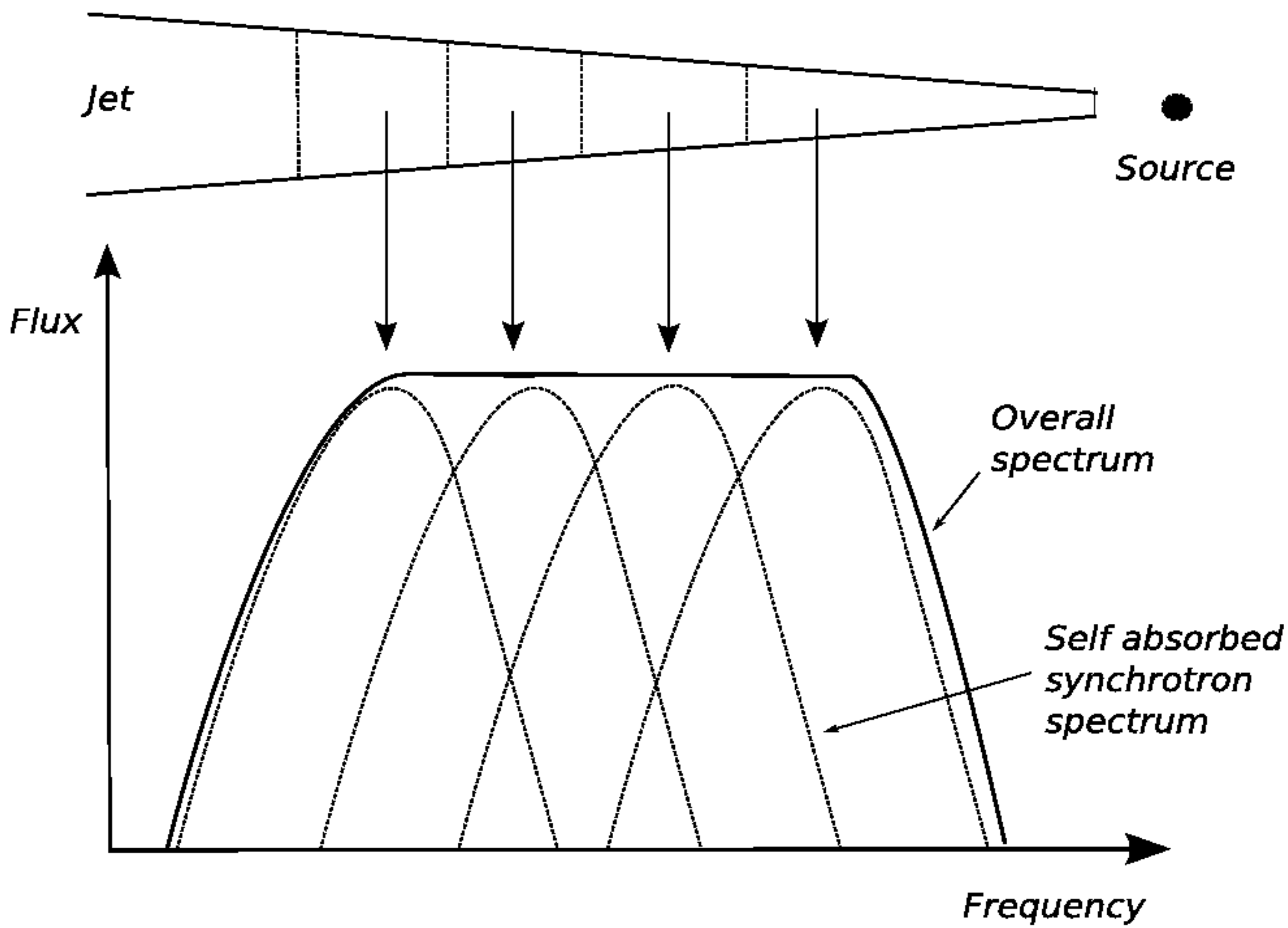
None of the numerical simulations consider all the physics – we <u>do not know</u> exactly how the jets are launched.

In 'bead on a wire' models like B-P 1982, centrifugal force can 'throw' out particles which are tied to magnetic field lines (in their case when angle to vertical > 60º)

The jets then need to somehow collimate..

Blandford & Konigl (1979)

Relativistic jets as compact radio sources



Superposition of synchrotron emission from different parts of a conical jet can produce a flat sprectrum across a broad frequency range

Emission at a given frequency arises from region where optical depth $\tau \sim 1$

The distance to this point (~ apparent size of jet) scales as ν^{-1}

This seems to explain many of the properties of black hole radio 'cores'

But: the model requires a 'magic' reheating of the jet material to keep it 'isothermal'. Without the reheating the spectrum is not flat for more than ~one decade in freq.

Maybe this reheating is via **internal shocks**.

Simulation of 1500 shells at ~1 / sec and small range in Γ

Notice

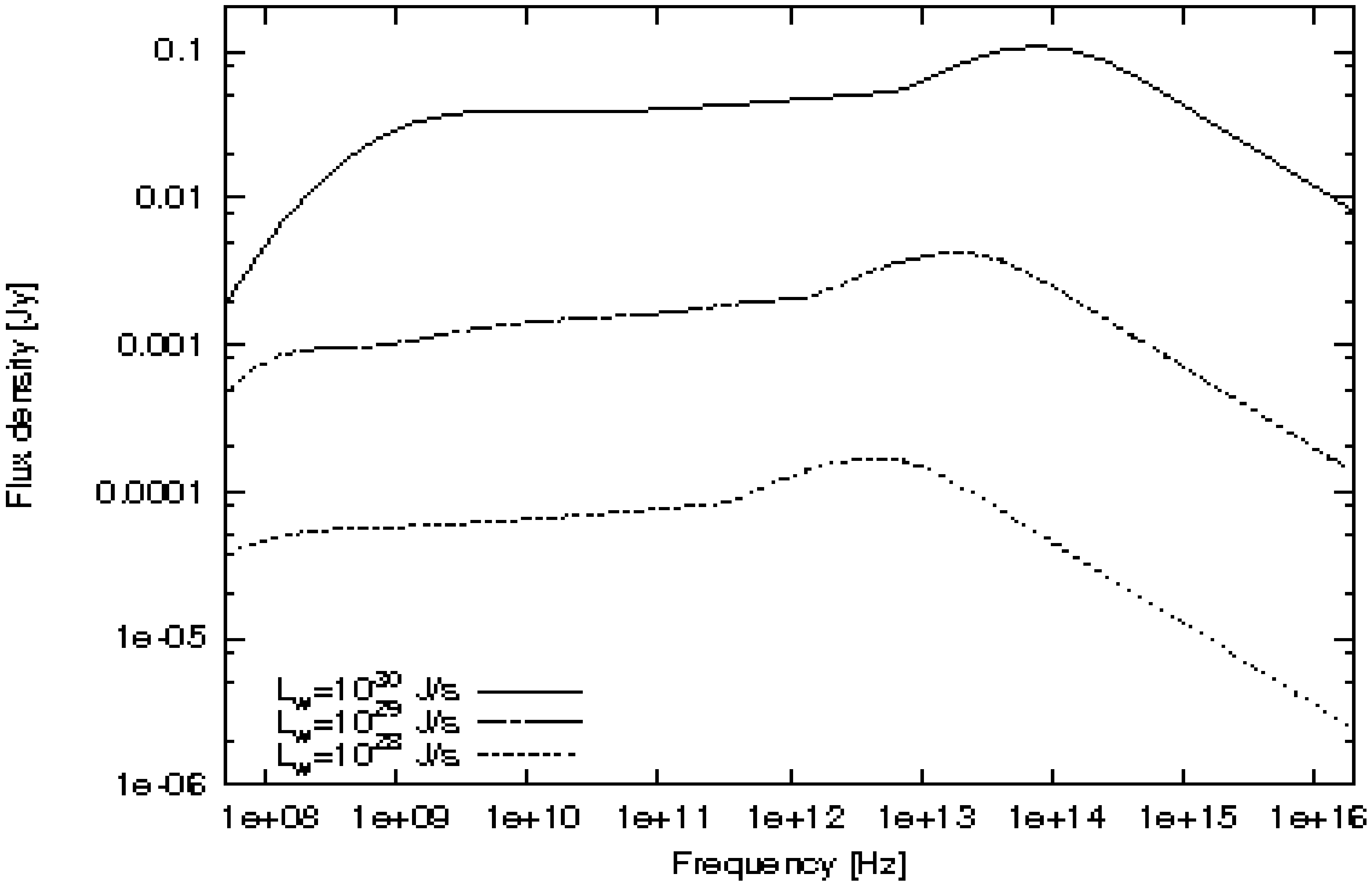
1. Merging and reacceleration of shocks further out in flow

2. Initial peak of IR compared to rising radio (optical depth)

3. Radio flux mostly arises further out than IR

[*iShocks arXiv:0909.1309*]

Using these simulations we can reproduce the observed flat spectrum as well as predicted scalings of the break frequency ($\nu \propto L_{jet}^{0.6}$) and flux ($F \propto L_{jet}^{1.4}$) with jet power



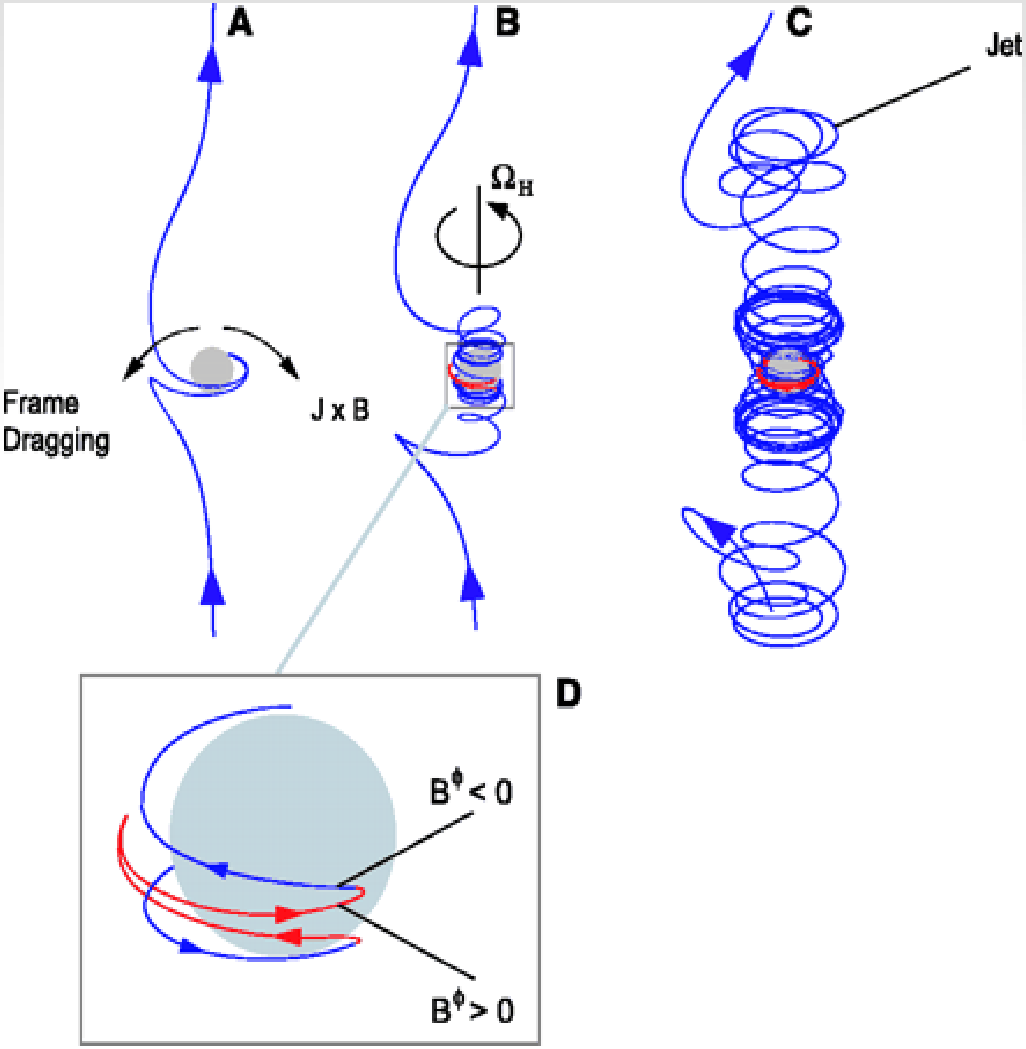
Blandford-Znajek (1977)

Electromagnetic extraction of energy from Kerr black holes

• 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 (**but** see Livio et al. 1999 for arguments against..)

• For a maximally rotating black hole spin can power 10 million years at Eddington (~Salpeter time)



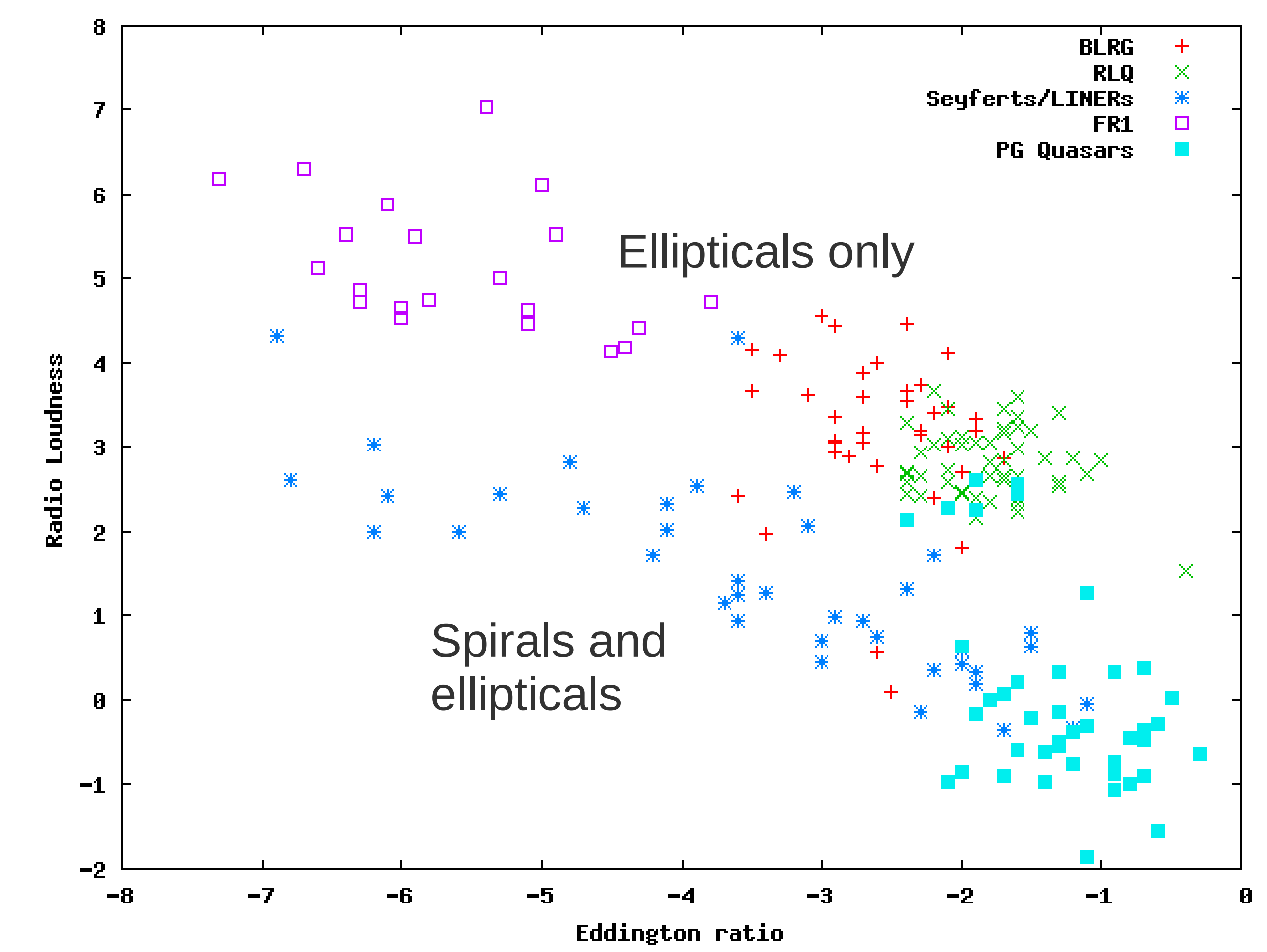
Black hole spin powering of jets: a very attractive idea

- The **spin paradigm** became popular to explain radio loud: radio quiet 'dichotomy' in AGN

- However, studies of BH XRBs showed large changes in radio loudness in the same source as a function of accretion rate and state (clearly **not** spin)

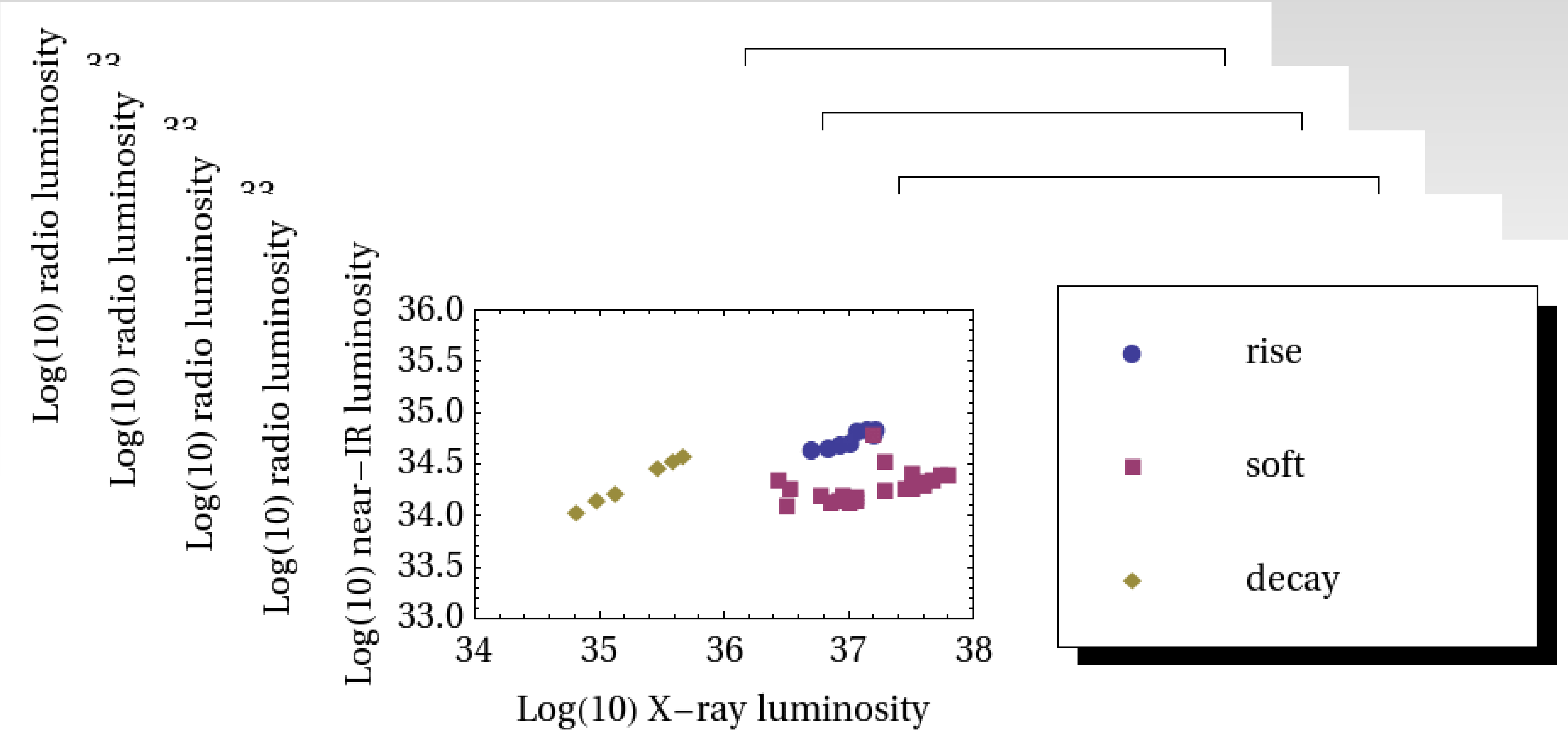
- … but, the 'dichotomy' remains. Sikora et al. (07) suggest that at lower luminosities spin dominates the radio loudness, but at high luminosities XRB-like state changes can have a strong effect

- There seem to be plausible arguments for a dichotomy in spins resulting from different merger histories



Sikora, Stawarz, Lasota (2007)

Its not all spin:X-ray binaries show large changes in jet power and radiative efficiency on short timescales

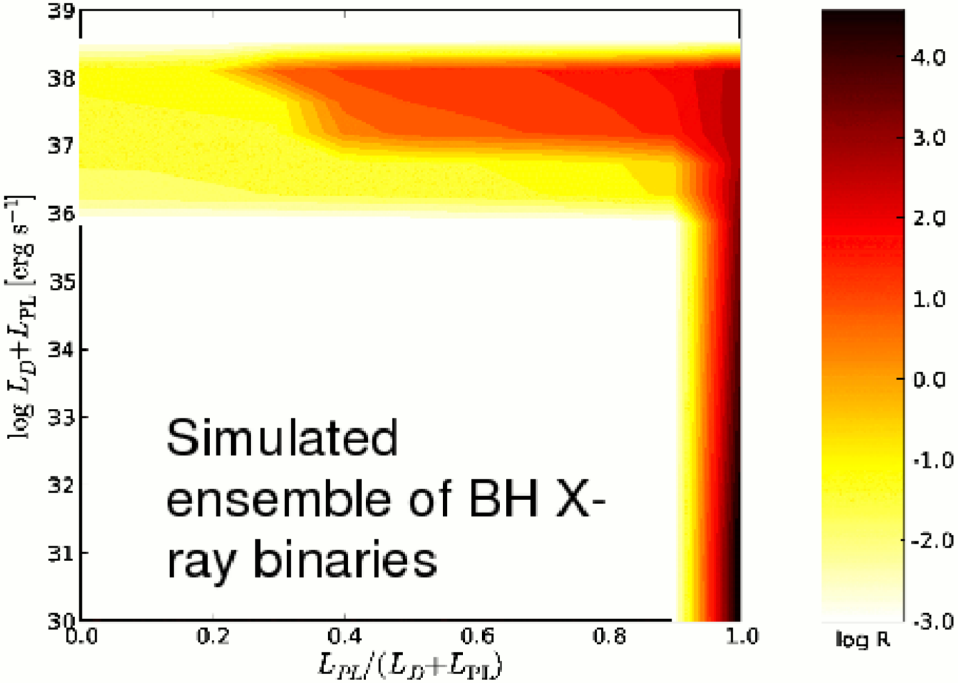


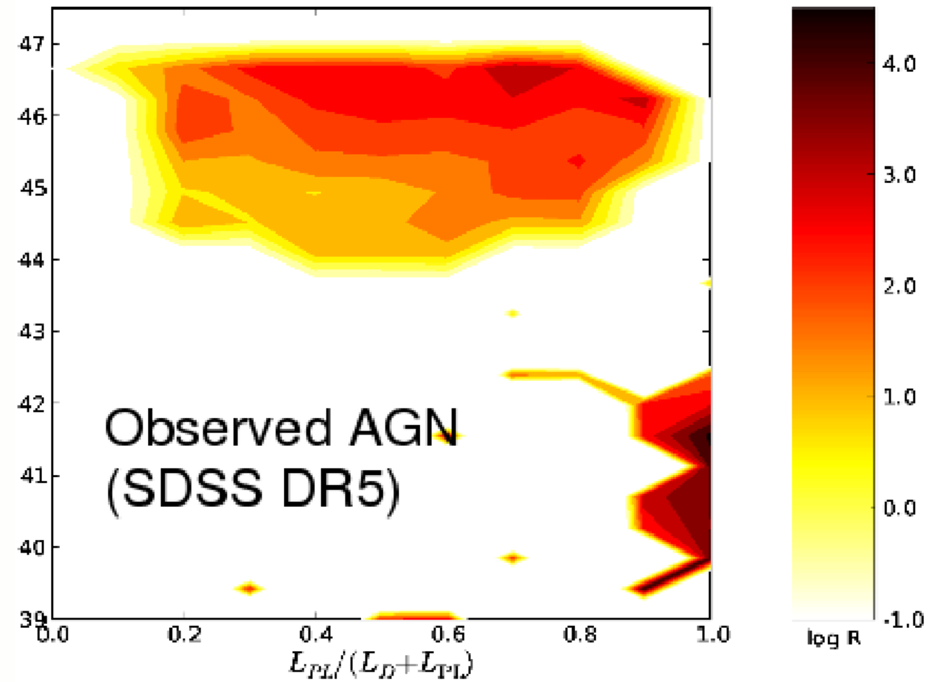
Most of the time (hard state) radio and X-rays nicely correlated

- 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 ...

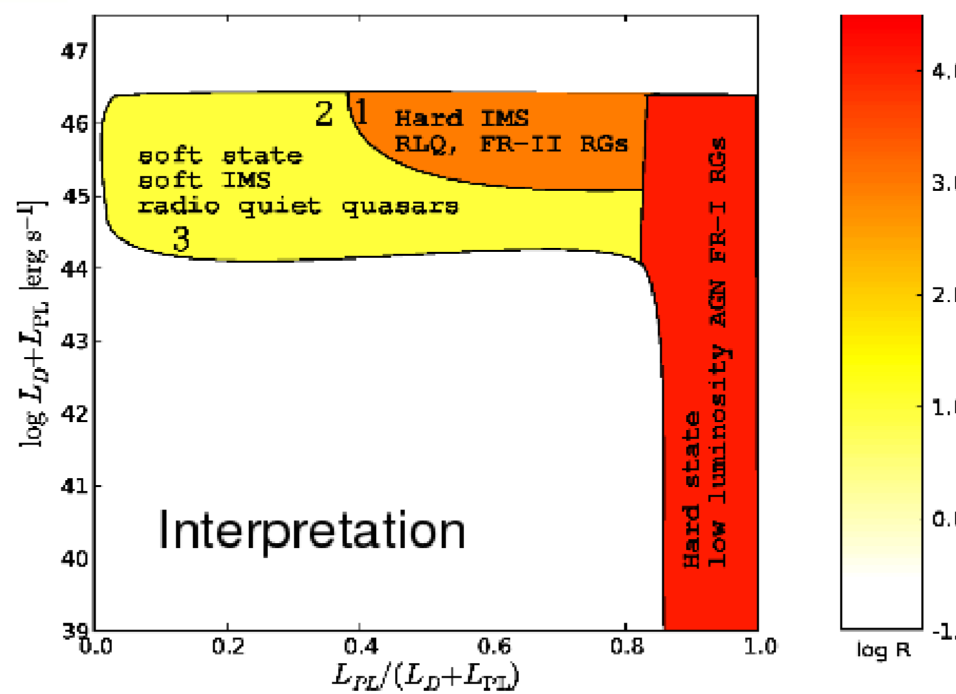
… it would be very dangerous to infer black hole spin from radiative efficiency of accretion flow and/or jet power

Many hints that XRBs and AGN work the same way

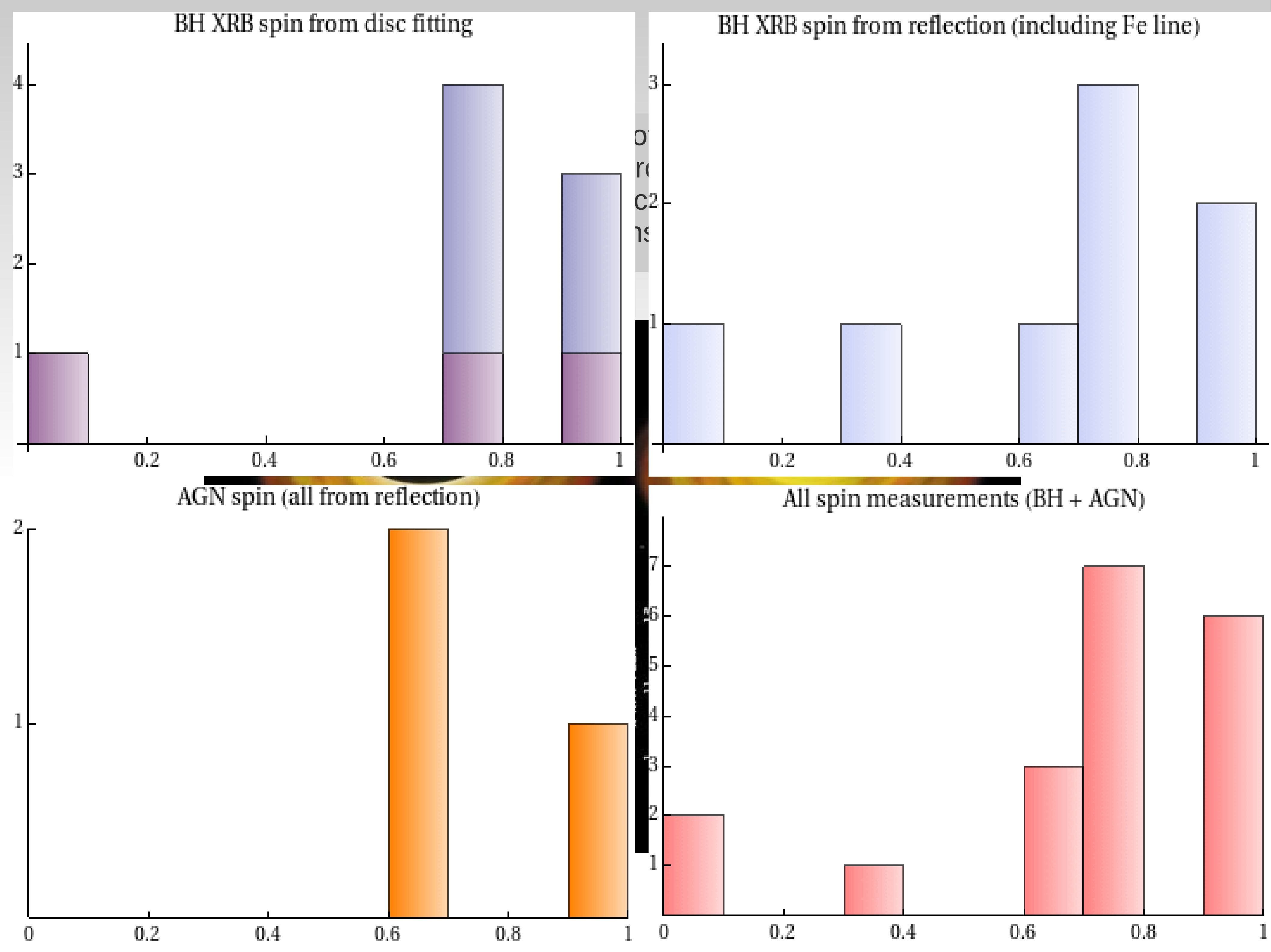




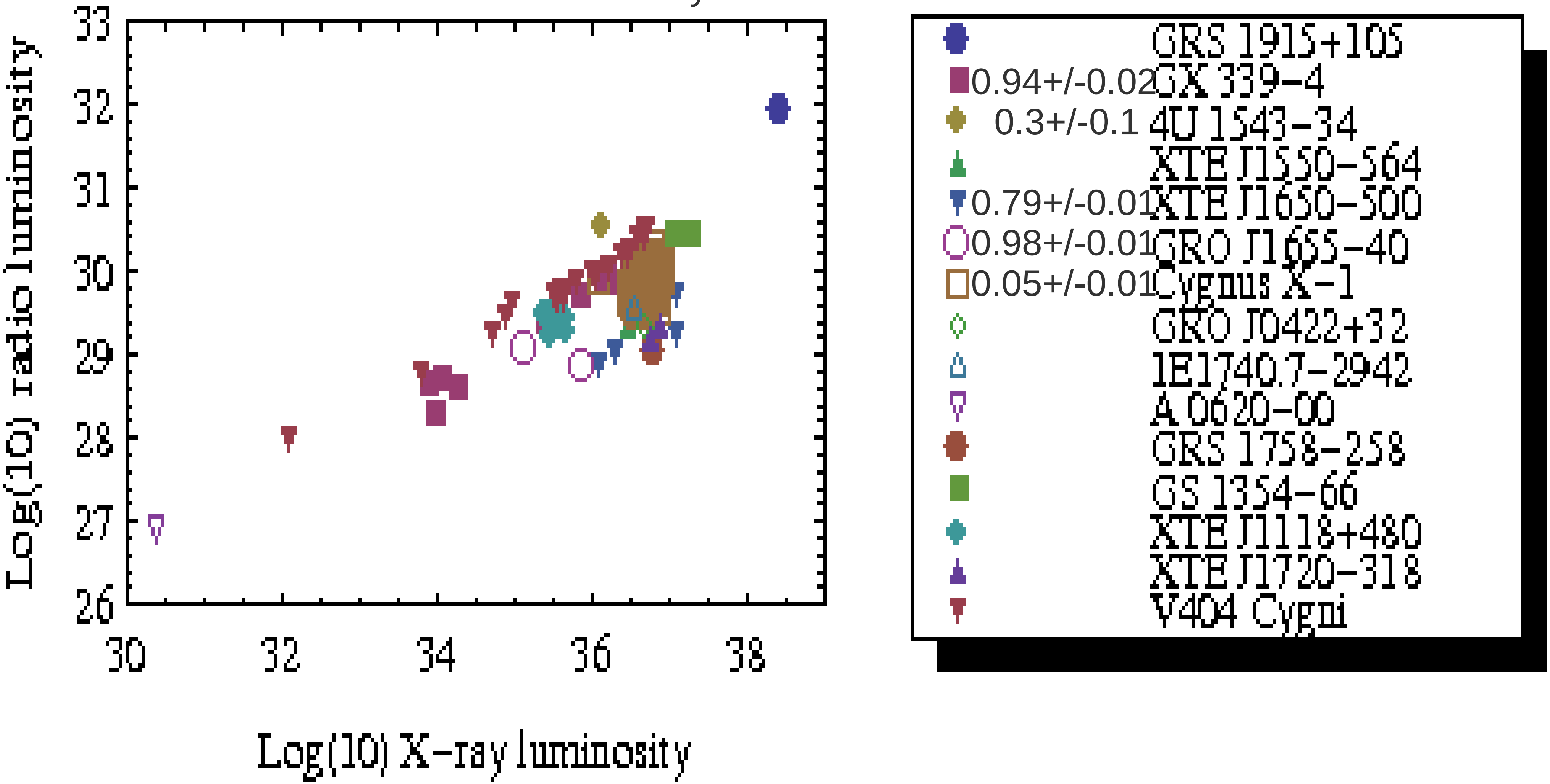
In these 'accretion-only' scenarios any additional parameter beyond accretion rate/state cannot be spin since it changes in the same source on short timescales.



(Koerding et al., Merloni et al., Heinz et al., Marscher et al., McHardy et al., Done et al. .....)

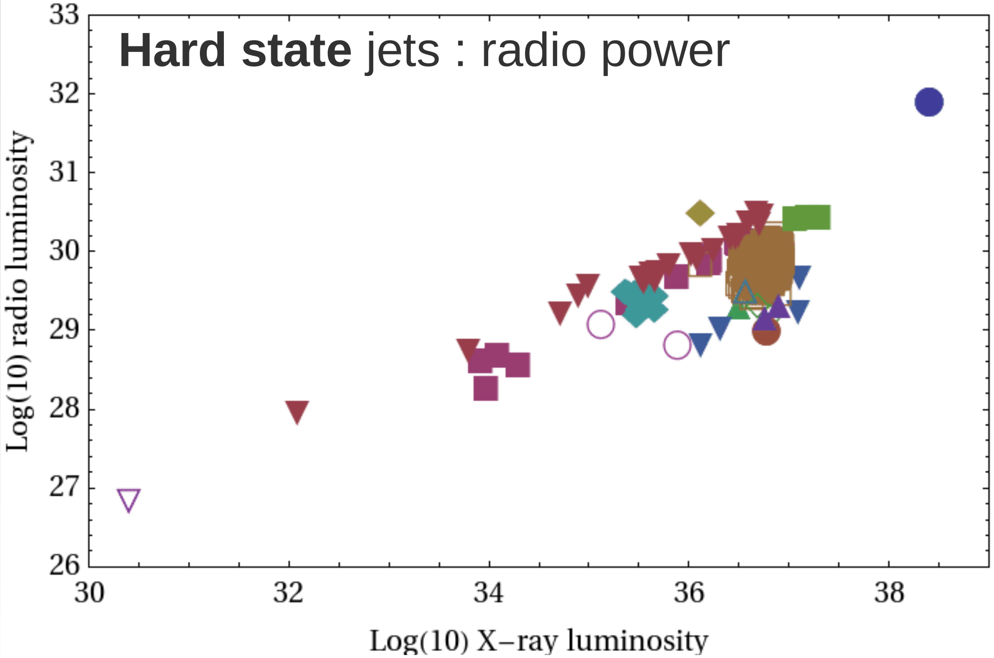

BH XRB spin from disc fitting
0.2
0.4
0.6
0.8
1
1
2
3
4
BH XRB spin from reflection (including Fe line)
0.2
0.4
0.6
0.8
1
1
2
3
AGN spin (all from reflection)
0
0.2
0.4
0.6
0.8
1
1
2
All spin measurements (BH + AGN)
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5
6
7

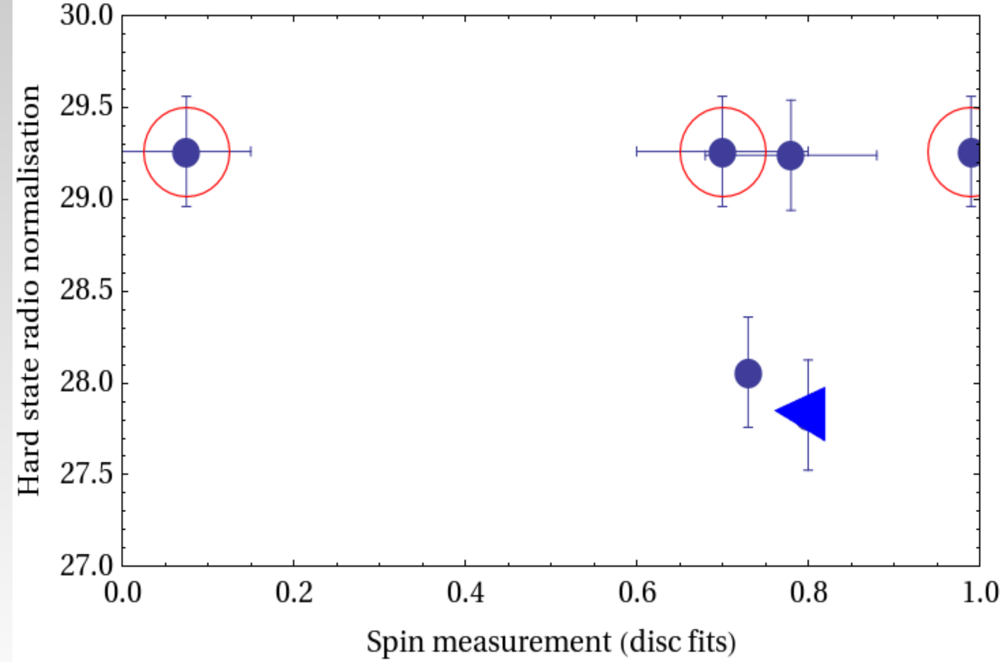
Hard state black hole X-ray binaries

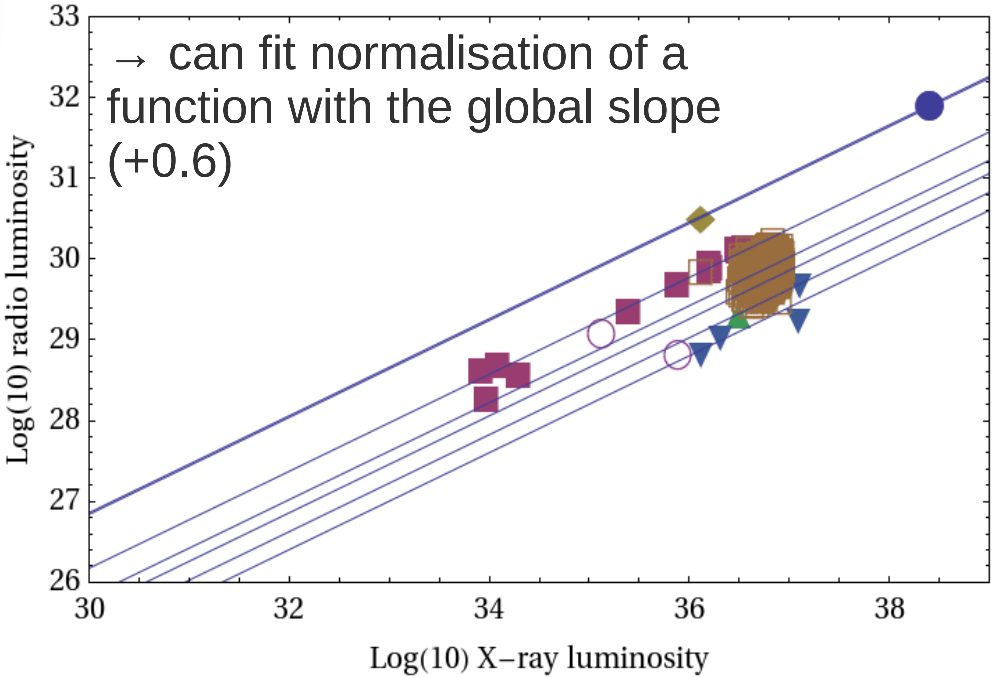


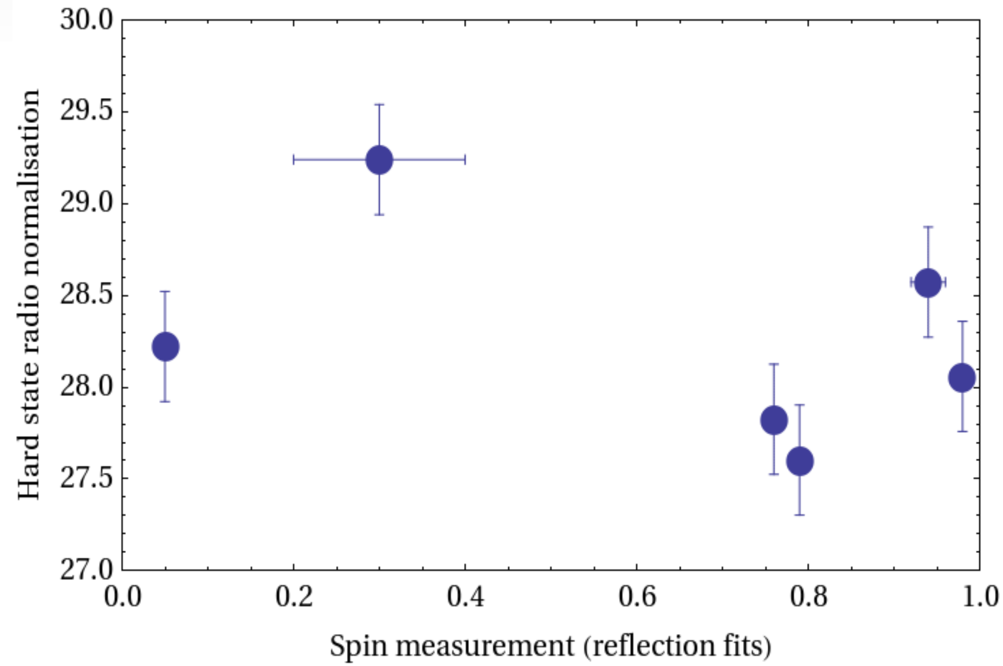
Correlation between radio and X-ray luminosities in **hard state** black hole binaries (Corbel et al., Gallo et al.)

No correlation of power with reported spin at face value

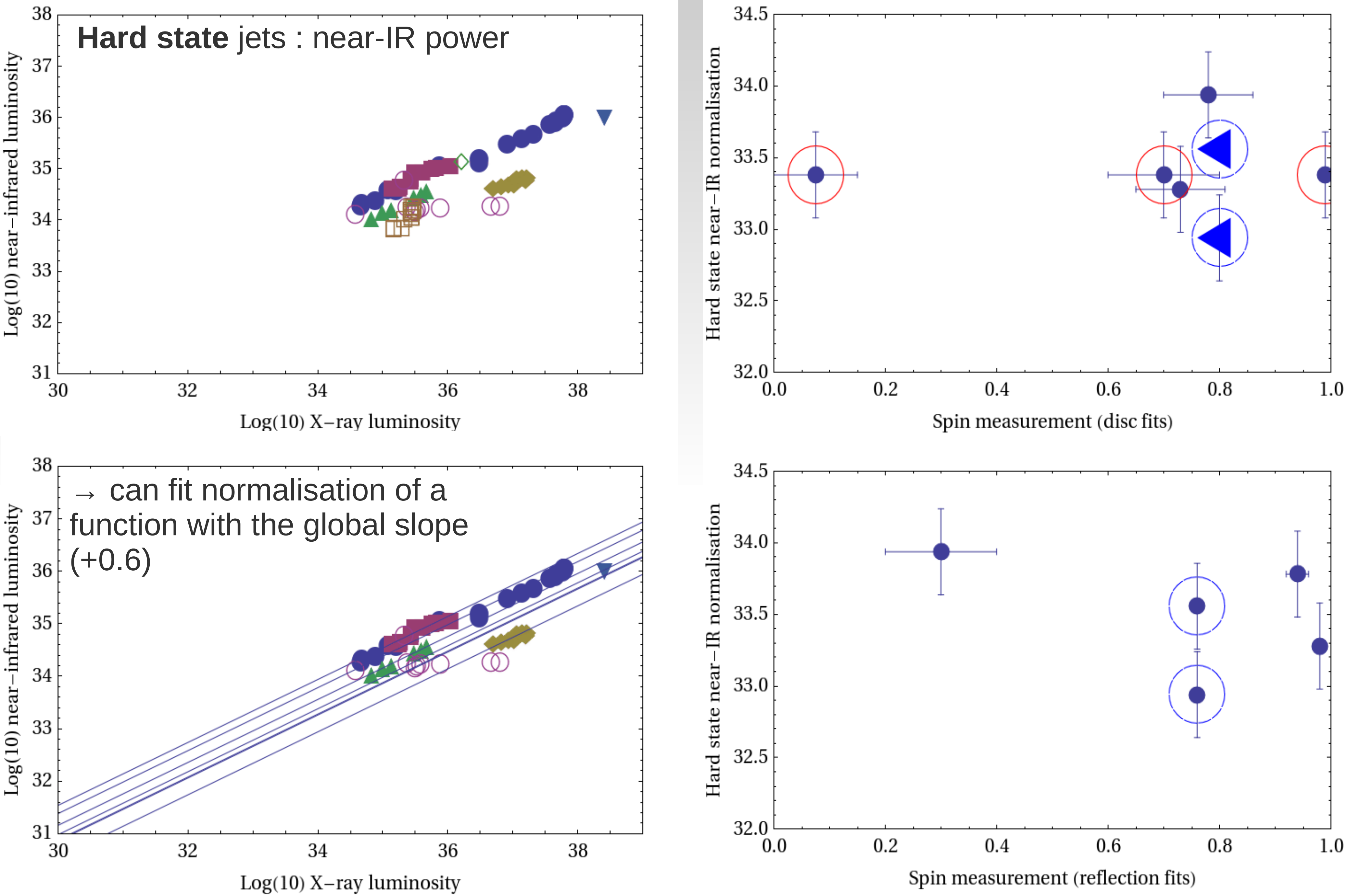






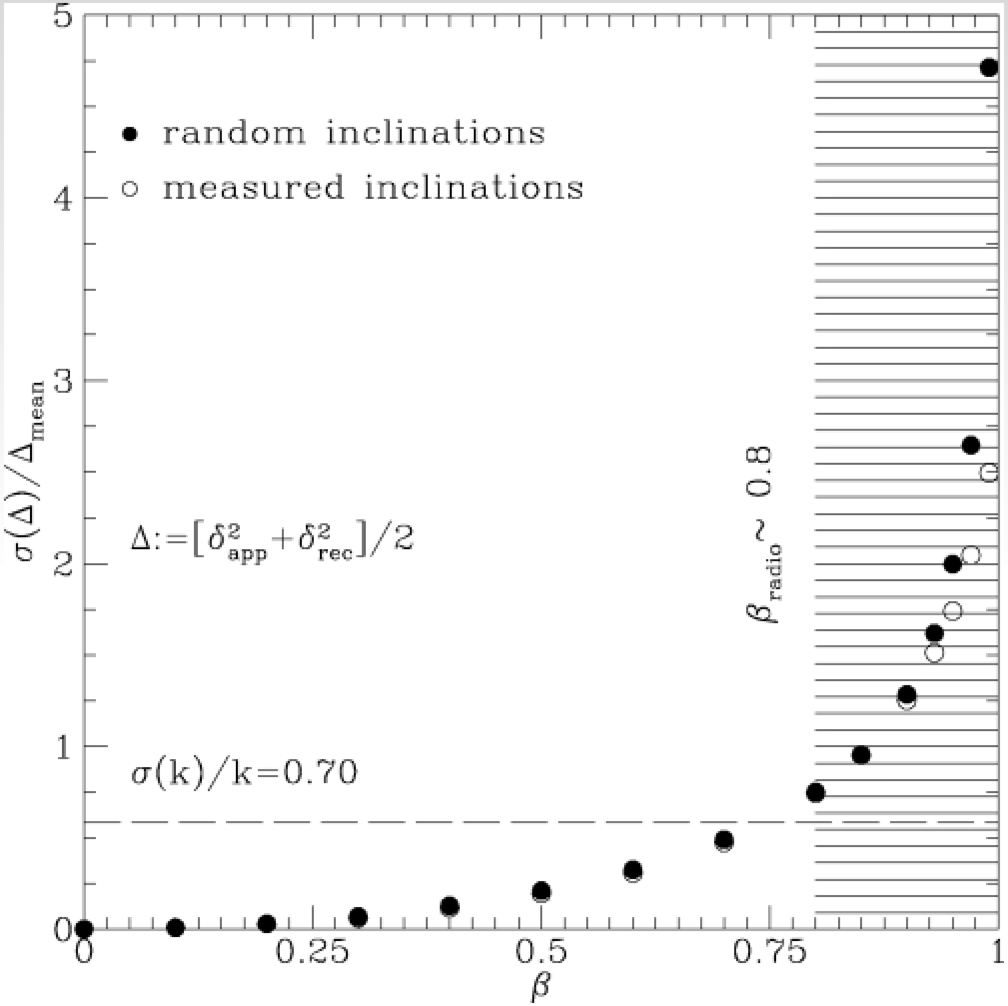


There is no correlation of hard state jet power and reported spin.



There is no correlation of hard state jet power and reported spin.

What about jet speed in the hard state ?



Gallo, Fender & Pooley (2003) used Monte Carlo simulations to show that the Lorentz factor in the hard state was likely to be small (v/c < 0.8)

Heinz & Merloni (2004) showed analytically that solutions are possible for larger Lorentz factor, but crucially that the range in Lorentz factors in the hard state must be small.

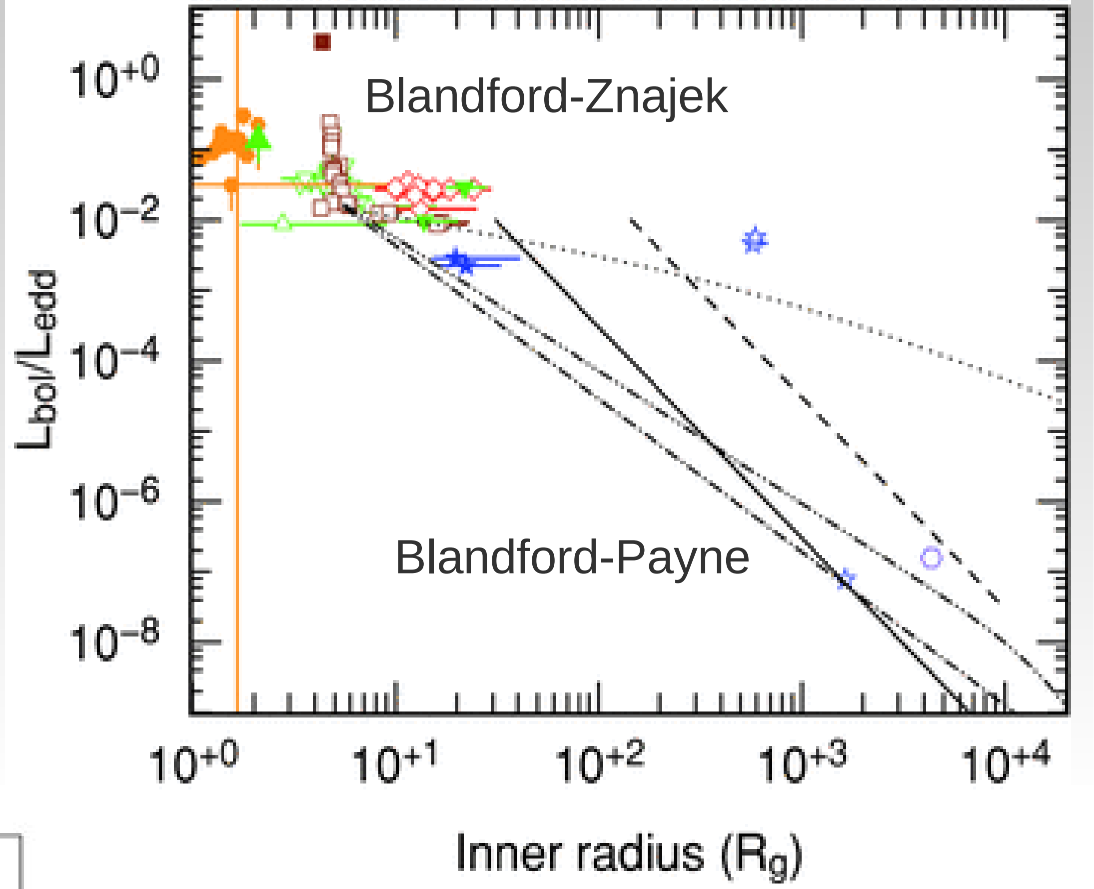
No evidence for any dependence of jet speed on spin* in hard state (the only possibility remaining is that spin affects speed in a sub-relativistic regime)

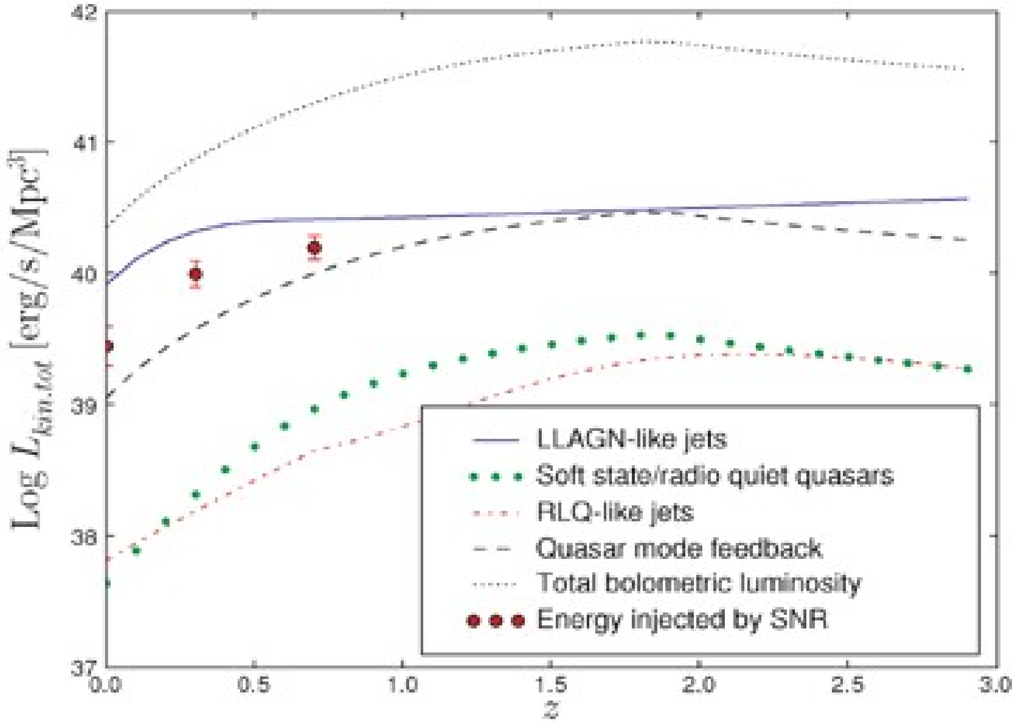
(* or any other extra parameter which is fixed for each system)

Maybe only the transient jets – formed close to the black hole – show evidence for spin powering ?

Jets at lower luminosities may be formed further from central black hole (truncated disc)

Cabanac et al. 2009



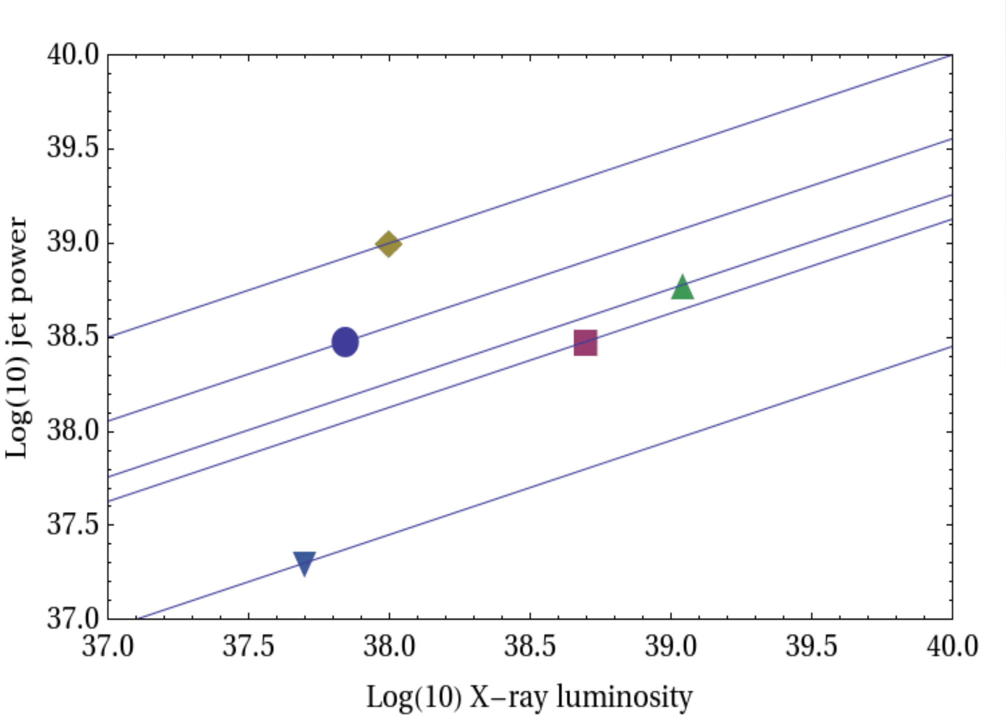


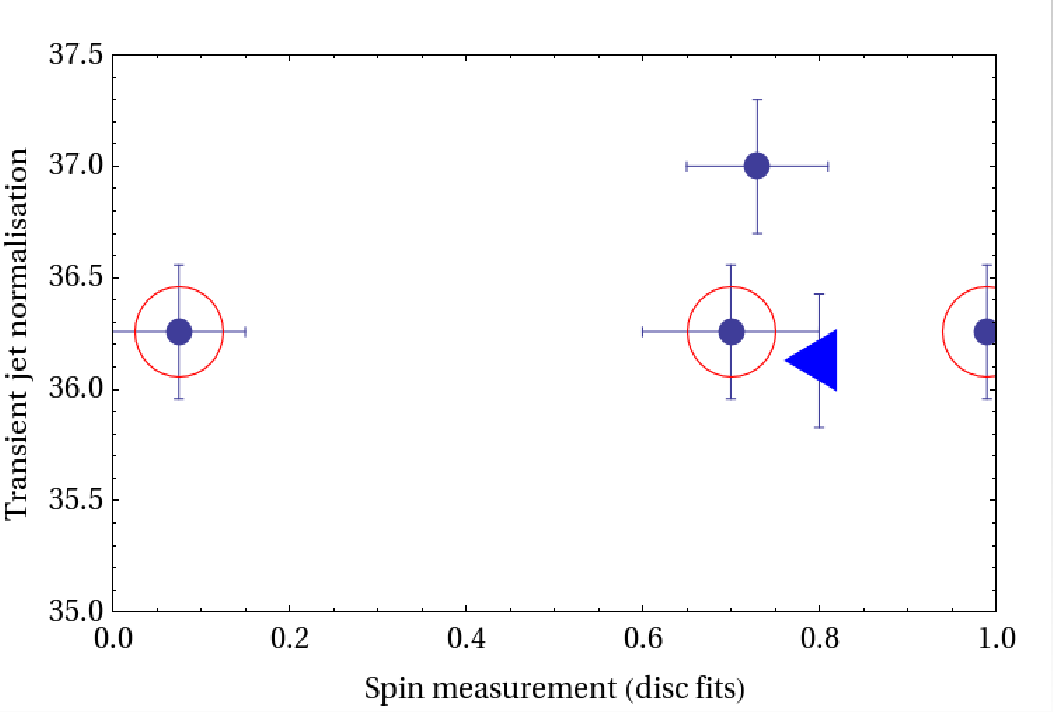
However, this is a not a complete get-out clause:

It has been argued that the kinetic feedback to the universe has in fact been dominated by such hard state jets (in AGN)

Koerding, Jester & Fender et al. 2007

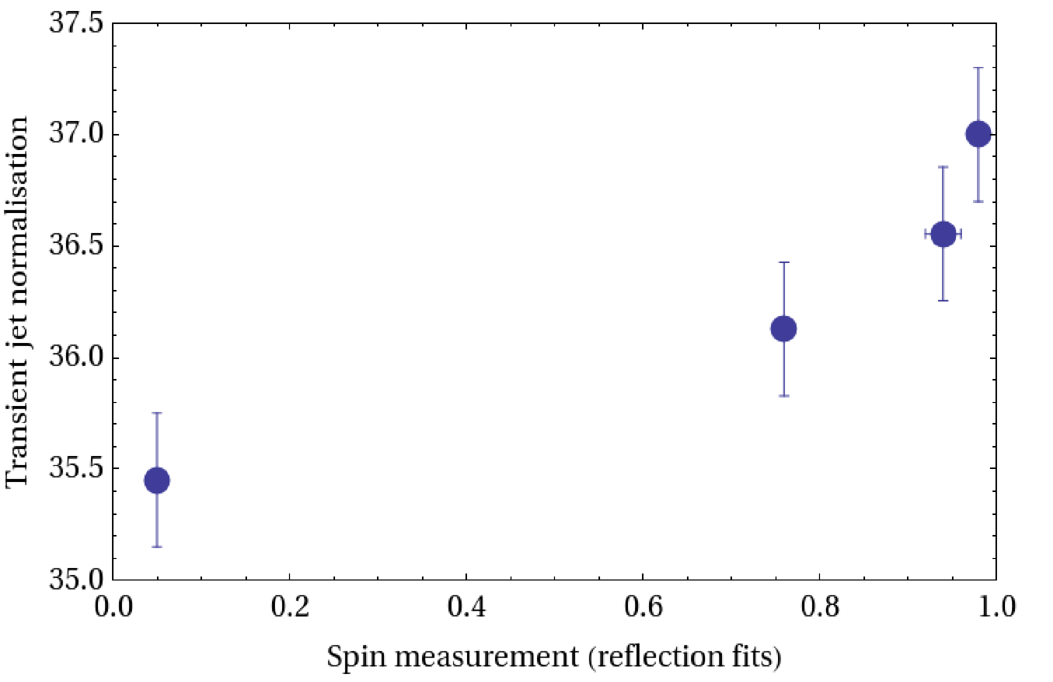
Transient jet power: hard to measure, dependent on sampling, **varies in the same source at the same luminosity → conclusions less certain**



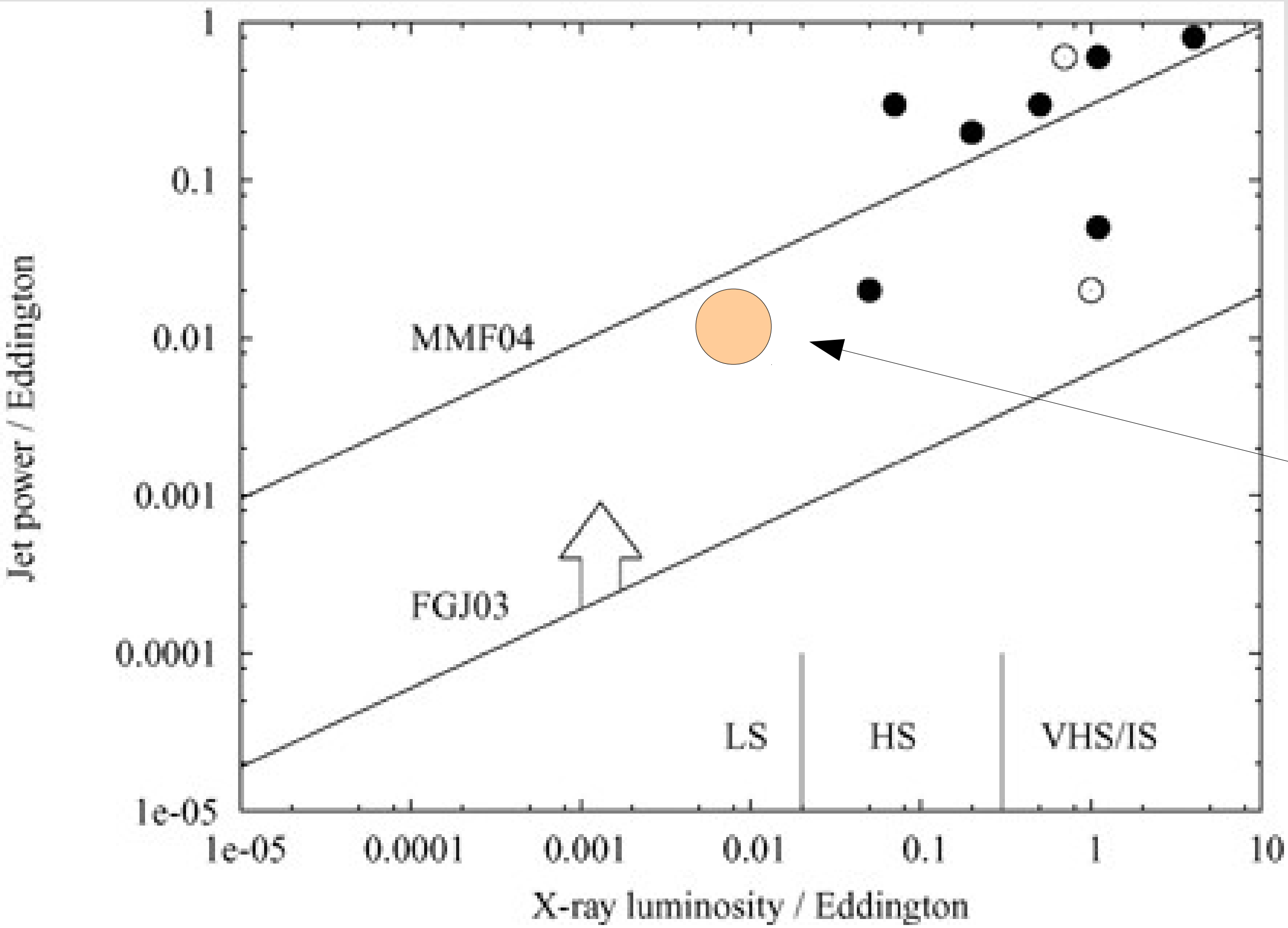


What is this – is it a correlation ? We think it it spurious (see also next slide).

It is also a much weaker dependence on spin than recent papers e.g. McKinney (2005)



If there is a contribution from spin only in the hard state (<u>and</u> only the reflection fits are correct) then if it is significant we would expect to see a 'step up' in jet power at transitions from hard to soft states.



Results from Gallo et al. and Russell et al. analysis of Cygnus X-1 nebula

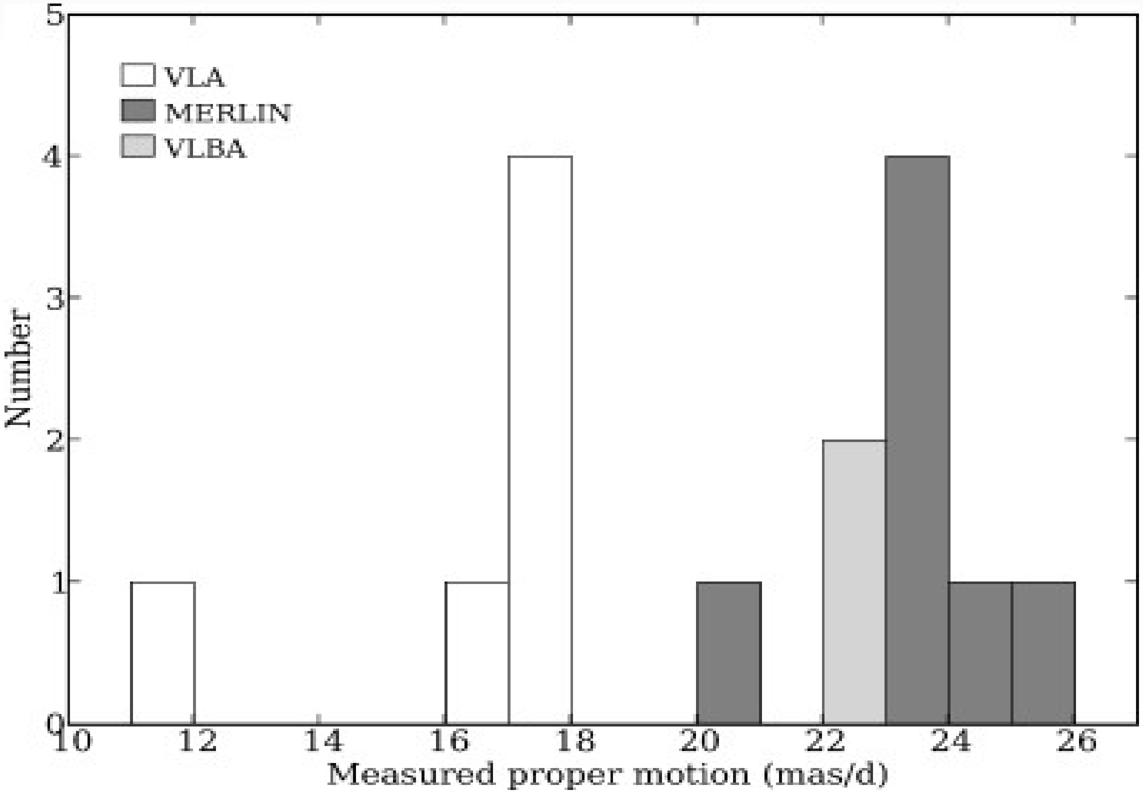
However, while we <u>do</u> see flares, the jet power estimates are, within uncertainties, continuous from hard state to major ejection.

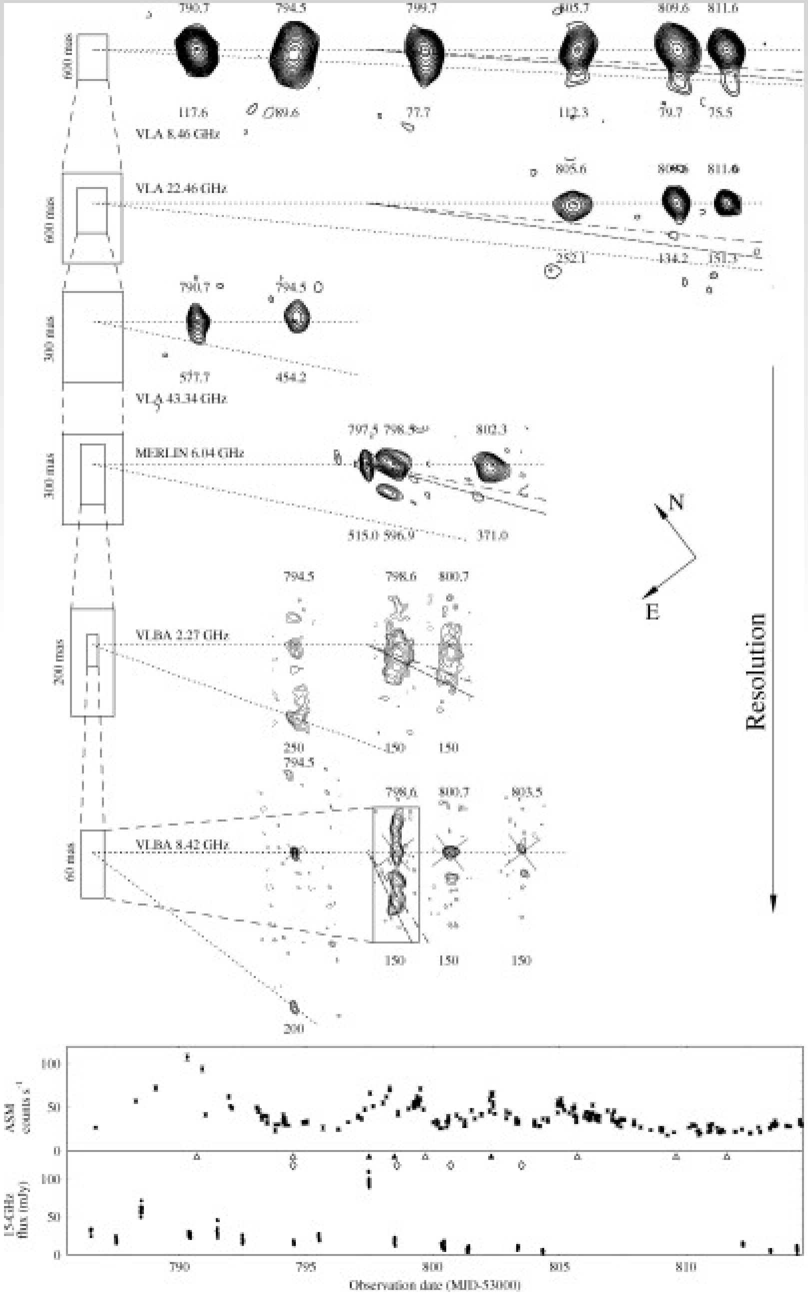
For **jet speed** nearly all measurements are lower limits (but are significantly relativistic with Lorentz factors >2)

No evidence for a correlation with reported spin

… and some evidence that the same source (GRS 1915+105, maybe others) can produce transient jets with different velocities at different times (although this may also be deceleration / resolution effects)

(Miller-Jones et al. 2007)





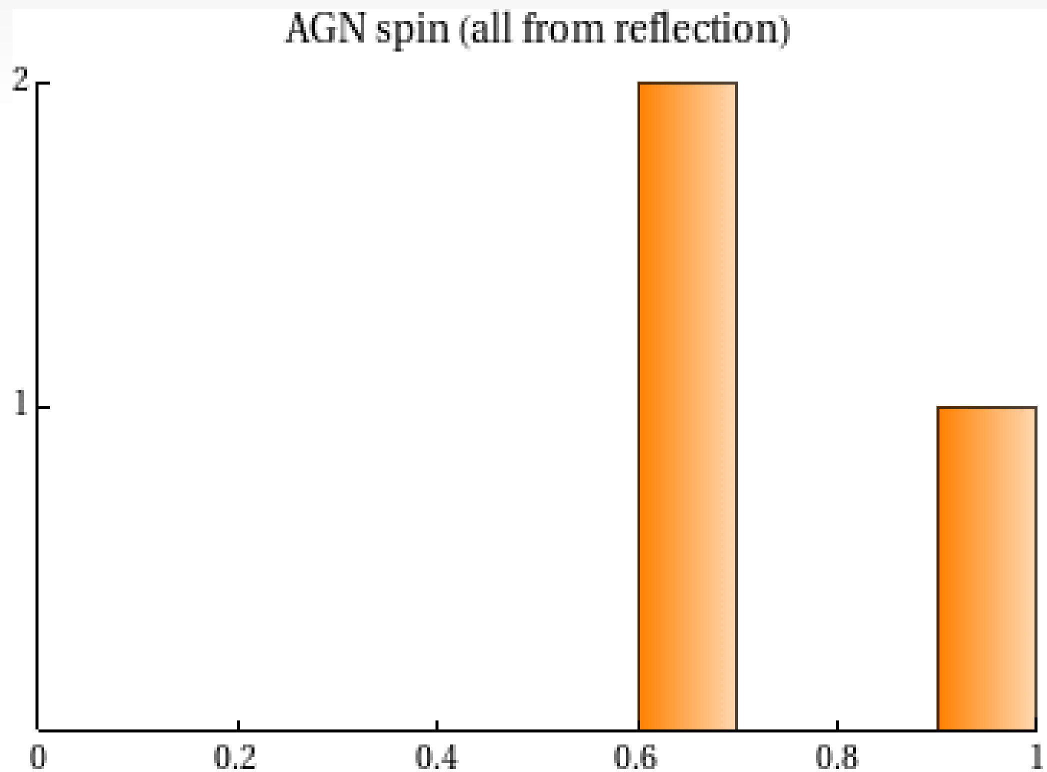
Soft state jets ?

There is evidence from AGN studies that sources in 'soft' states still produce jets, weaker by a factor ~100 than those in the same luminosity hard state. These are not known in X-ray binaries... however, the three reported AGN spins are all likely to be associated with soft state objects.

But, MCG 6-30-15 – with a very high, and very precisely reported – spin is not radio-loud, even compared to other 'soft state' candidates including the other two AGN with reported spins.

So if weak jets are produced very close to black holes in soft states, again they show no evidence for a correlation of power with spin.

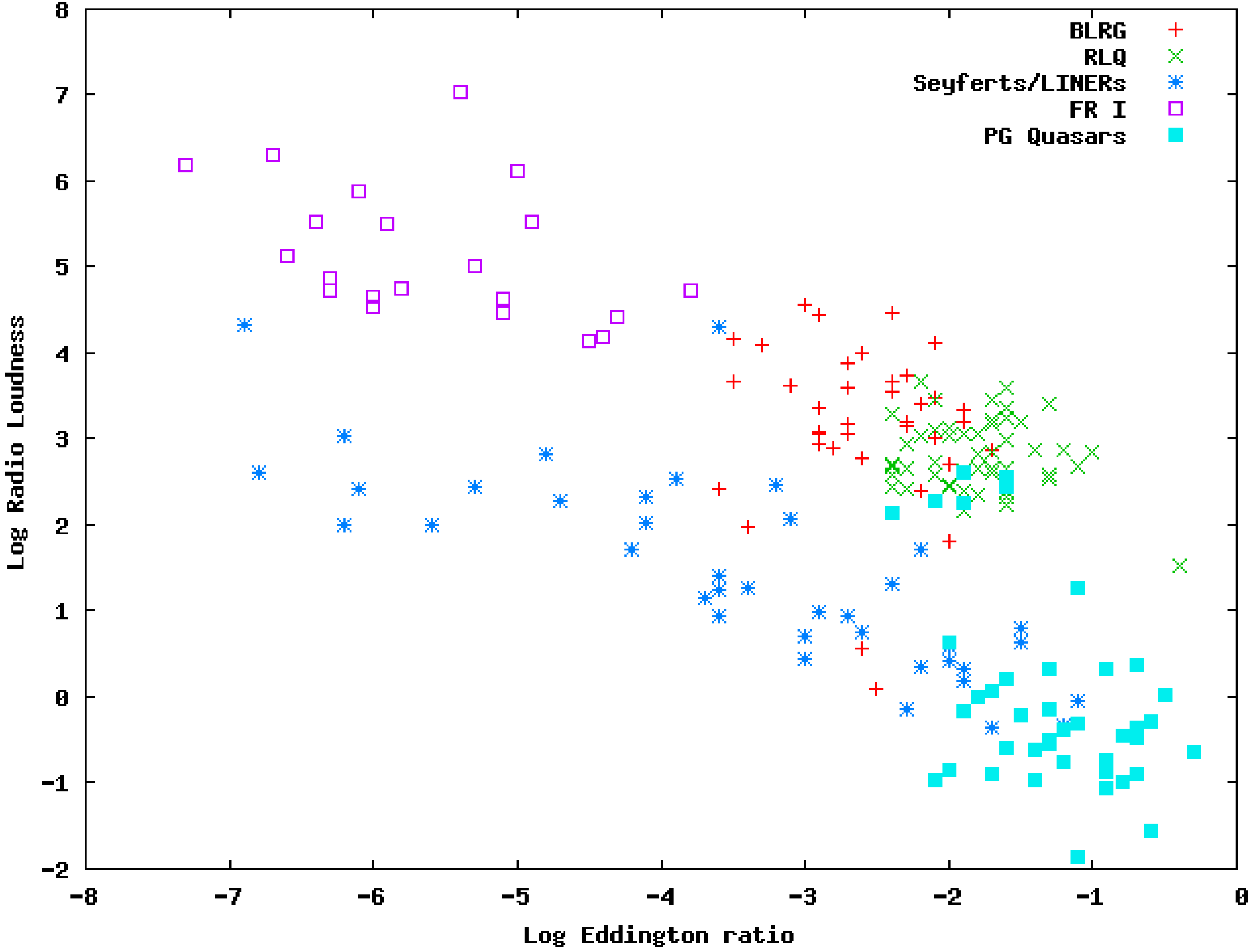
There are no good data on speeds of these jets..



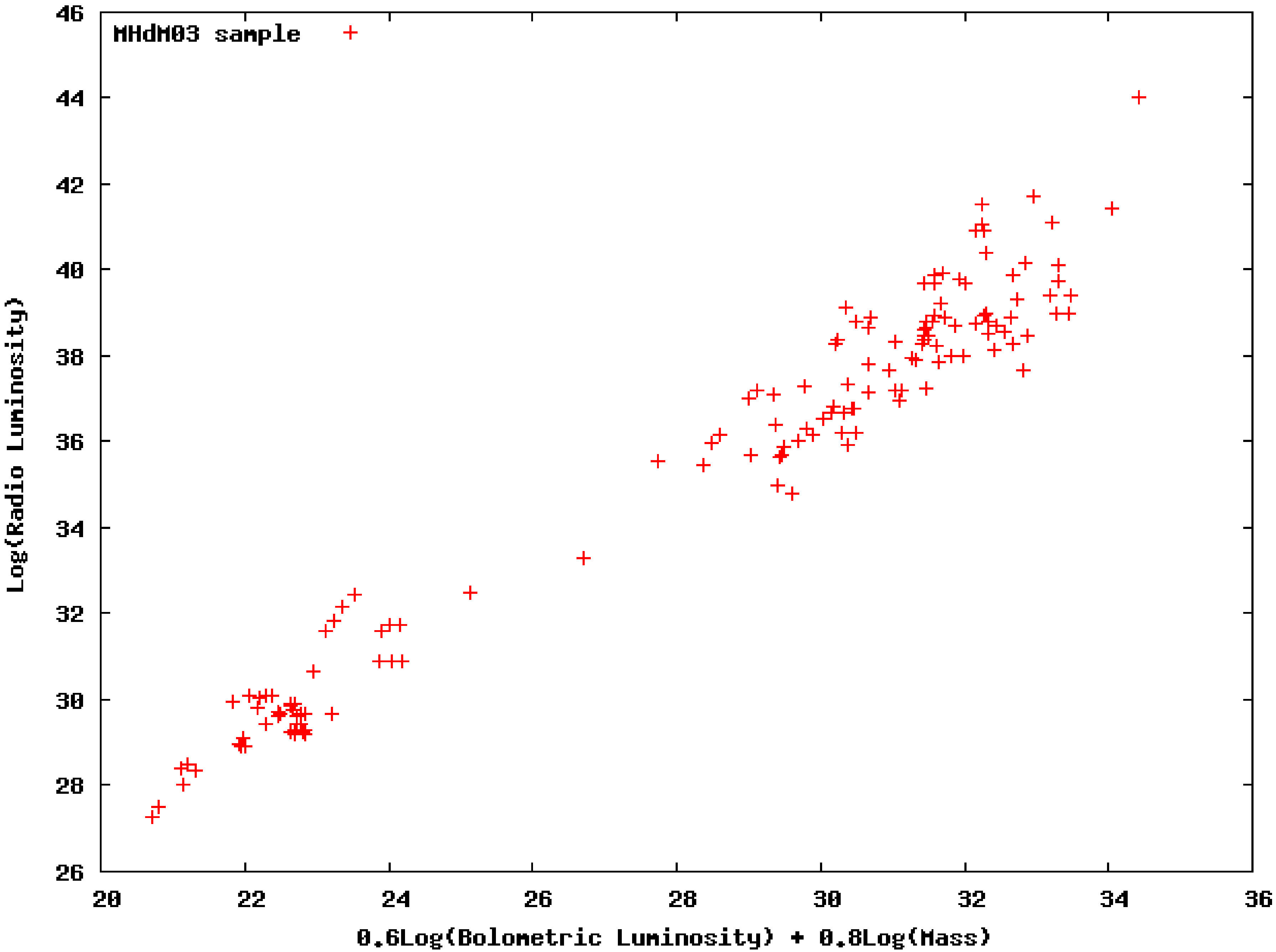
Summary of evidence for spin-powered jets

	Hard state	Transient	Soft state [?]
Power	Strong evidence against (from radio:X-ray correlations)	Moderate evidence against (from jet power:X-ray correlations)	Weak evidence against (from radio:X-ray correlations and AGN)
Speed	Strong evidence against (narrowness of sample distribution)	Weak evidence against (but only lower limits to jet speed)	No evidence

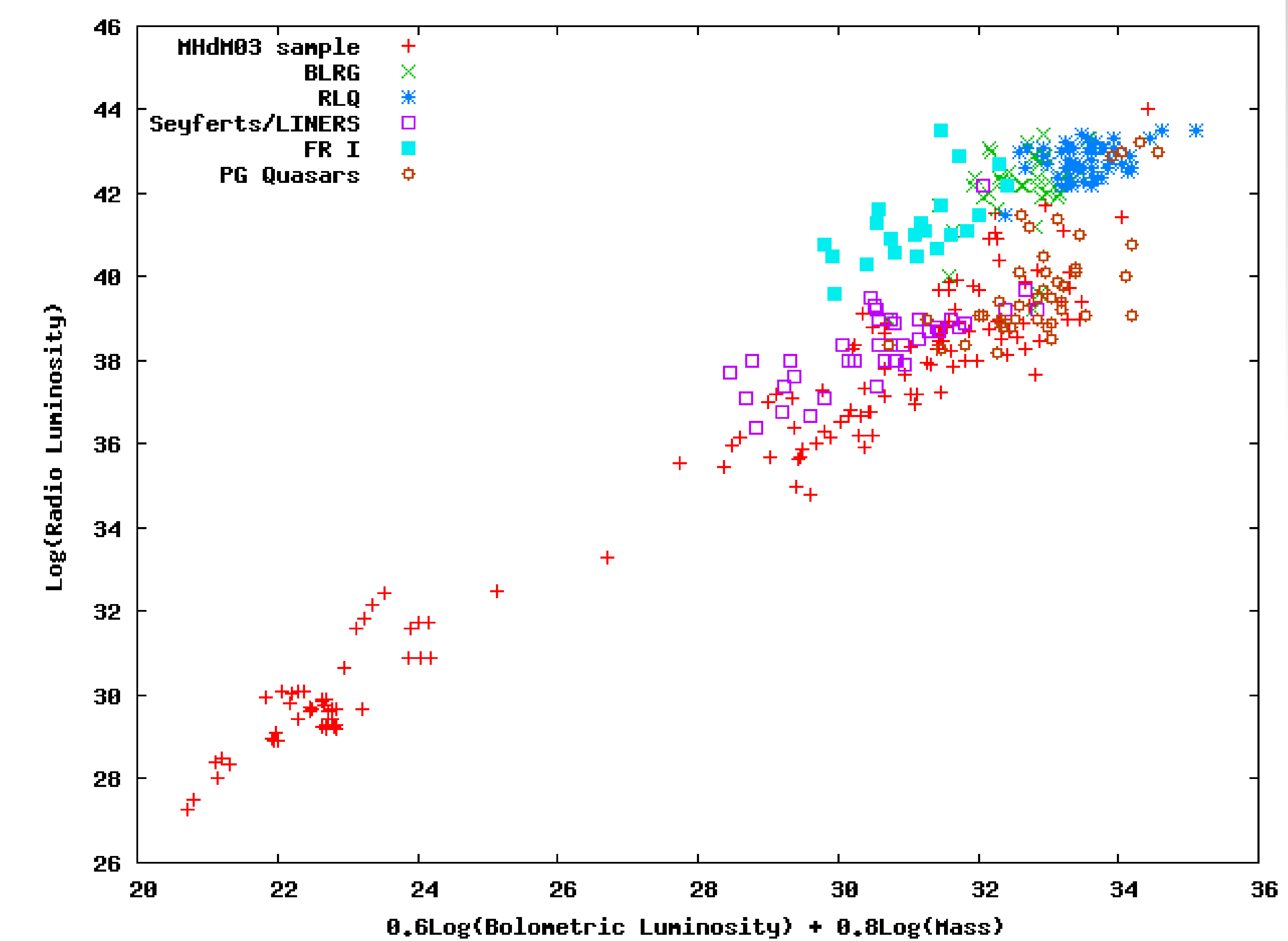
Sikora spin bimodality revisited

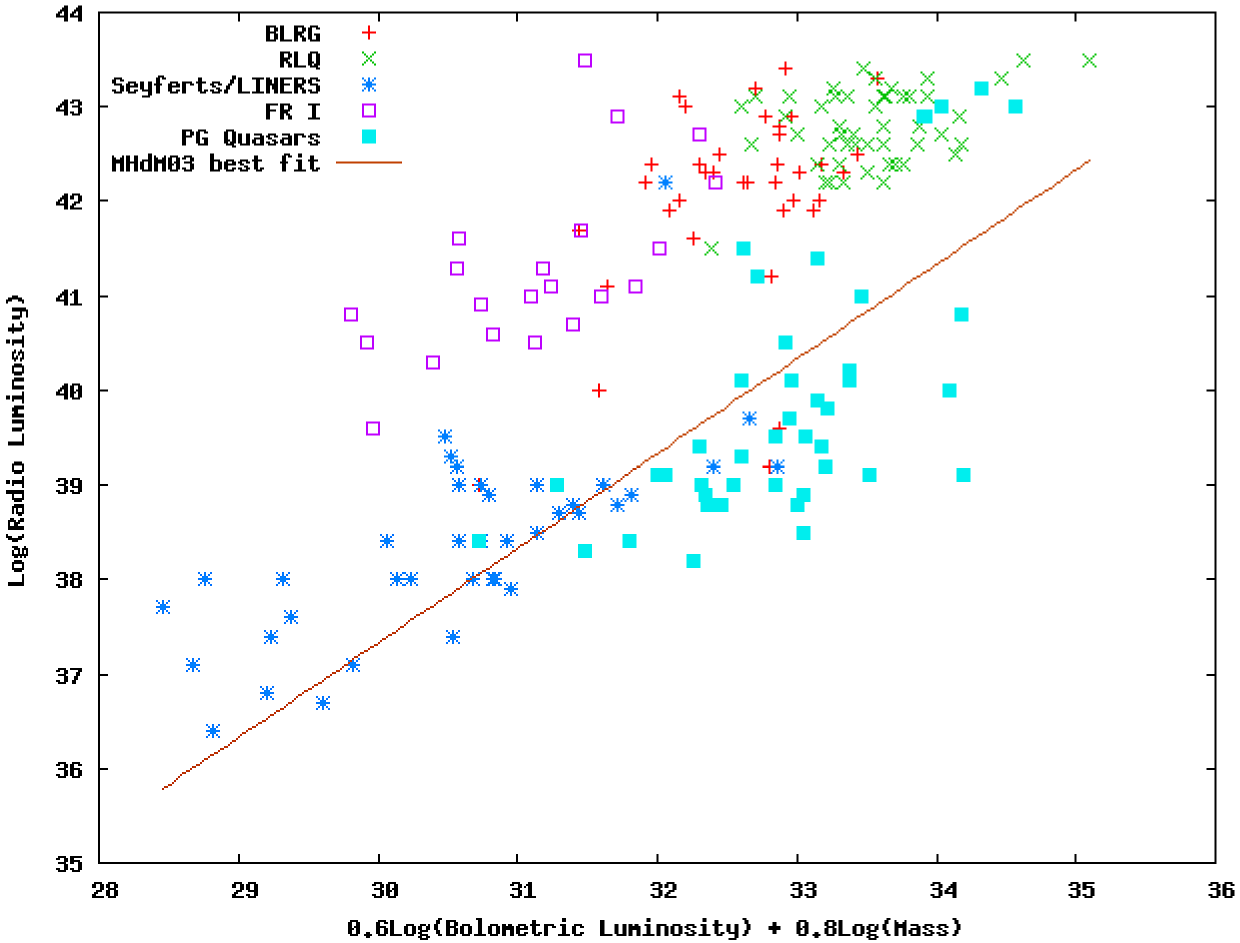


The fundamental plane – no bimodality here ?



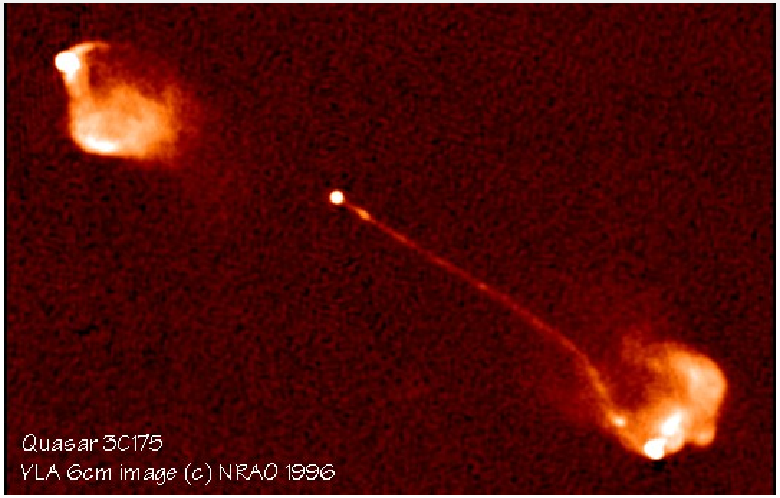
Sikora spin vs. fundamental plane





So is there a bimodality in AGN ?

Maybe: the effect reported by Sikora et al. seems to persist with the mass correction of the Merloni et al. fundamental plane, with the 'low spin' branch lining up well with the mean relation (which nicely extends to XRB hard state)



Reasons to be cautious:
The Sikora result is only there when extended emission is considered – as noted by Terashima & Wilson when using core radio luminosities there is no bimodality

This requires that the high-spin AGN produce much more powerful jets which however have no greater core radio luminosities, and only reveal this power in their large-scale interactions....

Are there alternative explanations ? Selection effects / history / environment .. ?

So we have a problem

One popular scenario goes as:
spin-dichotomy in AGN, all very similar spins in XRBs...

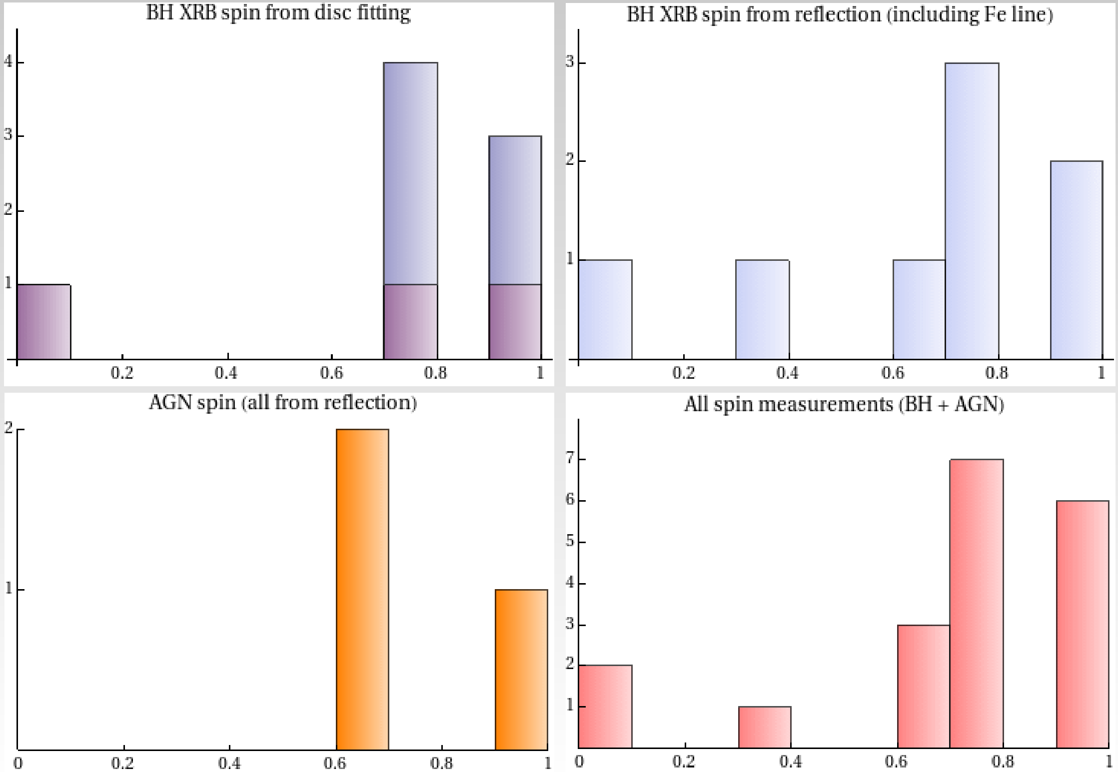
But in fact there is a large range reported in XRB spins, and these spins do not correlate with any measure of jet power or speed. Ditto for a (much) smaller sample of soft-state AGN.

Possible solutions ?

<u>Jet power measurements are wrong ?</u> Seems unlikely for the hard state, but may be possible for the transients (but not by orders of magnitude because already close to Eddington)

<u>Jets independent of spin ?</u> If accretion modes alone determine jet properties then they seem to operate to lower Eddington ratios in AGN... *and why the correlation with galaxy type ? environment ?*

<u>Spin measurements are wrong ?</u>



Perhaps only some spin measurements are wrong ?

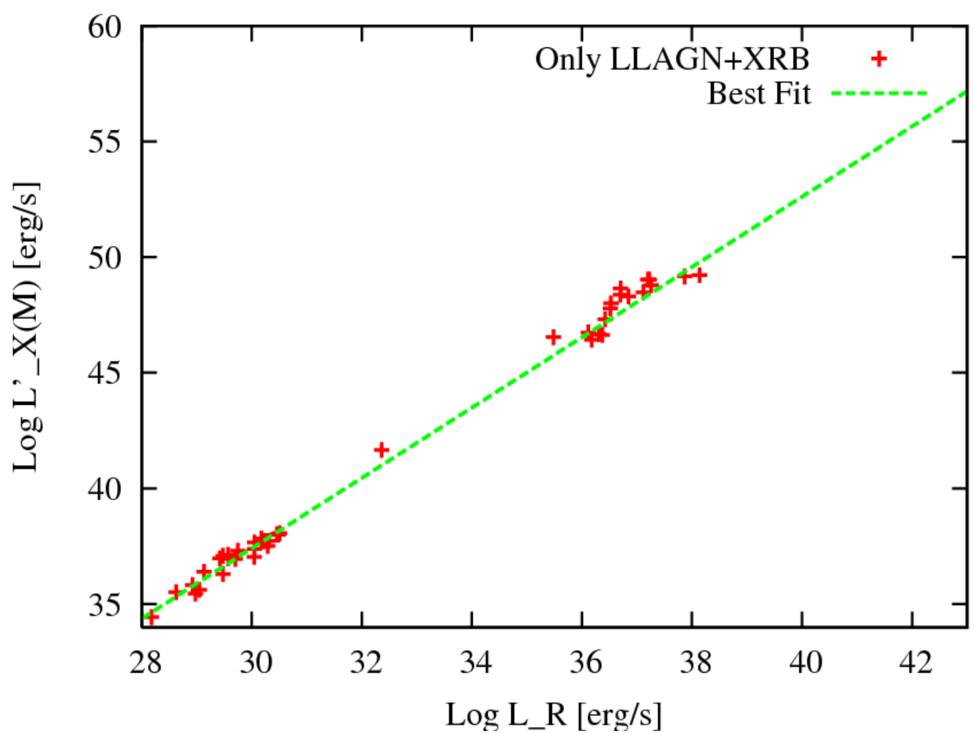
What about if only the 'reflection' fits – which have the two strongest claims for low BH spin – are wrong ?

This would leave essentially all high (>0.6) spin measurements and allow for low-spin only in AGN

Unfortunately, the X-ray binary population seems to have its tightest correlation (in the 'fundamental plane') with the LLAGN / Seyferts etc which are the <u>low-spin</u> objects in the Sikora intepretation...

… but then again, FR-I objects also fit this correlation tightly when only core radio flux is considered...

(Koerding, Falcke & Corbel 2006)



Conclusions on connection to spin

The ~20 reported measurements of black hole spin, **do not correlate strongly in any way** with any measurements of jet power (whether steady or transient) or speed in black hole X-ray binaries. These constraints are particularly strong when considering the hard state. On the other hand, individual sources show large changes in jet power, and possibly speed, on short timescales (i.e. unconnected to spin).

Therefore, one (or more) of the following must be true:

- Some or all of our jet power/speed measurements are wrong

- Some or all of the BH spin measurements must be wrong

- Black hole spin does not power jets in accreting systems and is not responsible for the radio-loud radio-quiet AGN divide

The end