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A New Connection Between Plasma Conditions Near Black Hole Event Horizons and Outflow Properties

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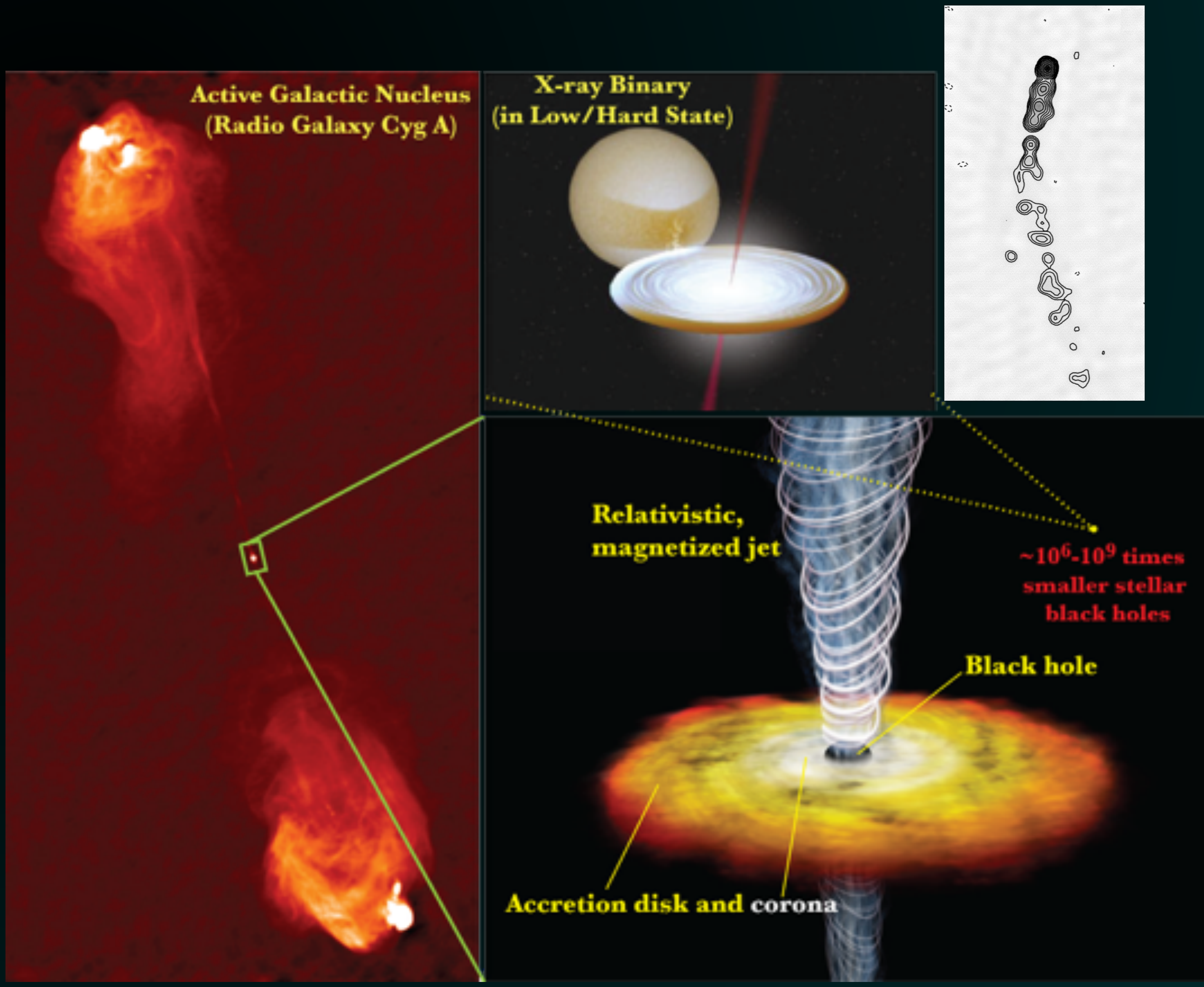
Jets at all scales

- Accreting black holes are responsible for producing the fastest, most powerful outflows of matter in the Universe.
- How is the jet produced? Necessary ingredients accretion flow and magnetic field.
- Can we compare jets that are produced in systems with different black hole mass?
- Are the jets self-similar?
- How is the accretion coupled to jet production?
- Is there a connection between jet properties and accretion rate/mode, or black hole spin?

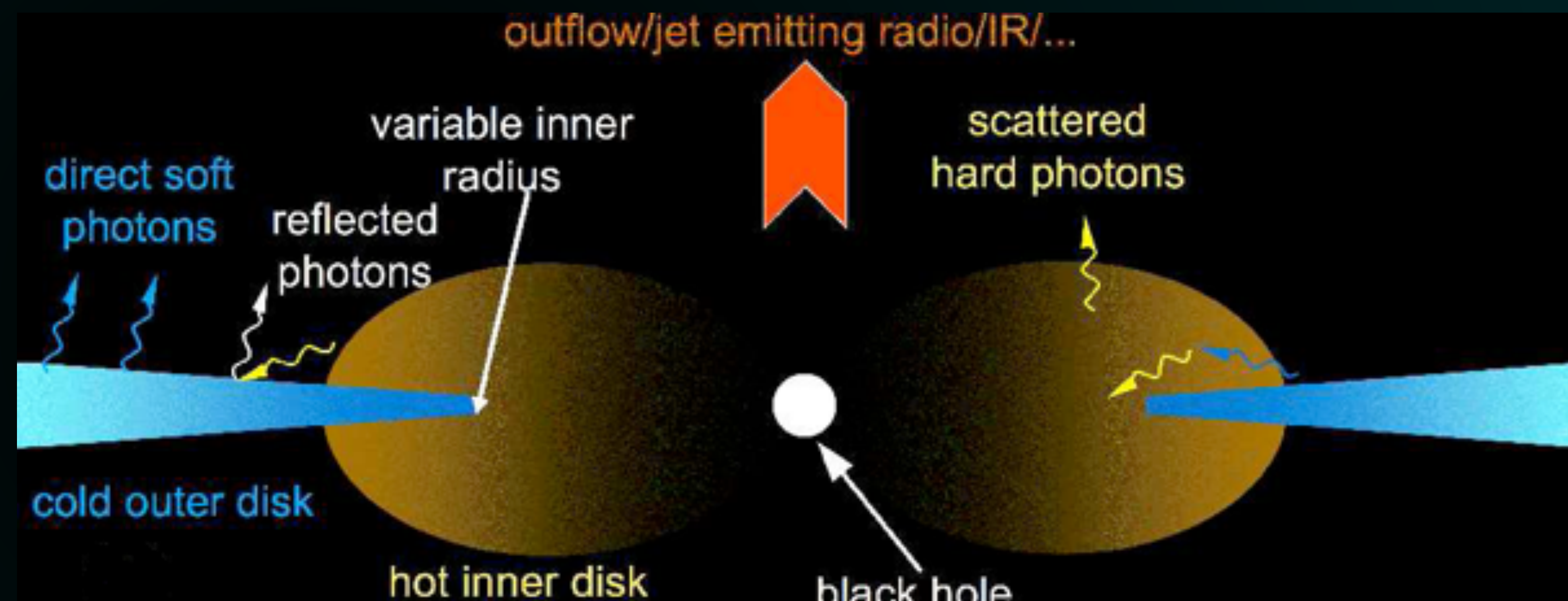


Accretion states in XRBs – disk/jet connection

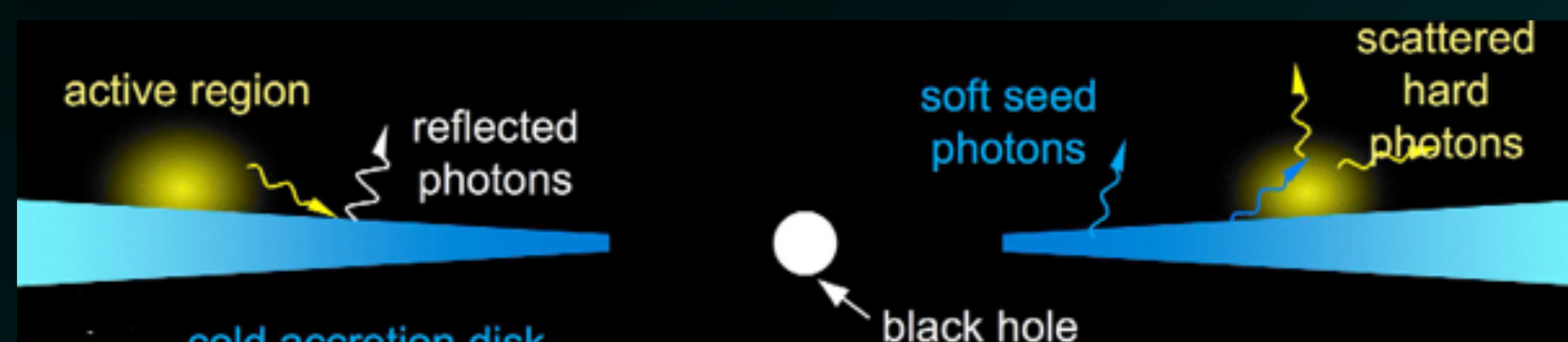
What is observed? Two distinct states of accretion:

- "Hard state" with Comptonisation dominated (i.e. power law with a cutoff) X-ray spectrum from a "corona" and a jet
  - Thermal Comptonisation dominated accretion flow (Zdziarski+98)
  - Radiatively inefficient accretion flow (Yuan+03)
  - Base of the jet (Markoff +05)
- "Intermediate state" in between of hard and…
- "Soft state" with disk dominated (i.e. blackbody) X-ray spectrum and no jet

Hard X-ray state (jet + corona)

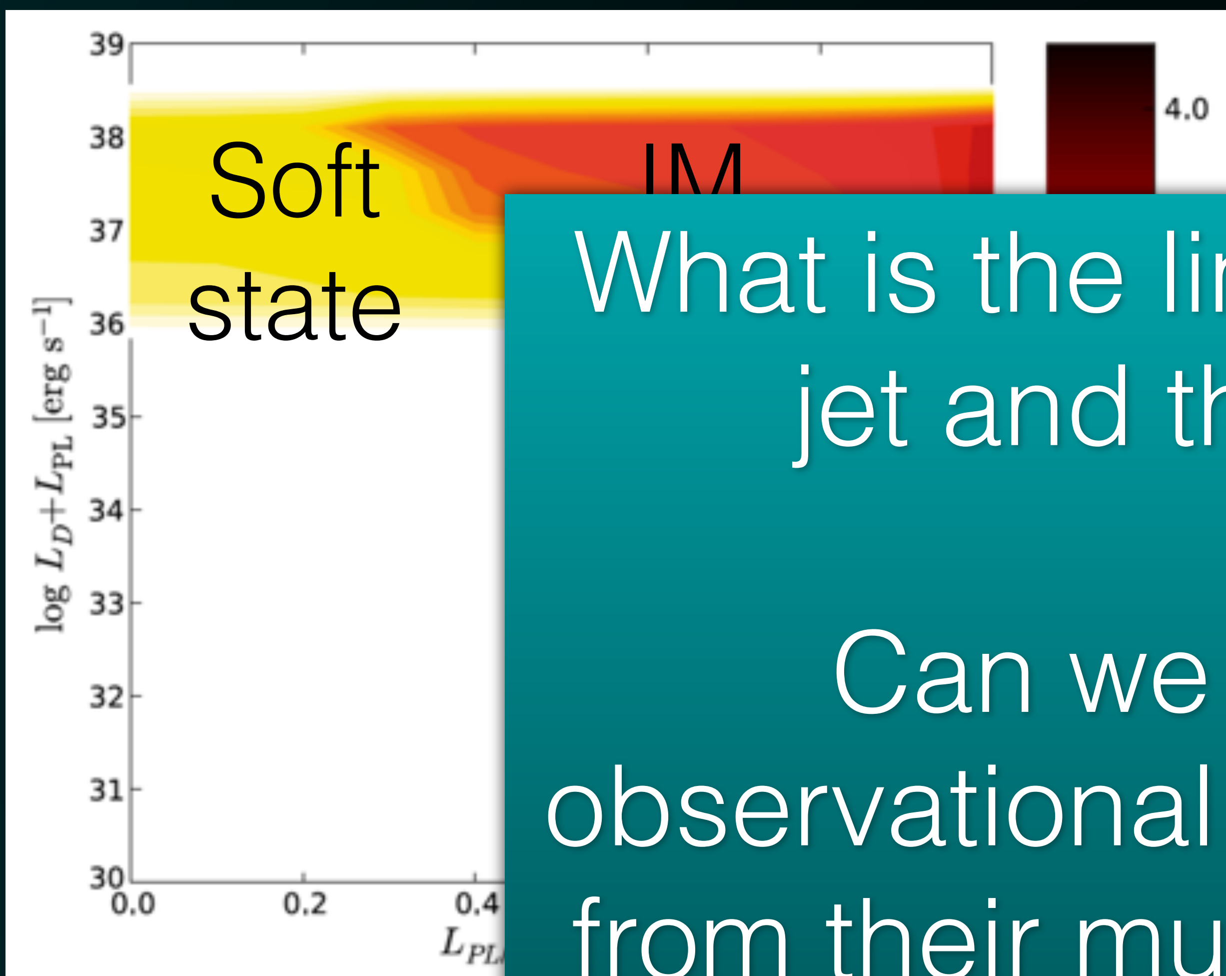


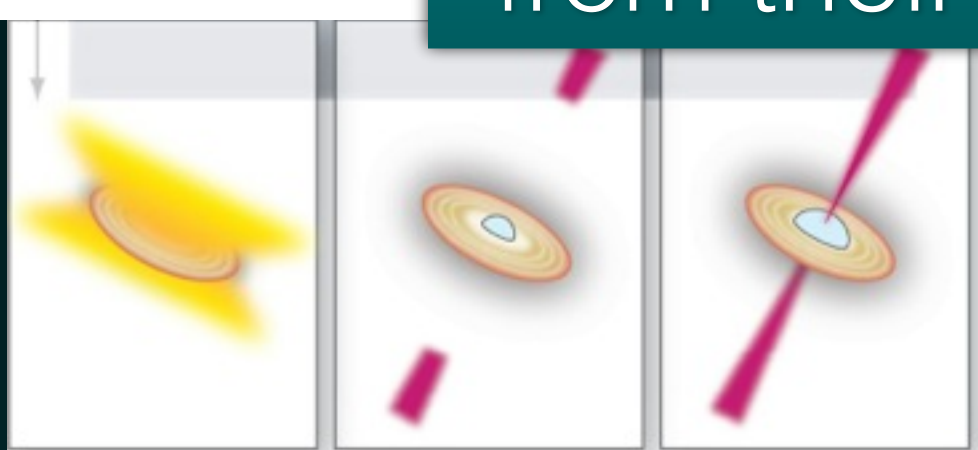
Soft X-ray state (no jet, no corona)

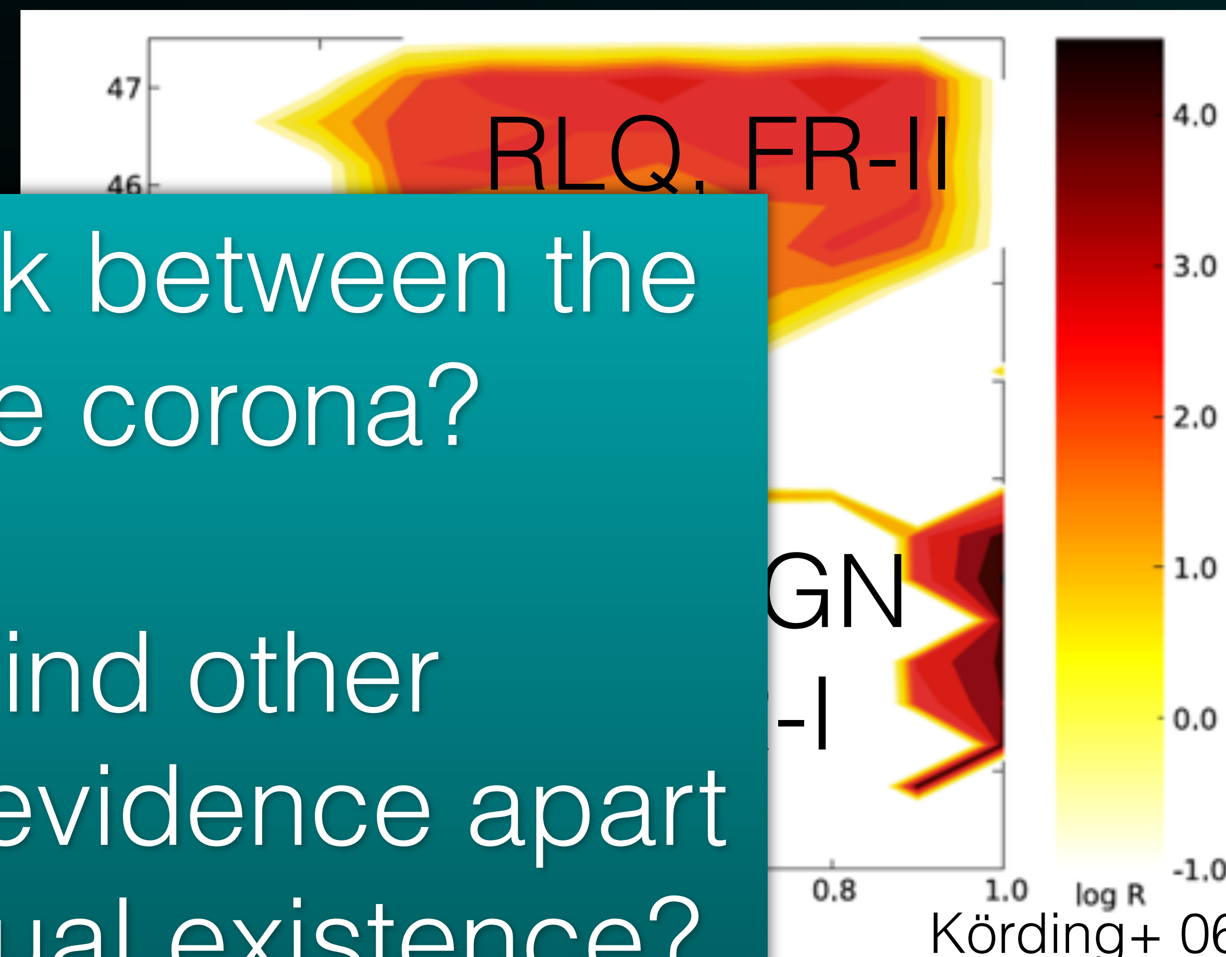


Zdziarski & Gierlinski 2004

Accretion states in XRBs and AGN – disk/jet connection







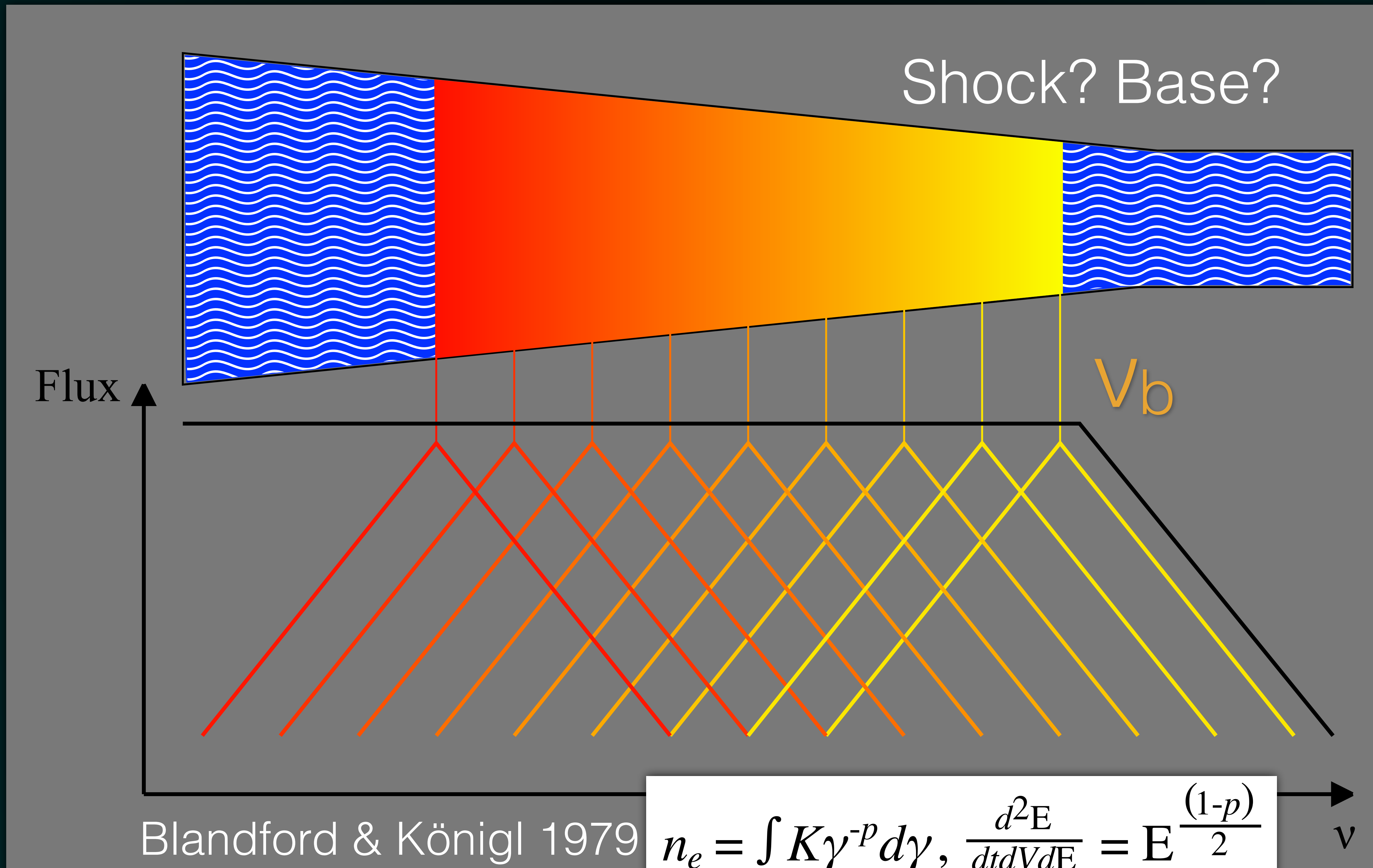
What is the link between the jet and the corona?

Can we find other observational evidence apart from their mutual existence?

AGN disk fraction/luminosity diagram: SDSS quasars, LLAGN (Ho+1999)

AGN type <—> Accretion state

What is the link between the jet and the corona?



$$n_e = \int K\gamma^{-p} d\gamma \,, \quad \frac{d^2E}{dt\,dV\,dE} = E^{\frac{(1-p)}{2}}$$

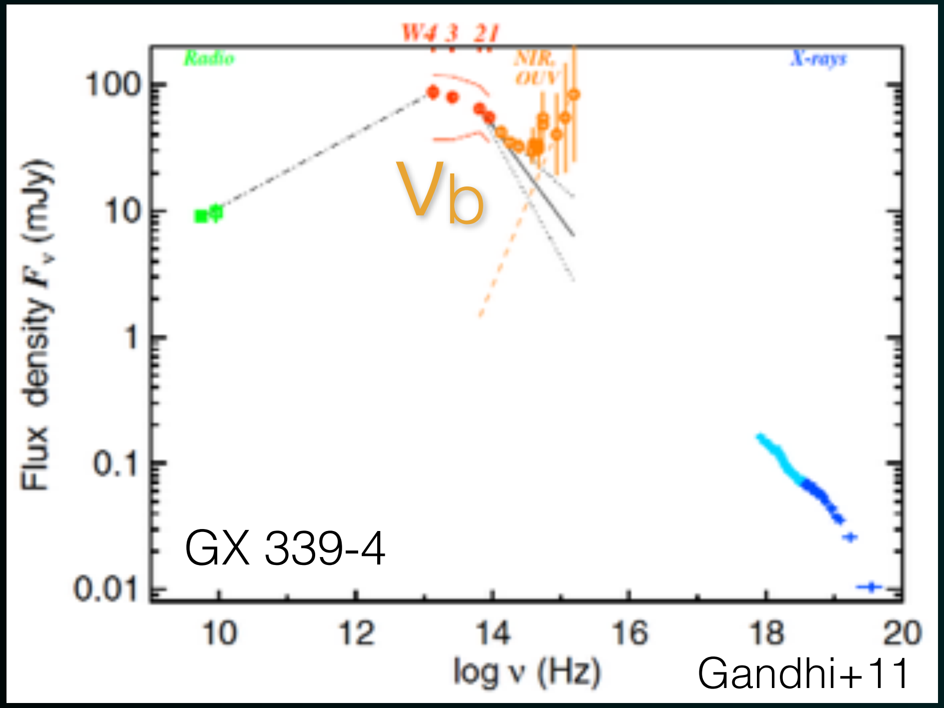
Observations from XRBs

List of sources (11):
- 4U 1543-47
- Cyg X-1
- GS 1354-64
- GX 339-4
- MAXI J1659-152
- MAXI J1836-194
- V404 Cyg
- V4641 Sgr
- XTE J1118+480
- XTE J1550-564
- XTE J1752-223

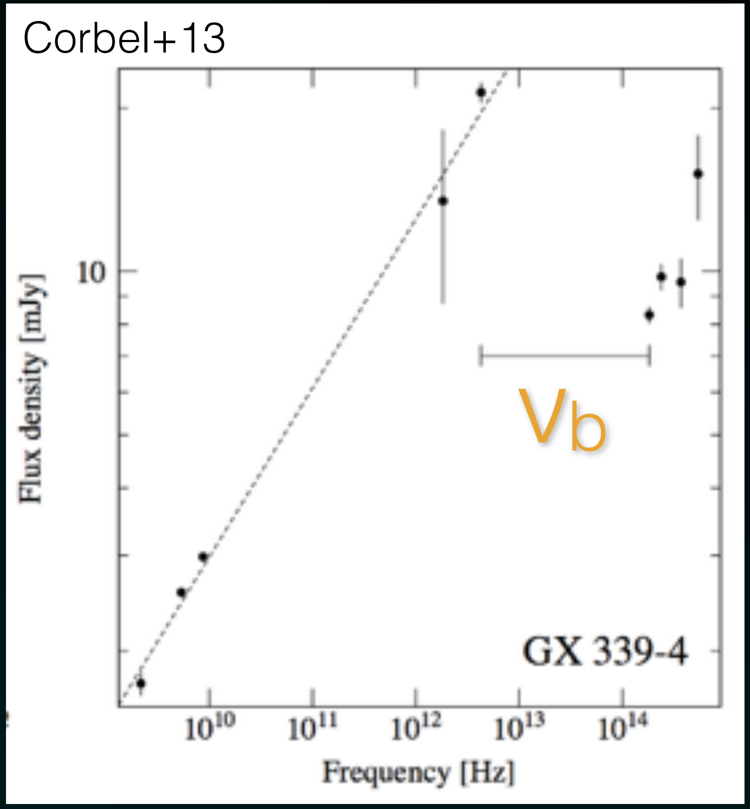
References:
- Corbel+13
- Gandhi+11
- Rahoui+11
- Russell, D.+12
- Russell, D.+13
- Russell, T.+14
- van der Horst+13

Hard state:
$\nu_b = 10^{13} - 10^{15}$ Hz
Intermediate states:
$\nu_b = 10^{10} - 10^{13}$ Hz
Soft states:
no compact jet

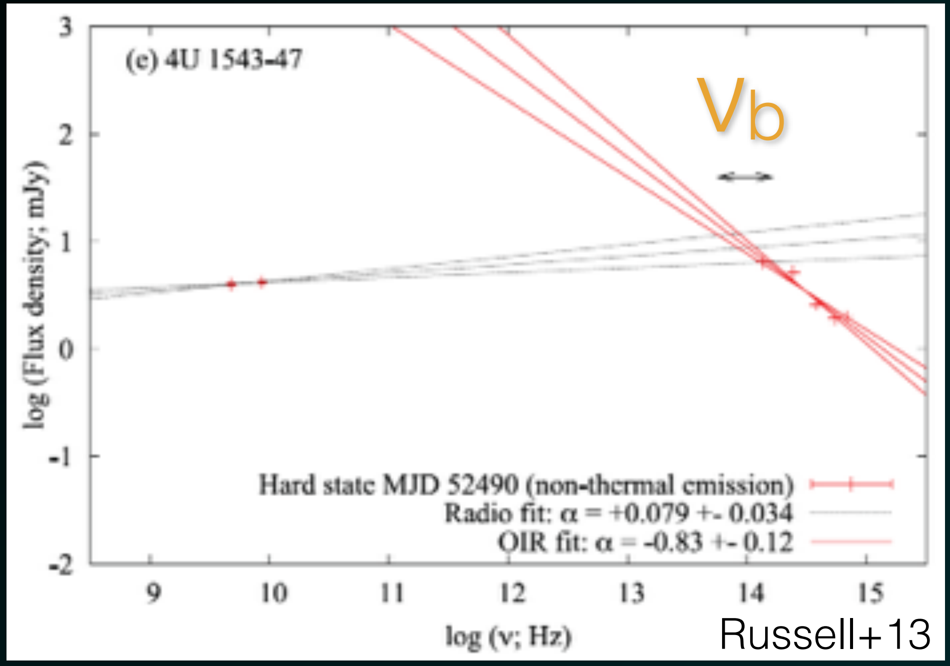
Direct measurement



Range



Indirect measurement



Observations from XRBs

Quasi-simultaneous (~1 day) X-ray data from RXTE (PCA+HEXTE) and Swift XRT

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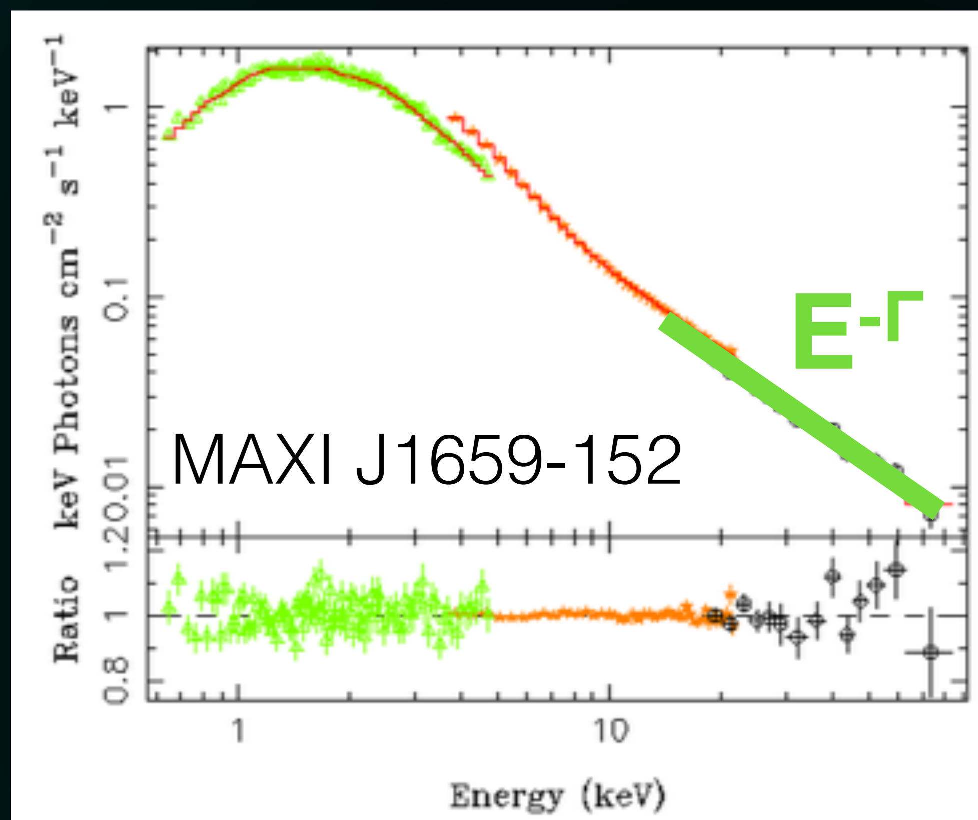
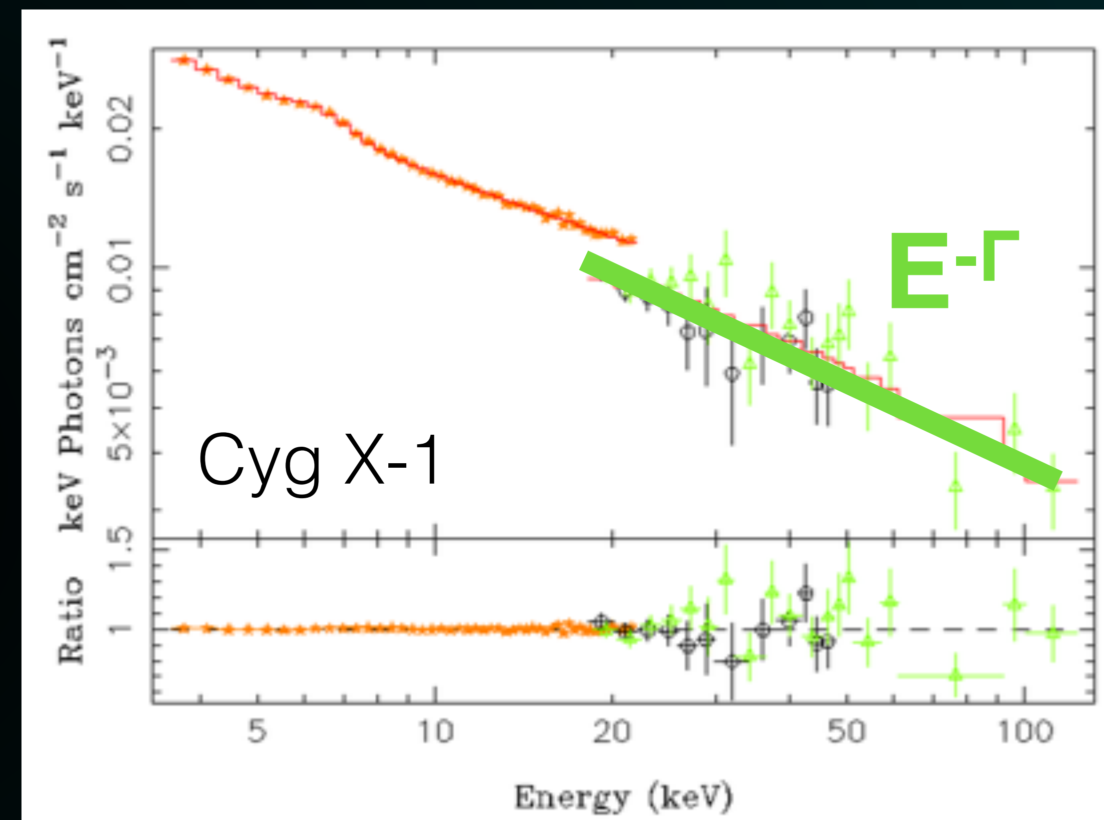


Intermediate state



Hard state

Hard state:

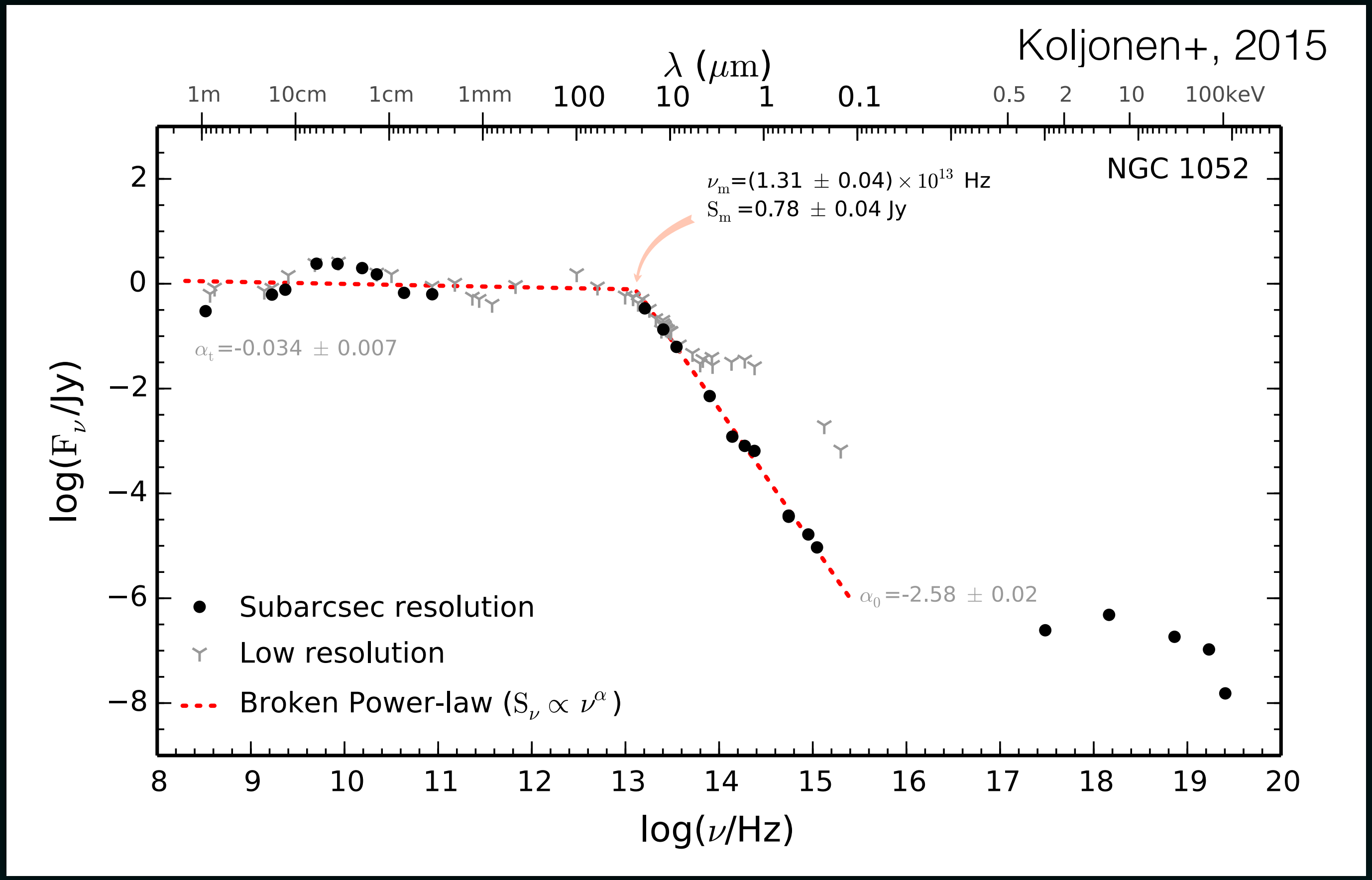
$\Gamma \sim 1.5$

Intermediate states:

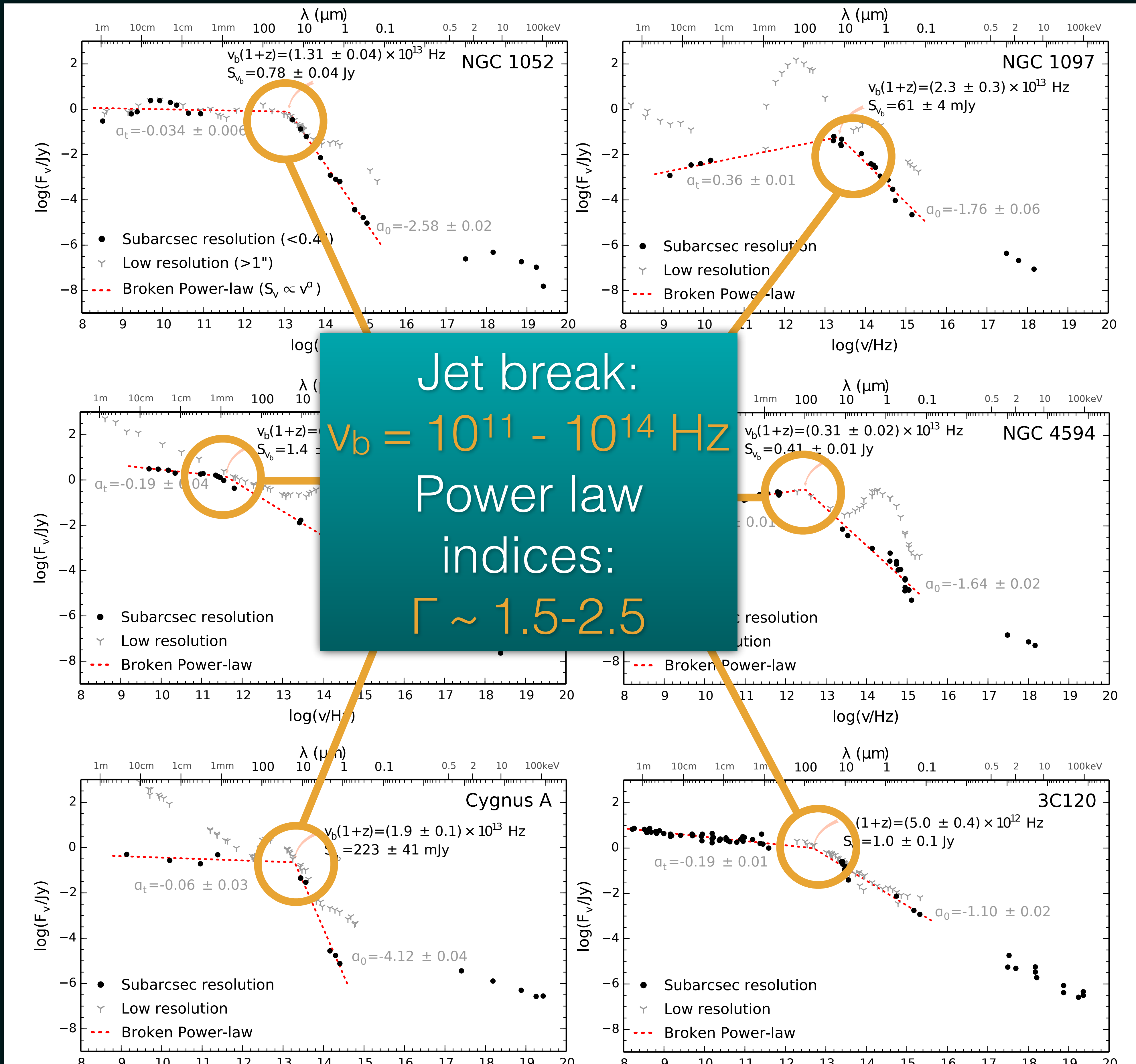
$\Gamma \sim 2.0\text{-}2.5$

Observations from AGNs

- Only small sample available due to lack of high-resolution NIR/MIR observations
- Mostly LLAGN with little dust
- Sub-arcsecond measurements from radio to UV with adaptive optics low-angular resolution data from archives
- Steep optically thin spectra, α < -1.0 (quasi-thermal/fast cooling)
- Well-measured X-ray power law photon indices from literature



List of sources (7): 5 LLAGN/LINERs (NGC 1052, NGC 1097, Sgr A*, M87, NGC 4594), Cyg A, 3C 120 (Fernandez-Ontiveros+12, Canalizo+03, Lopez-Rodriguez+14, Lee+08, Asmus+14, Doi+13, NED, WISE, Akari, 2MASS)

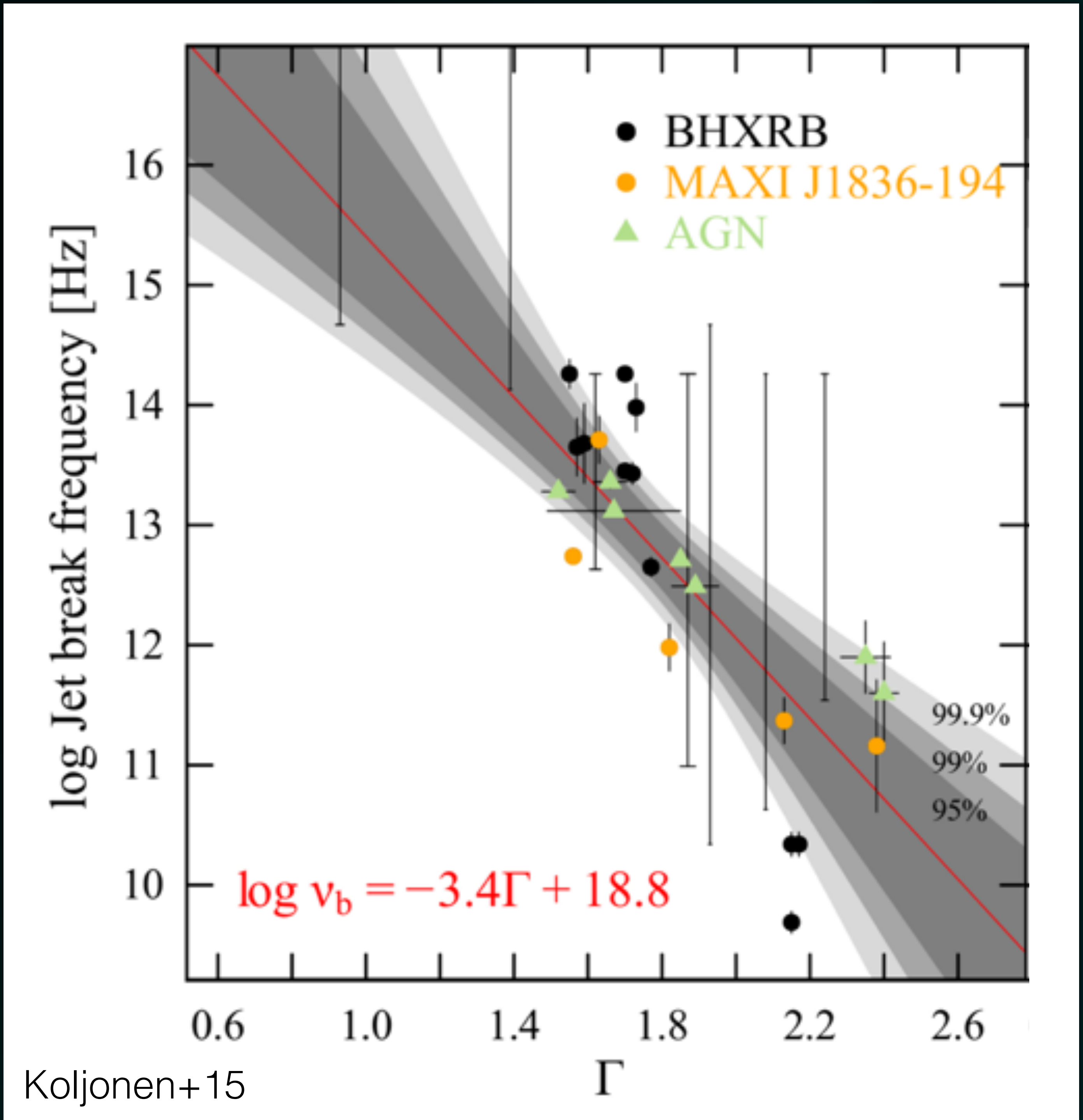


Koljonen+, 2015

Anti-correlation between the jet break and X-ray power law photon index

- Correlation analysis using Monte Carlo bootstrap:
  - Random data sets chosen from the normal distribution of the original data with normal errors, or from uniform distribution of the original data with limits
  - R = -0.76
  - Significance 4.6σ
  - Linear least-squares regression:

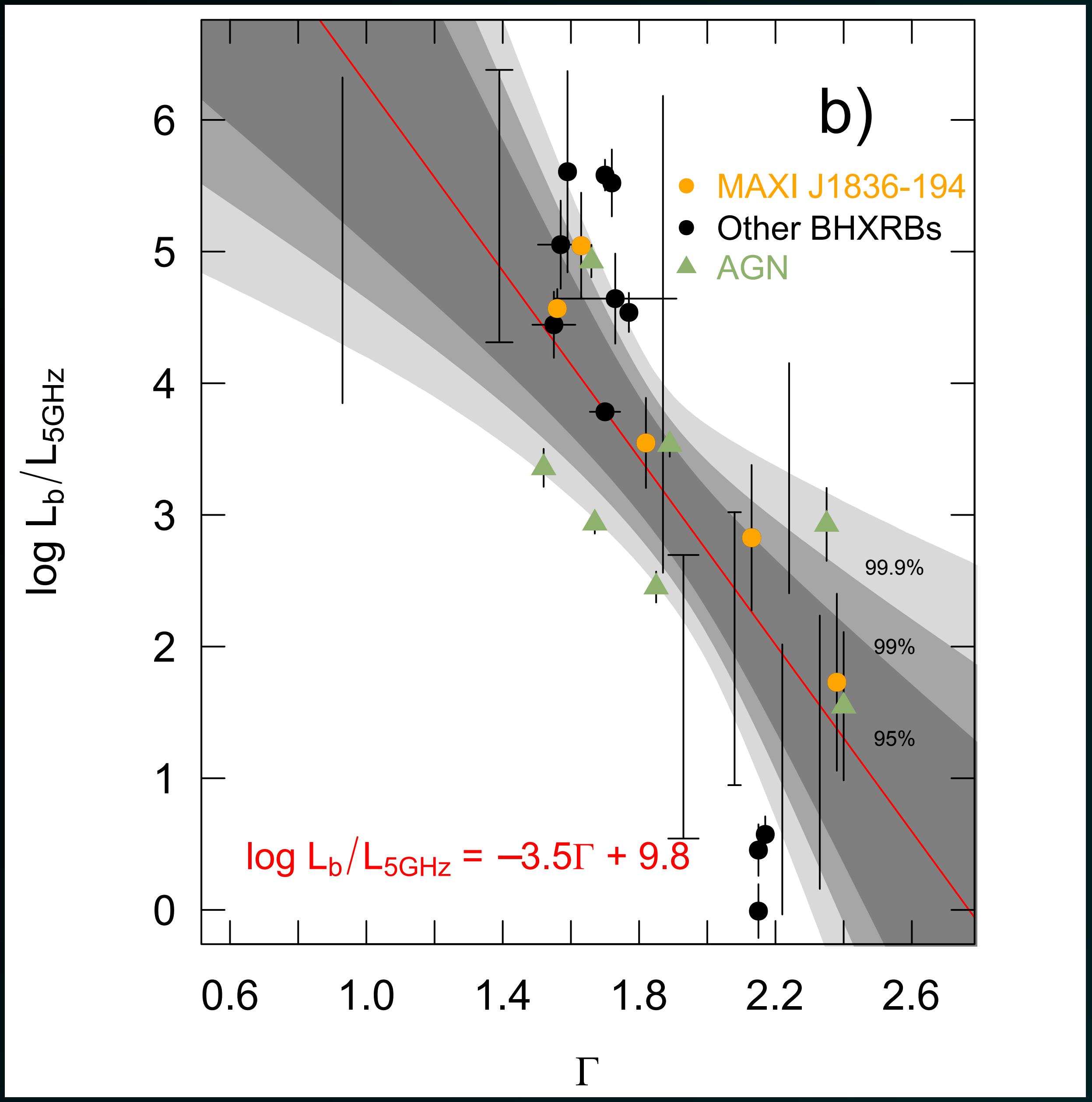
$$\log \nu_b = -3.4^{+0.9}_{-1.4}\Gamma + 18.8^{+2.5}_{-1.6} \text{ Hz}$$



Anti-correlation between L_b/L_{5GHz} and X-ray power law photon index

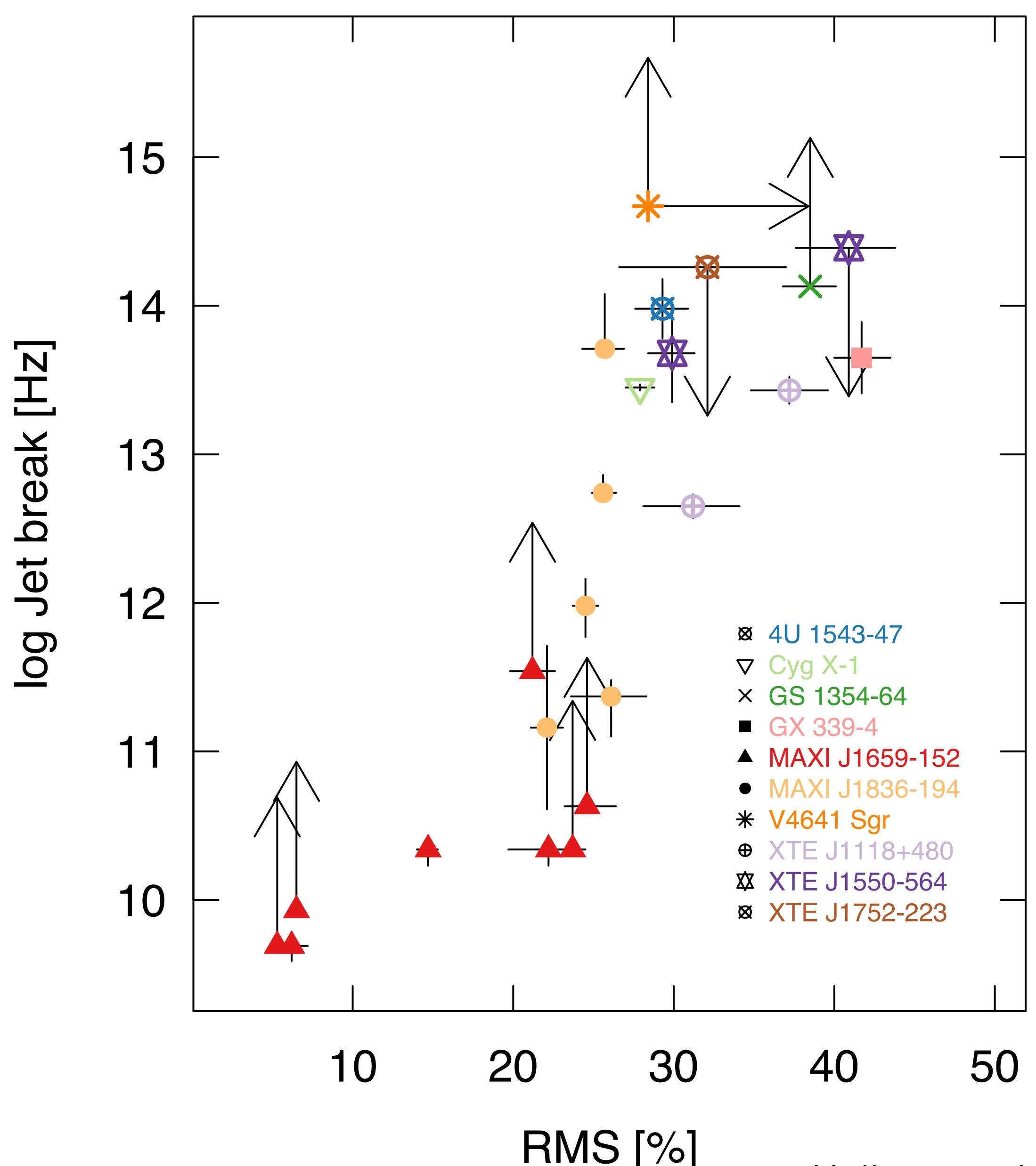
- L_b = Luminosity at the jet break
- L_{5GHz} = Luminosity at 5 GHz
- $L_b/L_{5GHz} = \nu_b S_{\nu,b}/\nu_{5GHz} S_{\nu,5GHz}$
  $= (\nu_b/\nu_{5GHz})^{1+\alpha}$
  = excess luminosity caused by the variable break frequency over the radio luminosity
- Varies between sources by six orders of magnitude
- Jet luminosities should be recalibrated taking the break frequency into account
- Monte Carlo linear least-squares regression:

$$\log L_b = \log L_{5GHz} - 3.5^{+0.9}_{-1.0}\Gamma + 9.8^{+2.0}_{-1.6}\ \mathrm{erg/s}$$



Correlation between the intrinsic rms and X-ray power law photon index

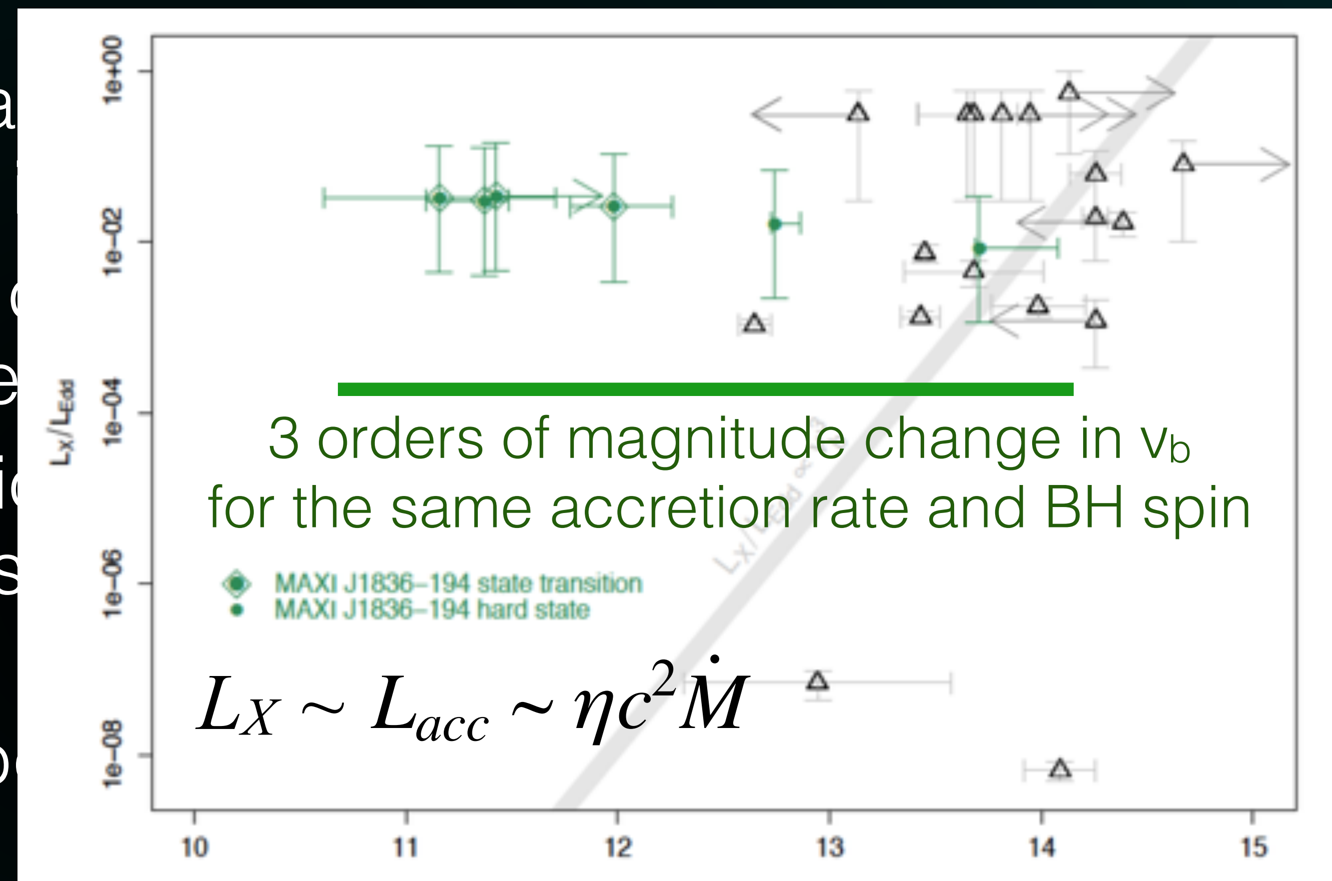
- Only for XRBs (long timescales needed)
- Not very surprising considering the anti-correlation between Γ and rms (Fender, Homan & Belloni 2009).
- But it is possible that the rms is the main driver?
- Internal shock model? (Malzac 13,14)



Koljonen+, in prep.

What affects the jet properties? Conditions in the corona?

- New correlation: the jet brea
  the X-ray power law photon i
- Ties in the conditions in the c
  conditions in the jet (particle
  - Unifying link: Magnetisati
    regimes (MHD processes
    corona)?
  - Benchmark that should b
    models



Fender & Gallo 2014

- No mass scaling! Unexpected in the light of the fundamental plane (Heinz & Sunyaev 2003): $\nu_b \sim M^{\left(-\frac{1}{3}\right)} \dot{m}^{\left(\frac{2}{3}\right)}$
- Lack of strong scaling with BH mass, accretion rate or spin hints at stable/self-similar feature

The internal properties of jets rely most critically on the conditions of the plasma close to the BH, rather than other parameters such as the BH mass, accretion rate or spin.