Radio/X-ray correlation in black hole accretion systems

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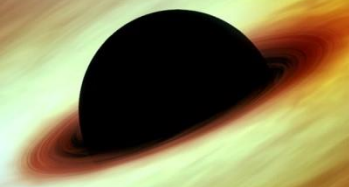
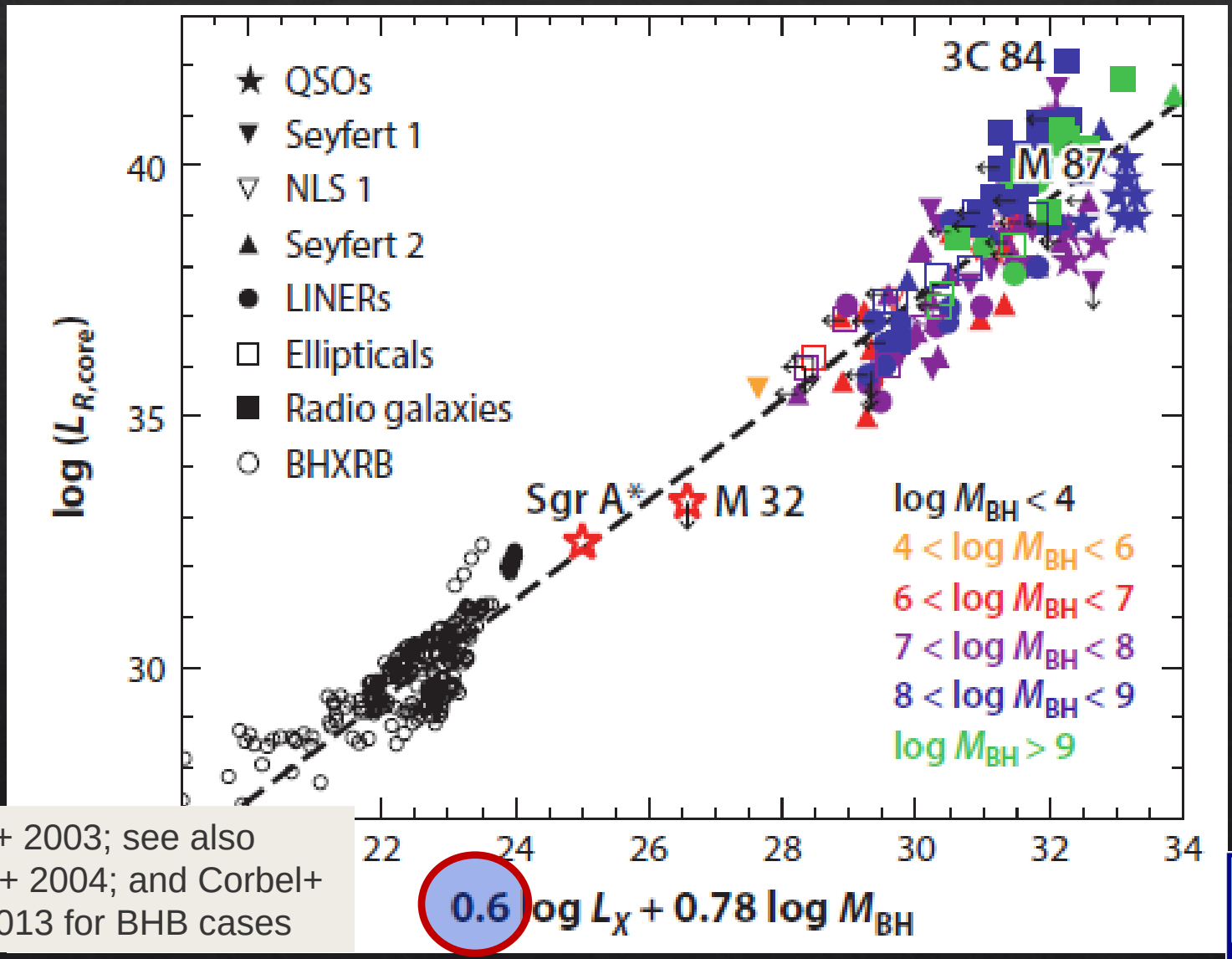


Collaborators:

Feng Yuan (SHAO), Andrzej A. Zdziarski (NCAC)

Shining from the heart of darkness: BH accretion and Jets,
6th Kathmandu meeting, Kathmandu, Oct. 16-21, 2016

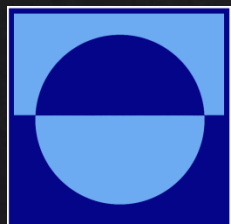
Fundamental Plane of black hole activity



Merloni+ 2003; see also Kording+ 2004; and Corbel+ 2003, 2013 for BHB cases

Context

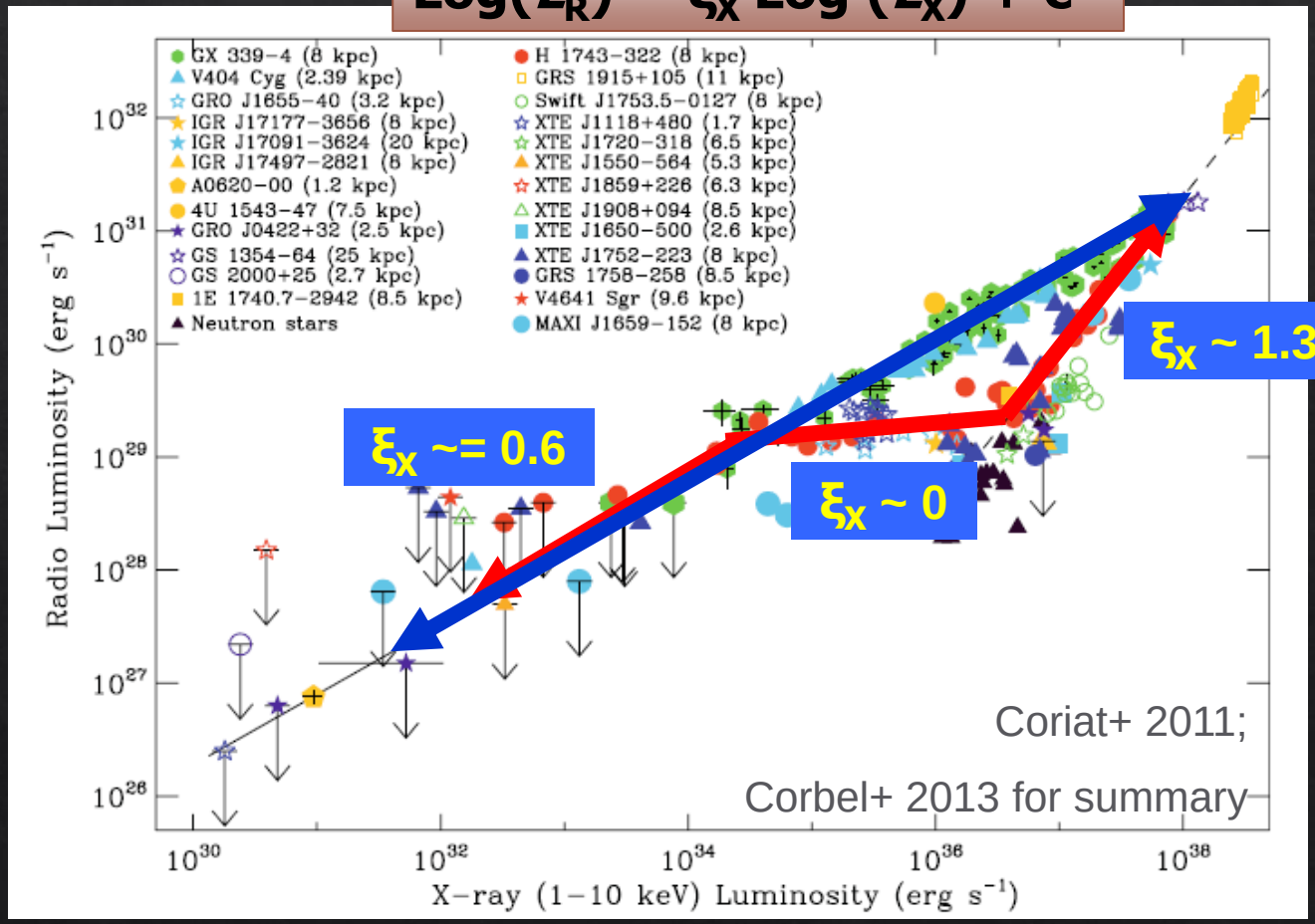
- **Topic 1: newly discovered hybrid RX correlation**
  - Observations of the hybrid correlation
  - Theoretical interpretation: different branches correspond to different accretion modes
- **Topic 2: RX correlation at very low L_x/L_{edd}**
  - Yuan & Cui (2005) predicts a steep $\xi_X \sim 1.2$ correlation
  - largest sample (72 sources) confirms the prediction
  - Why some works claim different result?
- Summary



Topic 1: hybrid correlation observed

- Some BHBs do not follow the original ξ_X~=0.6 correlation. They follow a hybrid correlation

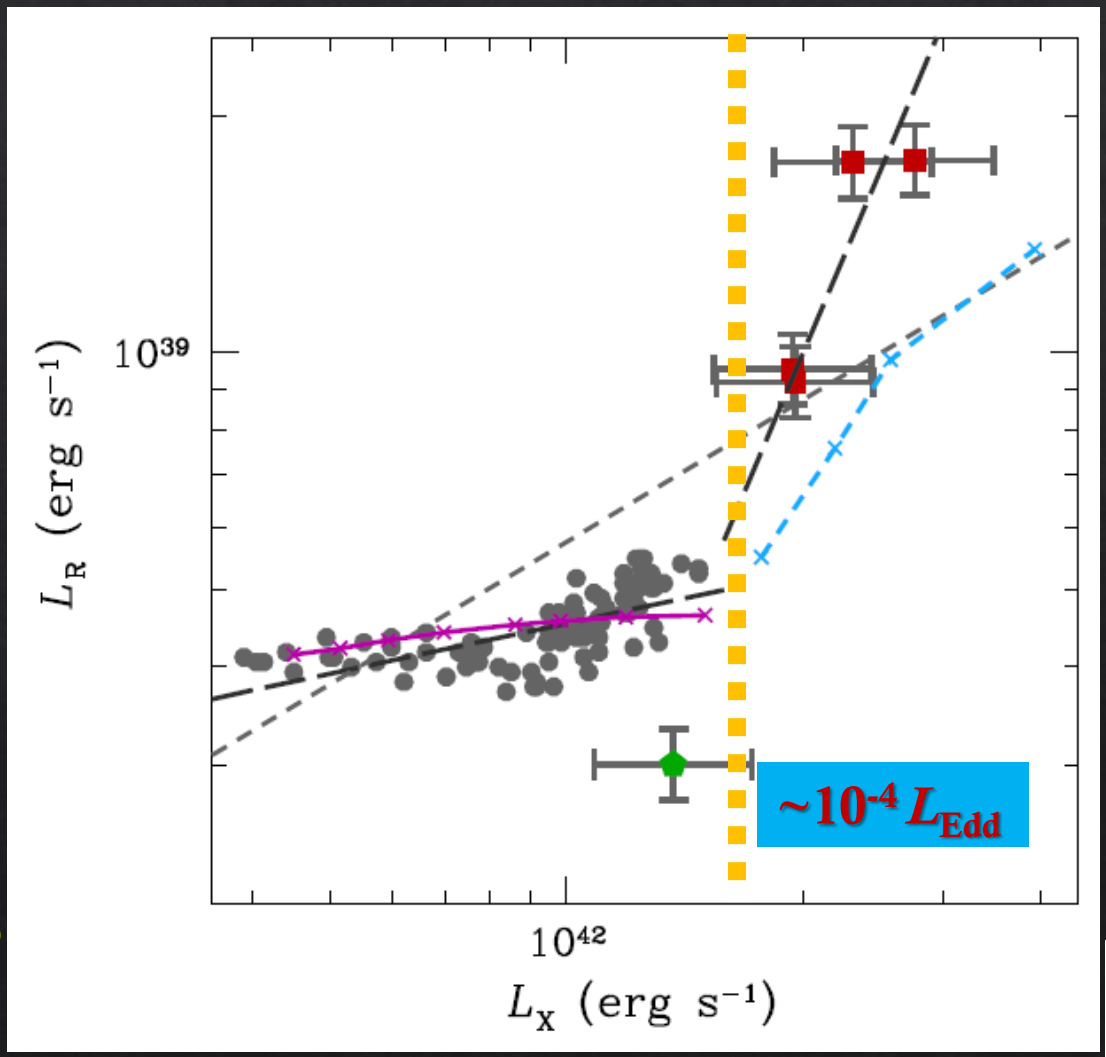
$$\mathrm{Log}(L_R) \sim \xi_X \,\mathrm{Log}\,(L_X) + c$$



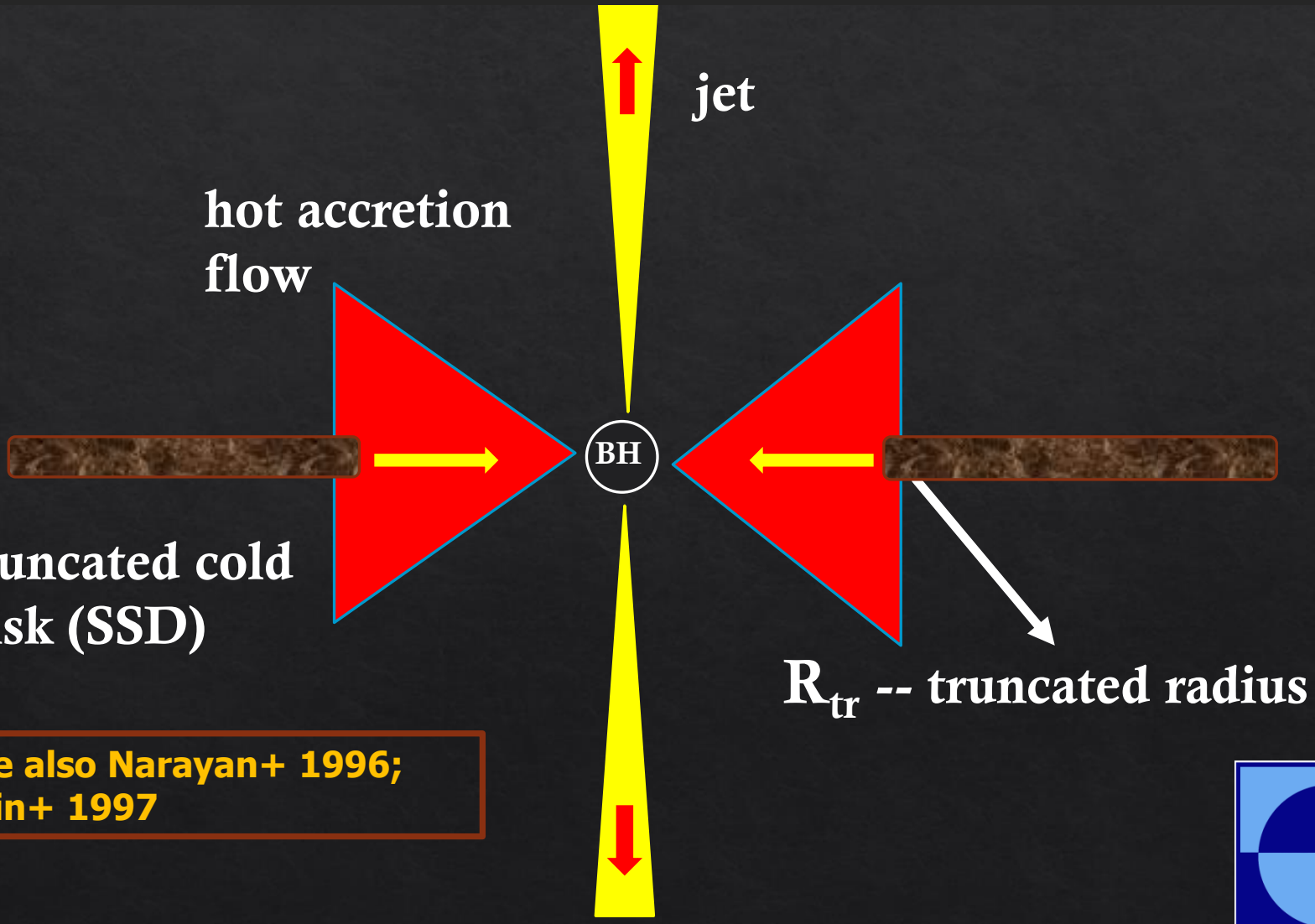
NGC 7213: (first) AGN to show hybrid radio/X-ray correlation

- A Seyfert 1/ LINER,
- $L_{bol} \sim 10^{-3}\ L_{Edd}$.
- 3+ yr ATCA/RXTE monitoring (Bell+ 2011)

Xie, Zdziarski+ 2016



Model: accretion-jet scenario
(Yuan, Cui & Narayan 2005)



see also Narayan+ 1996; Esin+ 1997

Theoretical interpretation

Coriat+ 2011

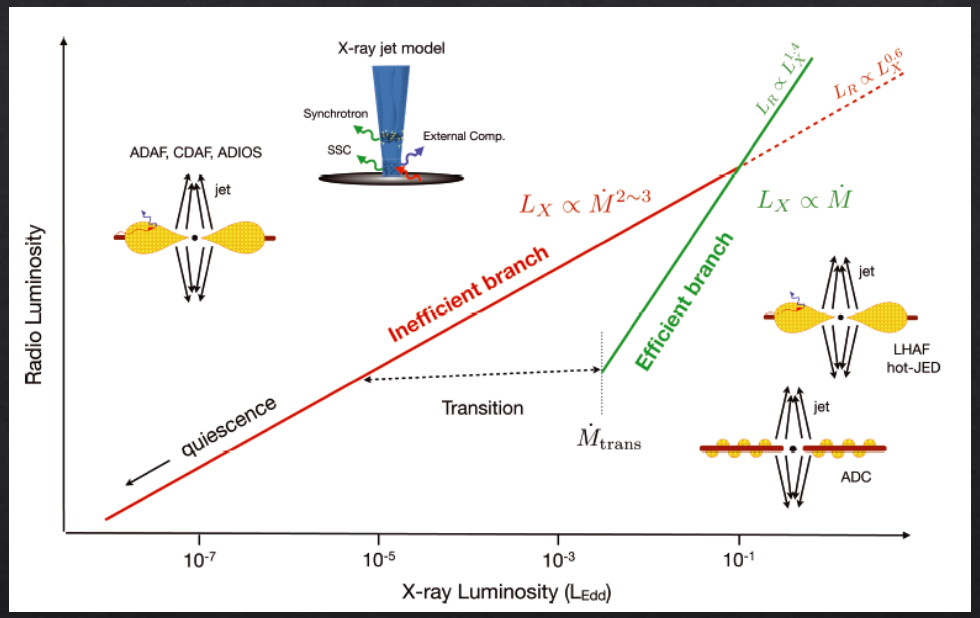
Radio (jet) power (Heinz & Sunyaev 2003)

$$L_\nu \propto Q_{\rm jet}^{\xi} \quad \text{with} \quad \xi = \frac{2p-(p+6)\alpha+13}{2(p+4)} \simeq 1.4$$

X-ray power

$$L_{\rm X} \propto \dot{M}^q$$

$$L_{\rm radio} \propto L_{\rm X}^{\xi/q}$$

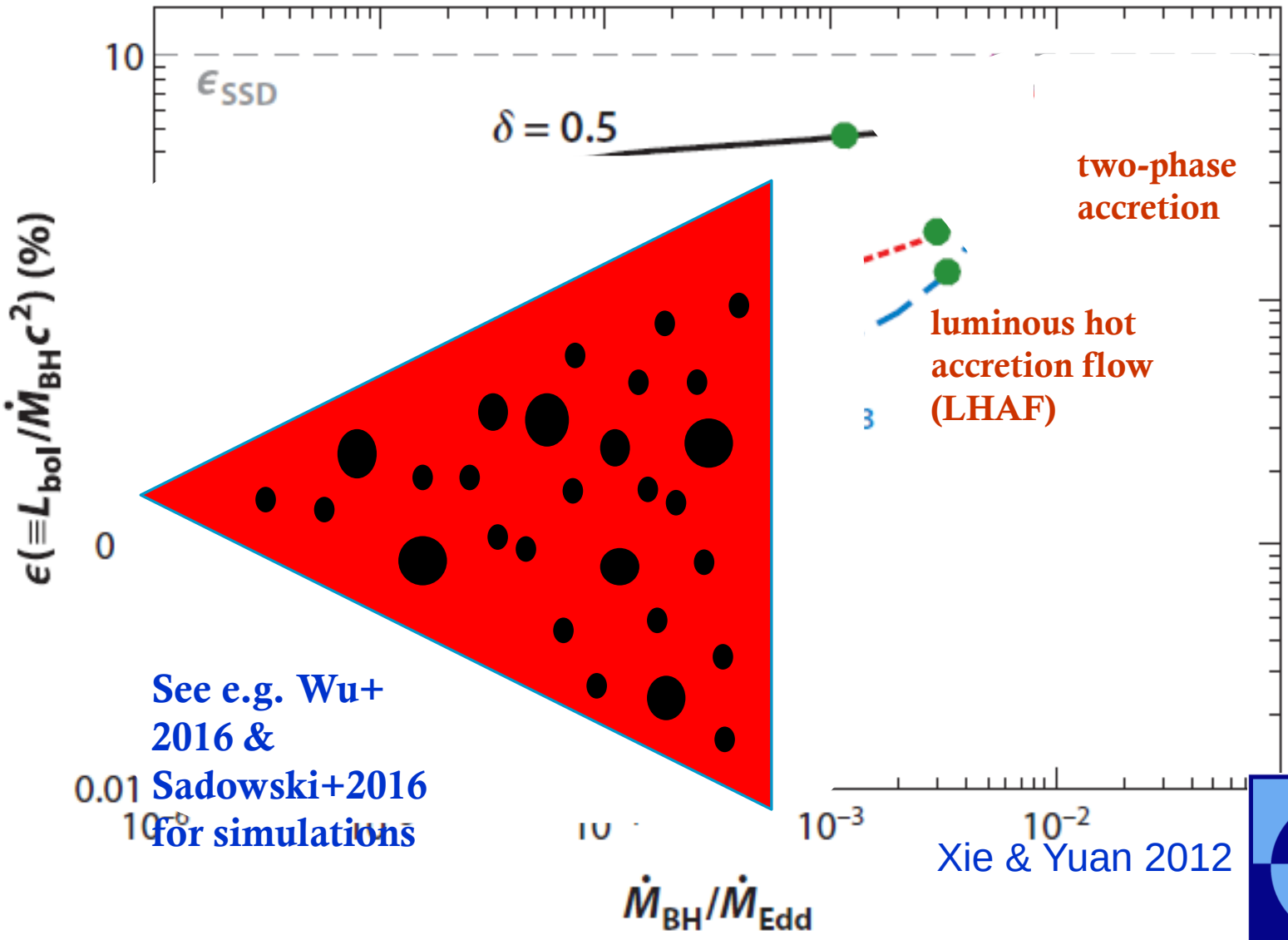


ξ_X ~= 0.6 ⟺ q ~= 2, radiative inefficient

ξ_X ~= 1.4 ⟺ q ~= 1, radiative efficient

ξ_X ~= 0 ⟺ q >> 1, quick enhance in efficiency

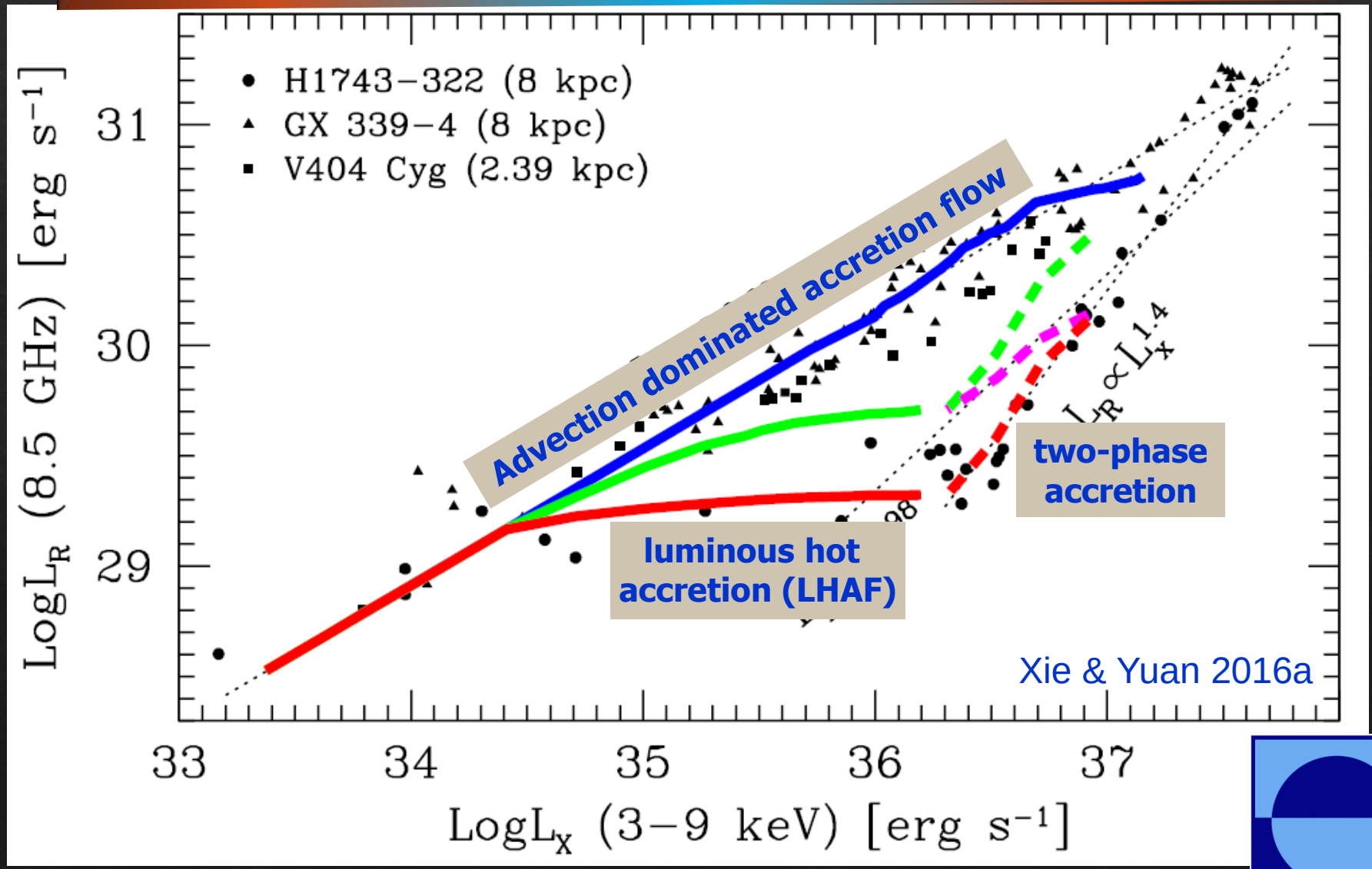
different hot accretion modes



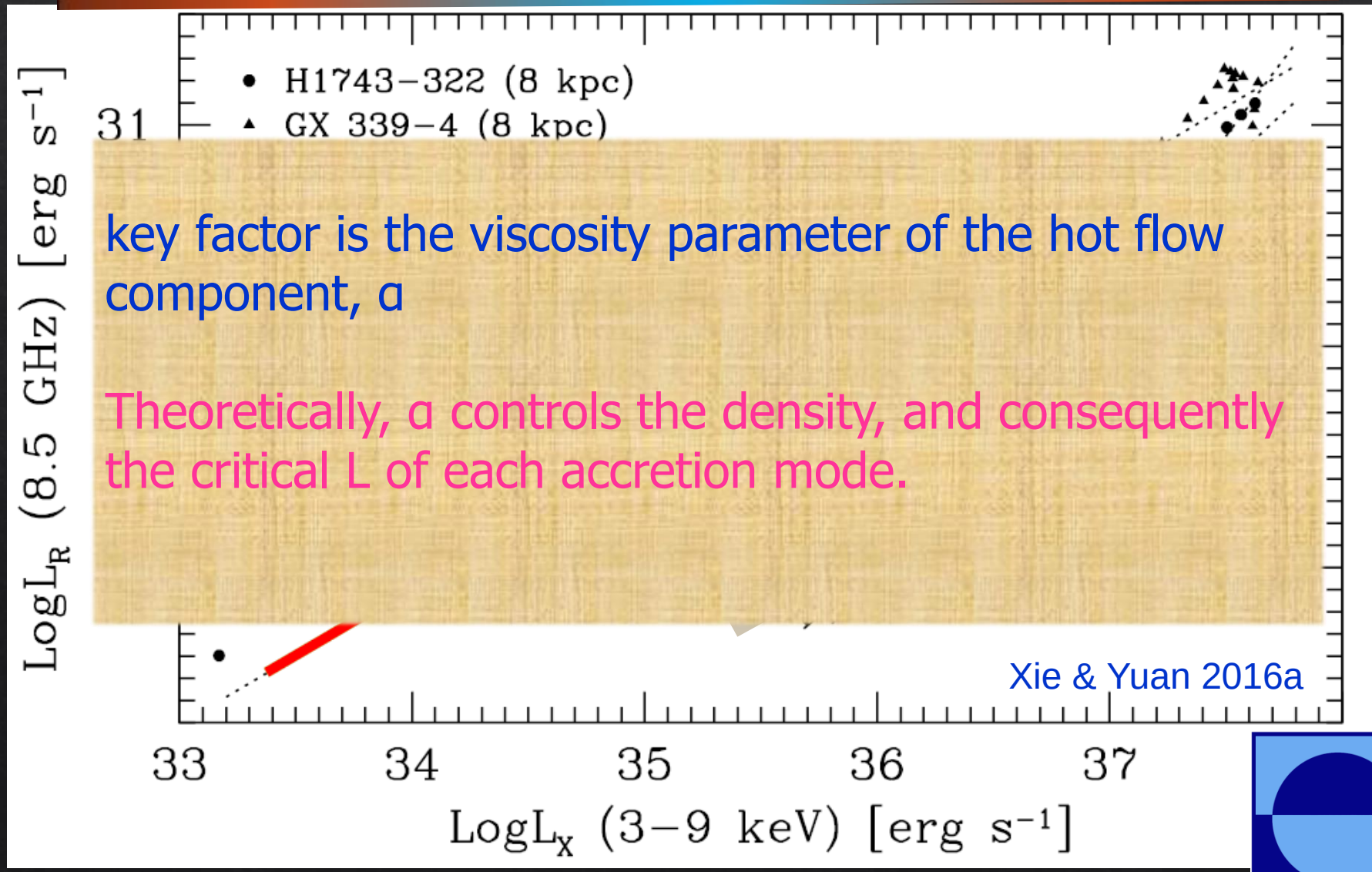
See e.g. Wu+ 2016 & Sadowski+2016 for simulations

Xie & Yuan 2012

Theory: radio/X-ray correlation



Theory: radio/X-ray correlation



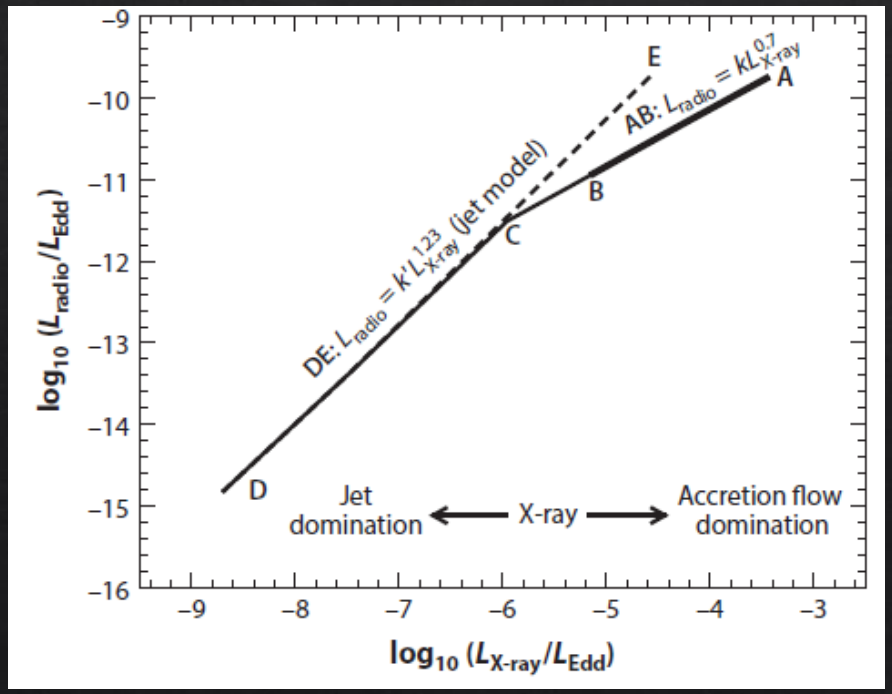
key factor is the viscosity parameter of the hot flow component, α

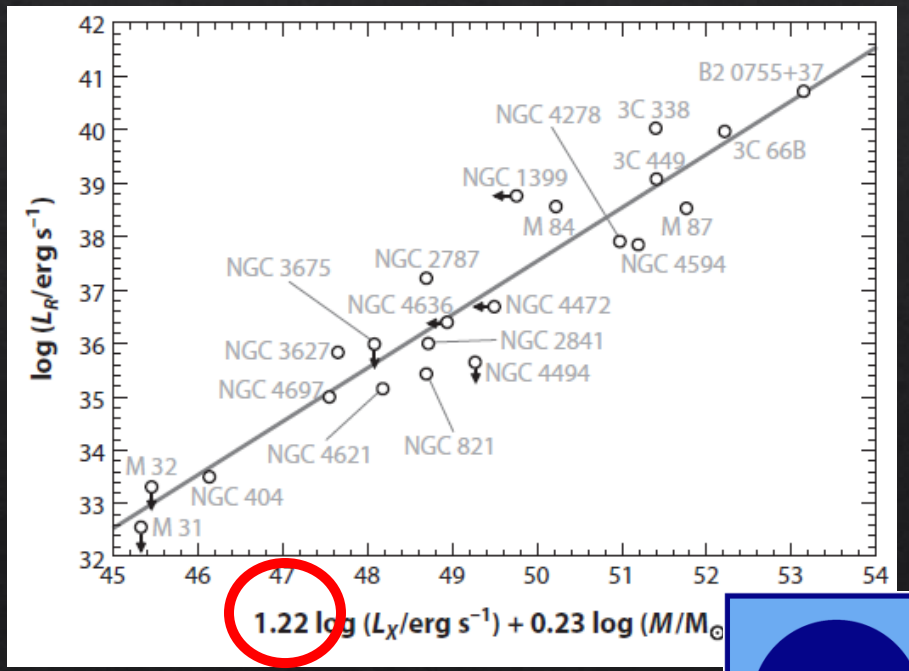
Theoretically, α controls the density, and consequently the critical L of each accretion mode.

Xie & Yuan 2016a

Topic 2: The correlation at very low L_x/L_{edd}

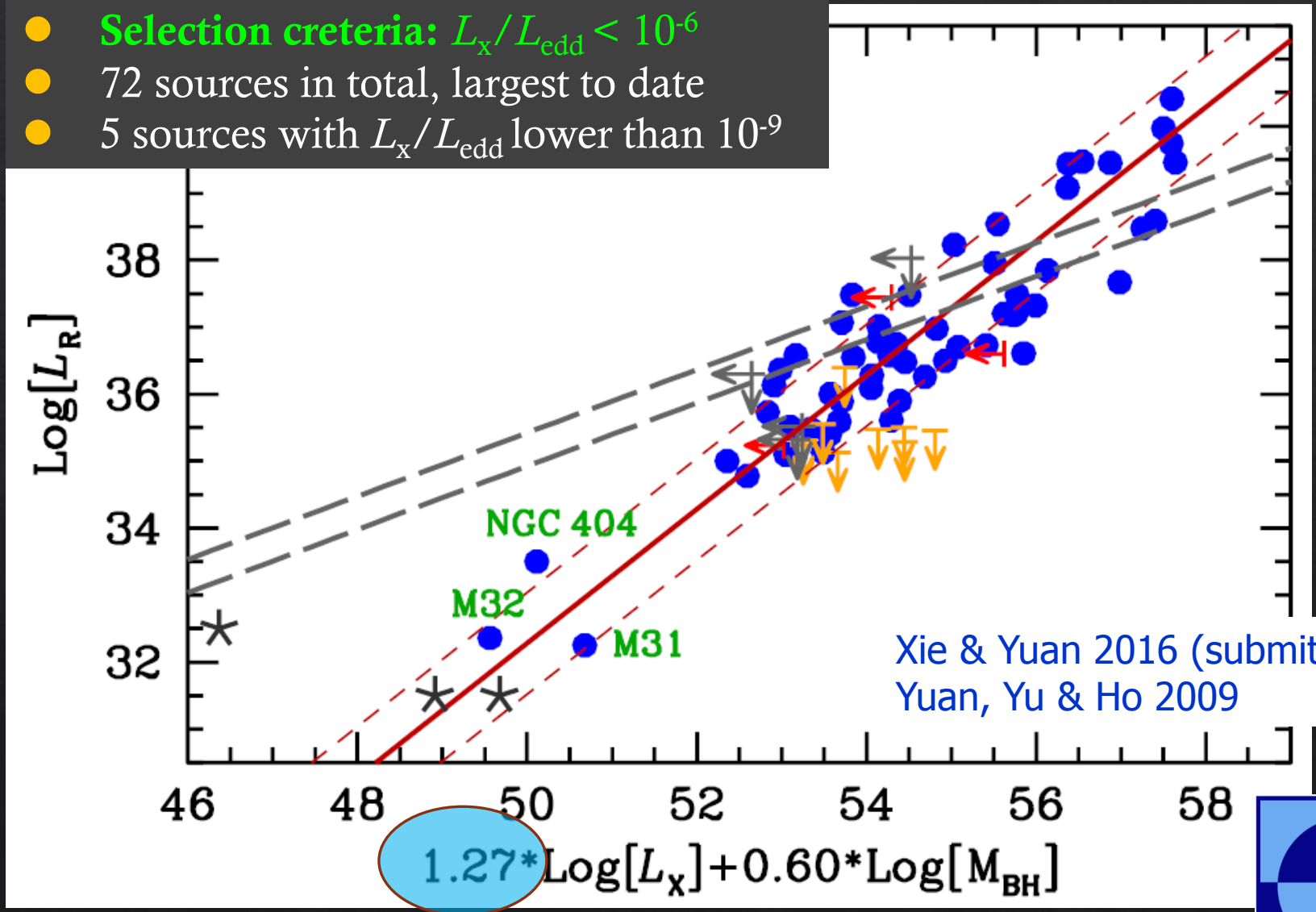
- Emission from jet, rather than hot accretion flow, dominates in X-ray band then (Yuan & Cui 2005).
- Correlation steepens, with $\xi_X \sim 1.23$.
- supported by many works (Pellegrini et al. 2007; Wrobel, Terashima & Ho 2008; de Gasperin et al. 2011; Younes et al. 2012; Yang et al. 2015a).





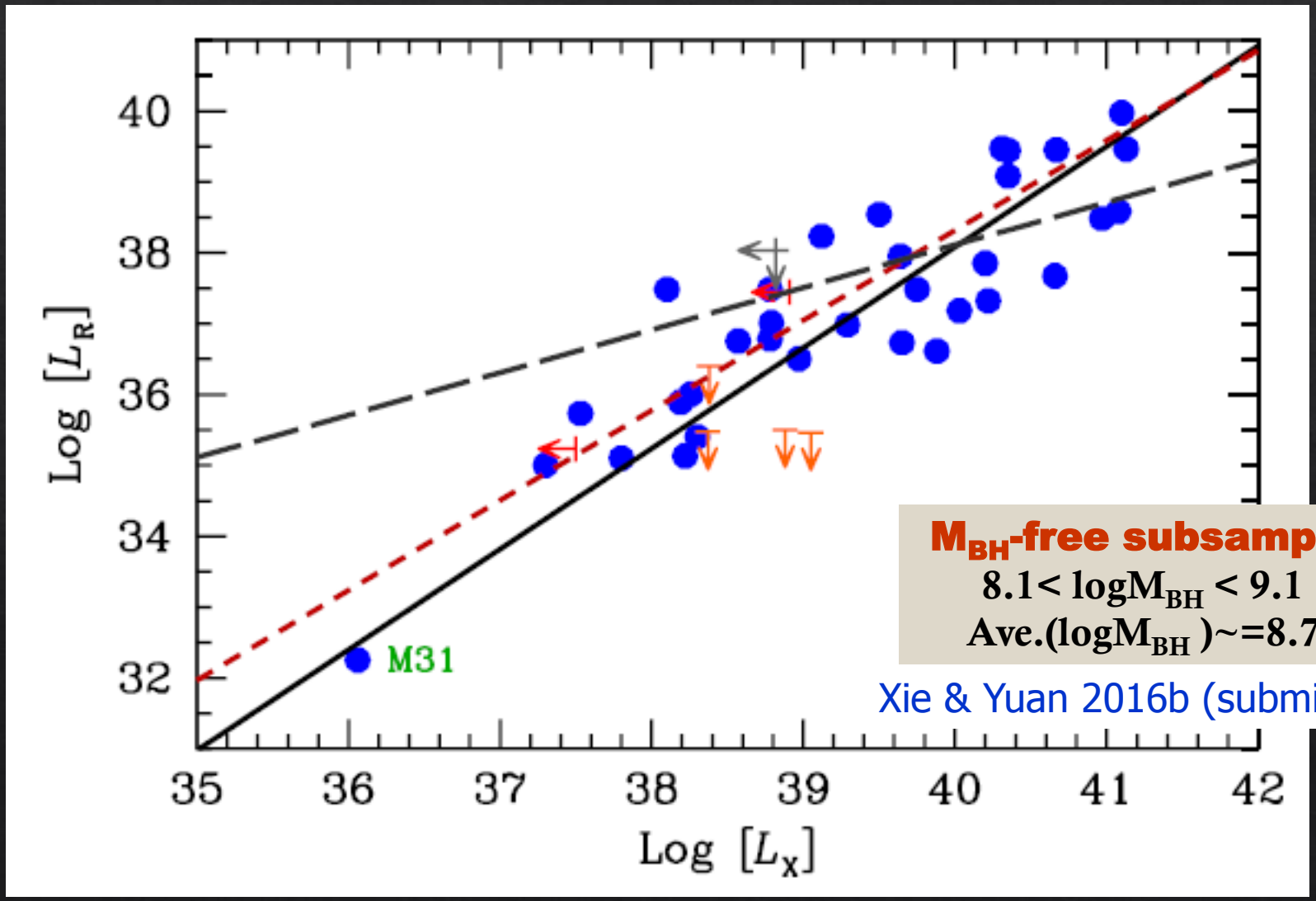
Topic 2: Fundamental Plane in quiescent AGNs

- **Selection creteria:** $L_x/L_{edd} < 10^{-6}$
- 72 sources in total, largest to date
- 5 sources with L_x/L_{edd} lower than 10^{-9}



Xie & Yuan 2016 (submitted);
Yuan, Yu & Ho 2009

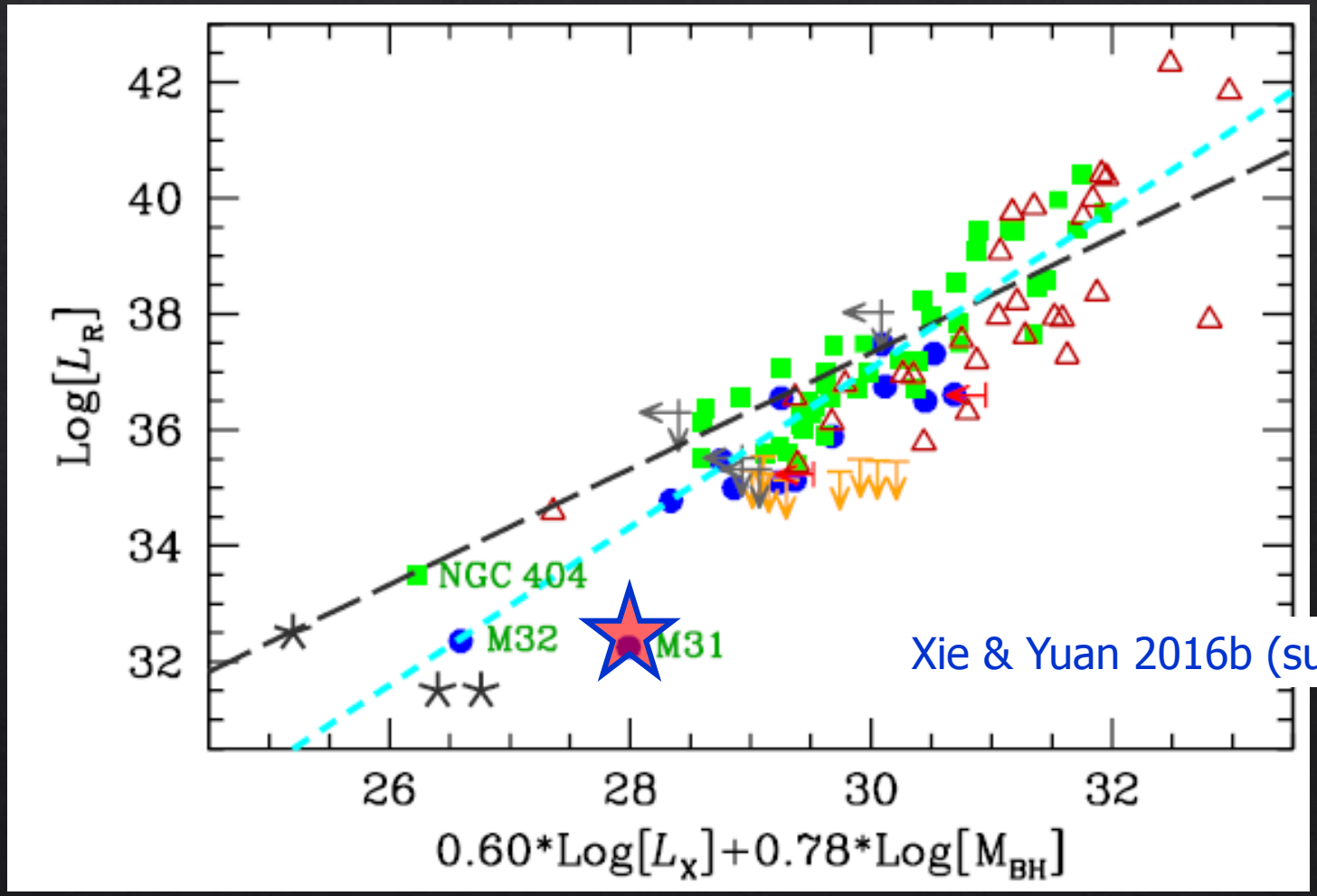
Topic 2: Fundamental Plane in quiescent AGNs



Fundamental Plane in quiescent AGNs

Why most previous works missed this new correlation?

① large difference in M_{BH}, sources mix up in L_R and L_X with different L_X/L_{edd}

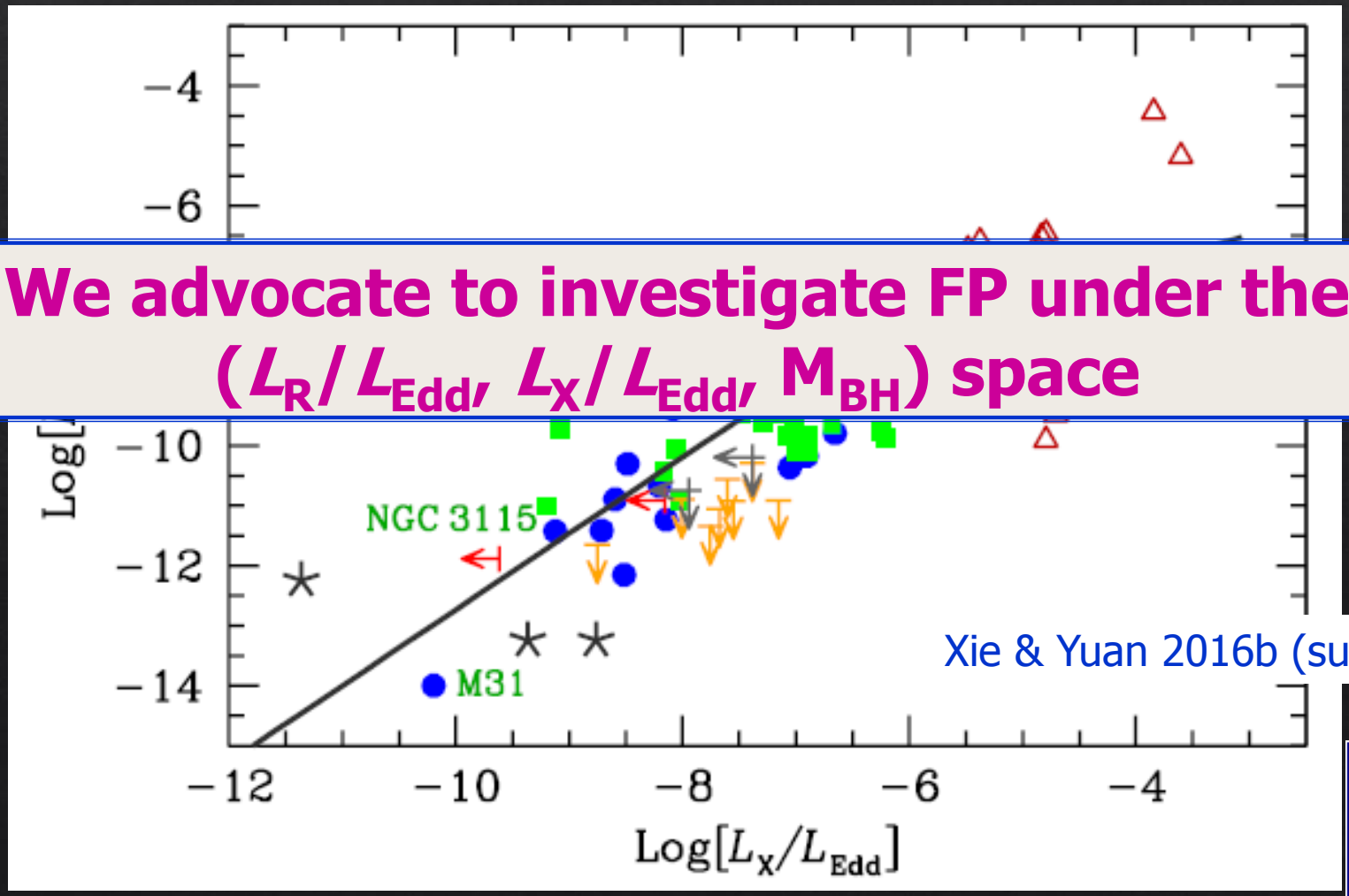


Fundamental Plane in quiescent AGNs

Why most previous works missed this new correlation?

② they lack faint (in L_X/L_{Edd}) source; more these sources, steeper the correlation.

We advocate to investigate FP under the (L_R/L_{Edd}, L_X/L_{Edd}, M_{BH}) space



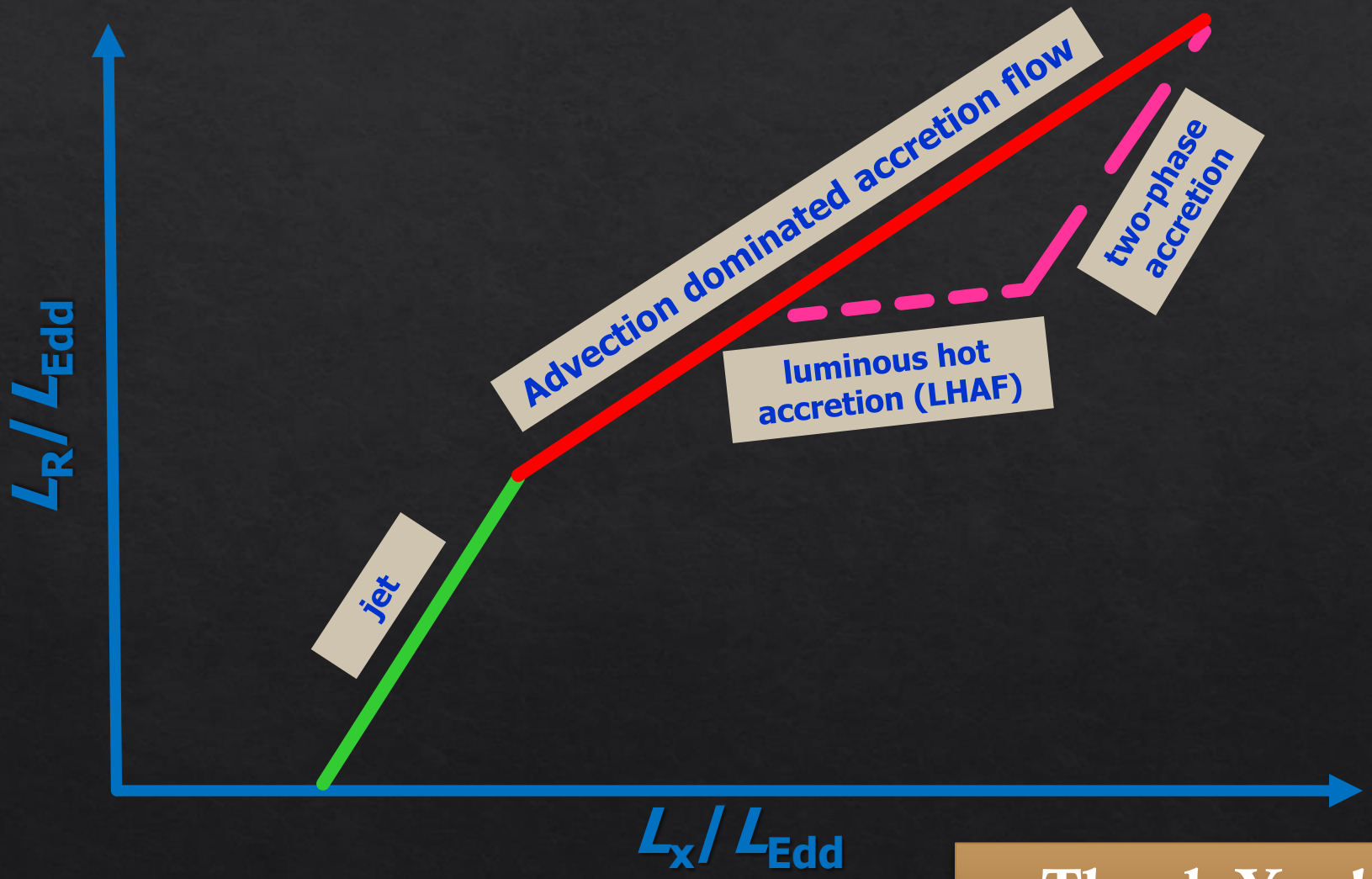
Xie & Yuan 2016b (submitted)

Summary

- Fundamental Plane (FP; or radio/X-ray correlation for individual sources) provides important clues on accretion theory.
- **hybrid radio/X-ray correlation is observed in BHBs (e.g. H1743-322) and recently also in one AGN, NGC 7213.**

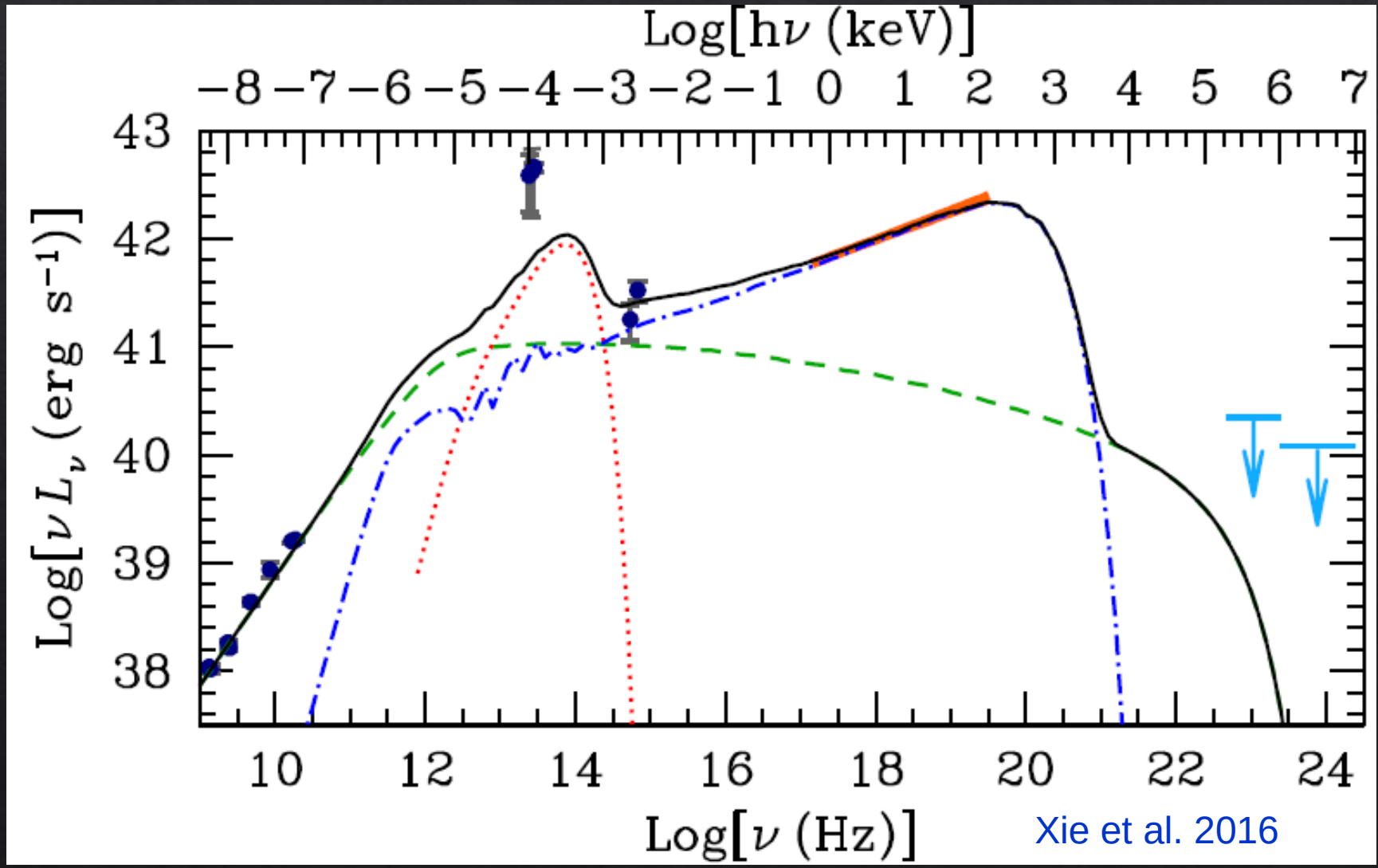
  → unique opportunity to probe accretion theory.
- We argue the hybrid systems exhibit changes in the hot accretion flow modes, i.e. from ADAF to luminous hot accretion flow, and then to the two-phase accretion flow.
- We modelled the SED, the V-shaped X-ray index-luminosity correlation, the radio/X-ray timelag in NGC 7213. Consistent with our theoretical interpretation.
- We confirm that quiescent AGNs follow a new ξ_X=1.27 FP, consistent with expectation that most emission comes from jet.

Summary



Thank You!

SED modelling of NGC 7213



Xie et al. 2016

Radio/X-ray correlation of BHBs

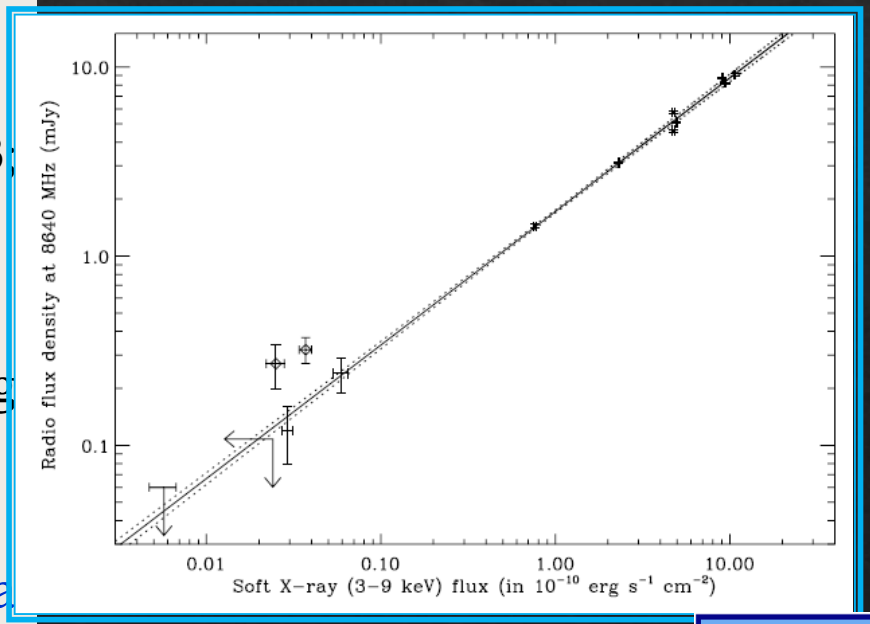
Ways to probe the geometry/physics of accretion systems

- Spectral (SED) fitting/decomposition
- Time lags between different frequencies (i.e. X-ray reverberation)
- empirical relationships between various wavelengths

- Tight radio/X-ray correlation was originally found in GX 339-4 (e.g. Hannikainen+ 1998; Corbel+ 2000, 2003; Gallo+ 2003), i.e.

$$L_R \propto L_X^{0.5-0.7}$$

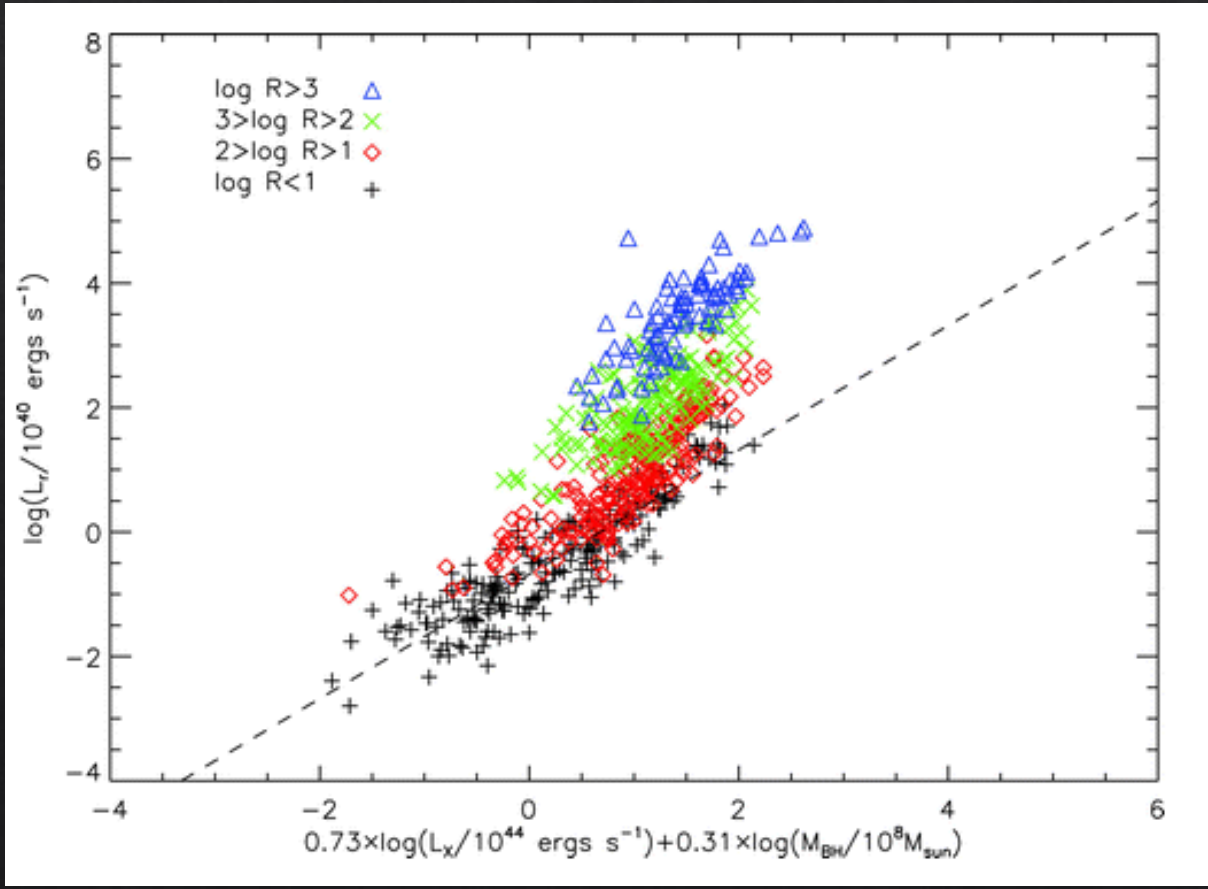
- Soon extends to other wavebands (e.g. Opt./IR vs. X-rays: Russell+ 2006)
- Direct evidence for strong coupling between jet and X-ray emitting media (corona or hot accretion flow)



Corbel+ 2003

Progress: complexities revealed

- Systems with different radio-loudness (defined as radio luminosity to the bolometric/X-ray luminosity) follow different correlations, in both slope and normalization.

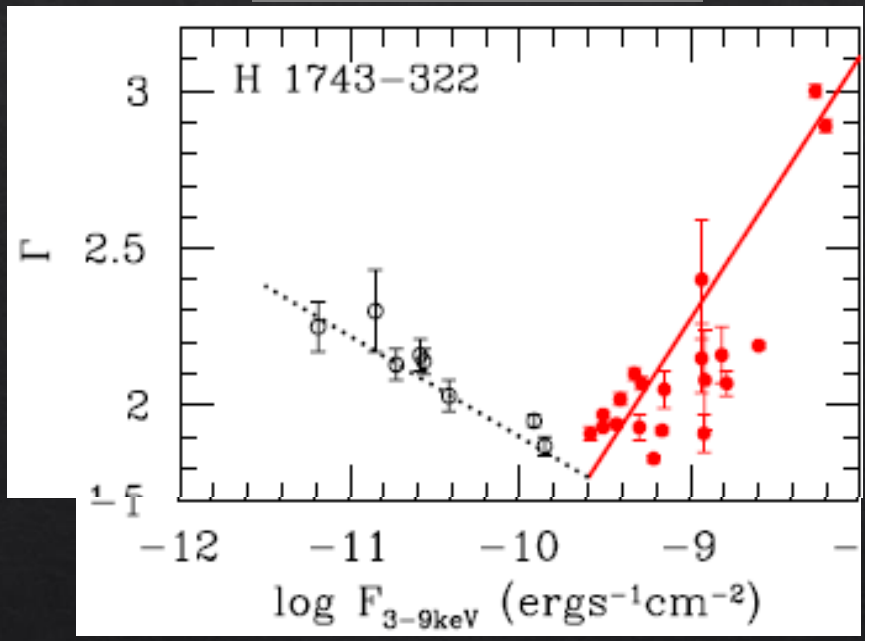


Li+ 2008;

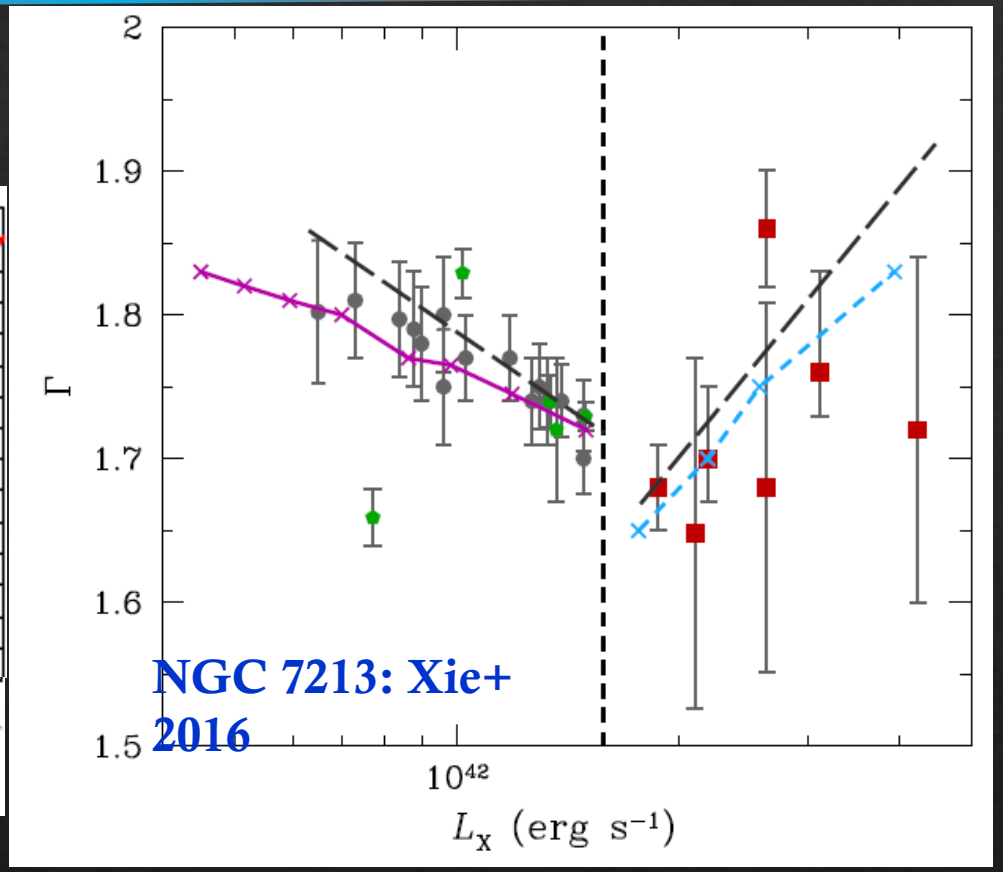
Wang+ 2006

hybrid L_R-L_x correlation associates with V-shaped index-L_x correlation

$F(E) \sim E^{1-\Gamma}$



Cao+ 2014



Yang+ 2015; see also Emmanoulopoulos+ 2012 and Sobolewska & Papadakis 2009 for the left and right branches, respectively

Theory: X-ray index-L_x correlation

Yang+ 2015

Additional constrains: radio size and radio/X-ray timelags

- **LBA at 8.4 GHz unresolved, i.e. size < 3mas**

$$A_{8.4} \lesssim 0.33\,\mathrm{pc} \approx 6.8 \times 10^4\ R_g$$

theoretically,

$$A_{8.4} \approx \max(2 z_{8.4} \phi_{\rm jet} \cos i,\ \Delta z_{8.4} \sin i)$$

$$z_{8.4} < 3.6 \times 10^5\ R_g$$

$$\Delta z_{8.4} < 2. \times 10^5\ R_g$$

- **radio lags the X-rays by,**

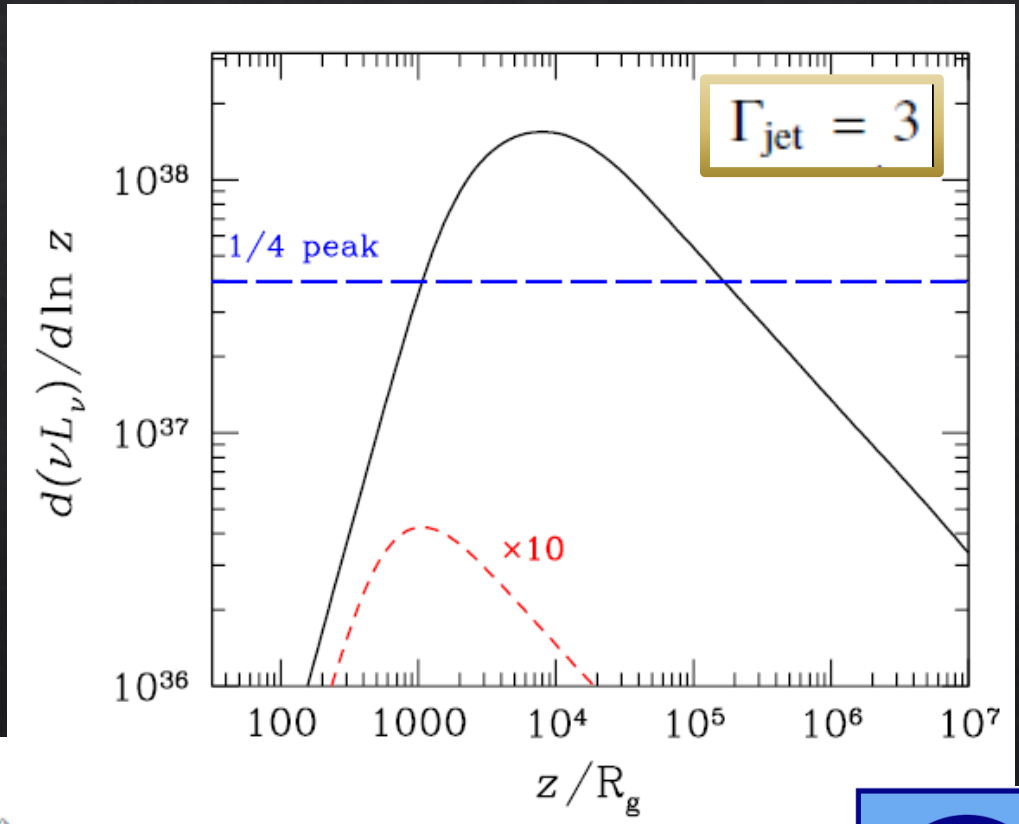
$$\delta t_{8.4} = 24 \pm 12\ \mathrm{d}$$

$$\delta t_{4.8} = 40 \pm 13\ \mathrm{d}$$

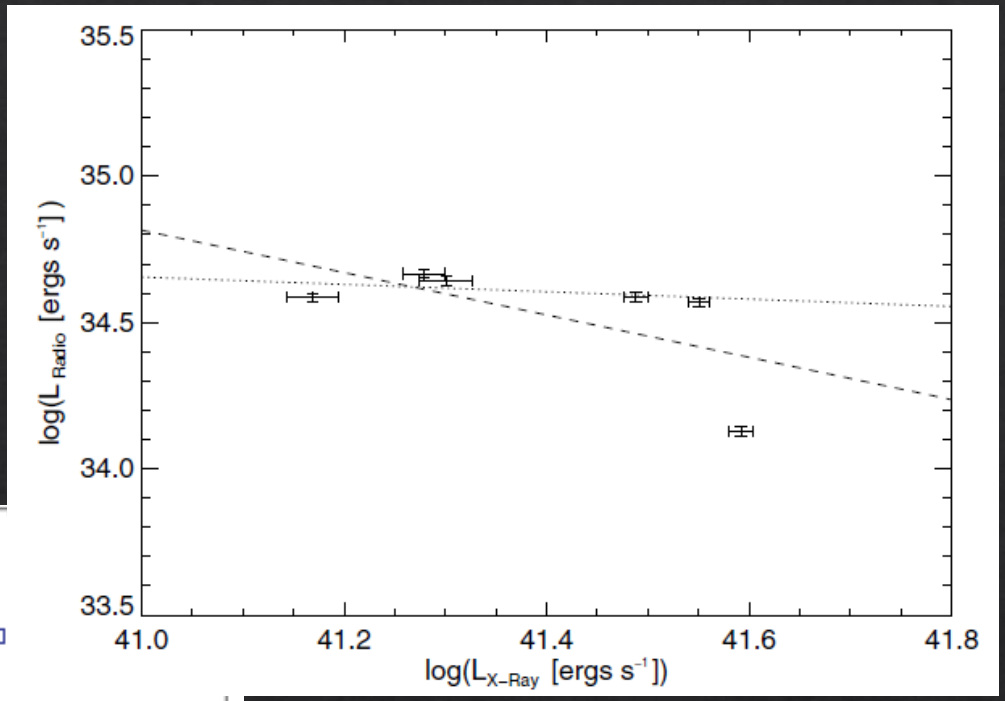
theoretically,

$$z_{8.4} = \beta_{\rm jet} c \delta t_{8.4} / (1 - \beta_{\rm jet} \cos i)$$
$$\approx (4.2 \pm 2.1) \times 10^3\ R_g\ \beta_{\rm jet} / (1 - \beta_{\rm jet} \cos i)$$

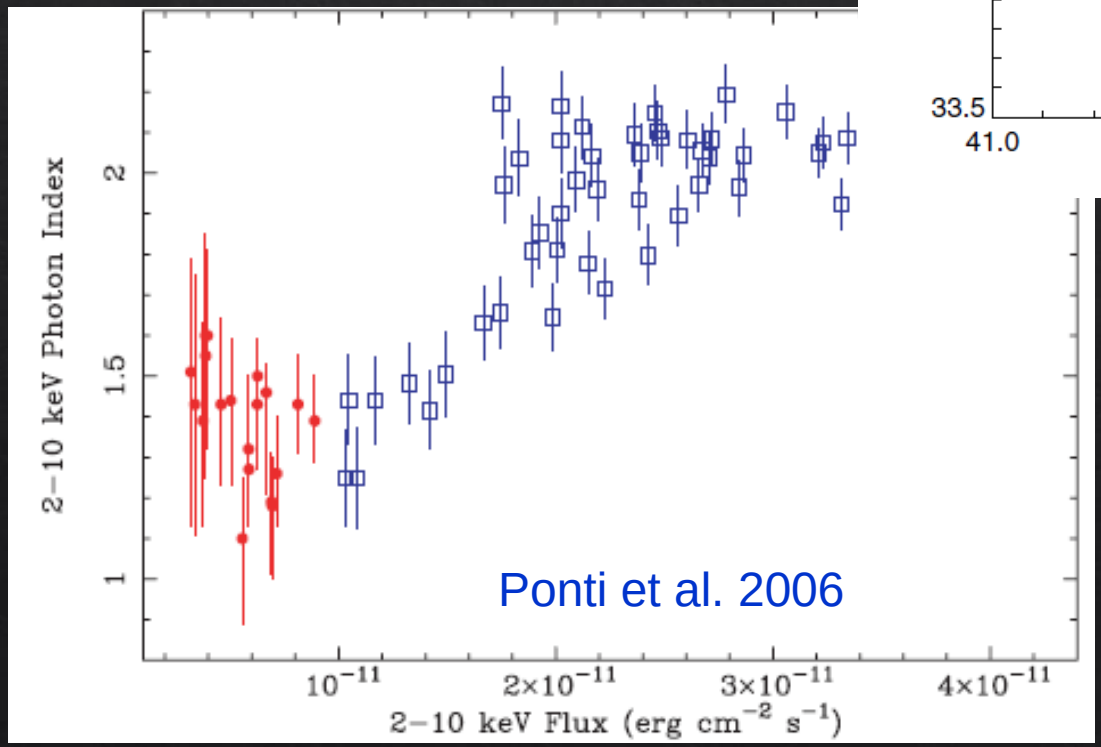
$$z_{8.4} \approx (3.4 \pm 1.7) \times 10^4 R_g \quad \text{for} \quad \Gamma_{\rm jet} = 3$$



Discussion: NGC 4051



King et al. 2011



Ponti et al. 2006

D_{4051} = 10 Mpc

1E-11 erg/s/cm^2 =1E41 erg/s

$M_{bh,4051}$ = 1.7E6 M_{sun}