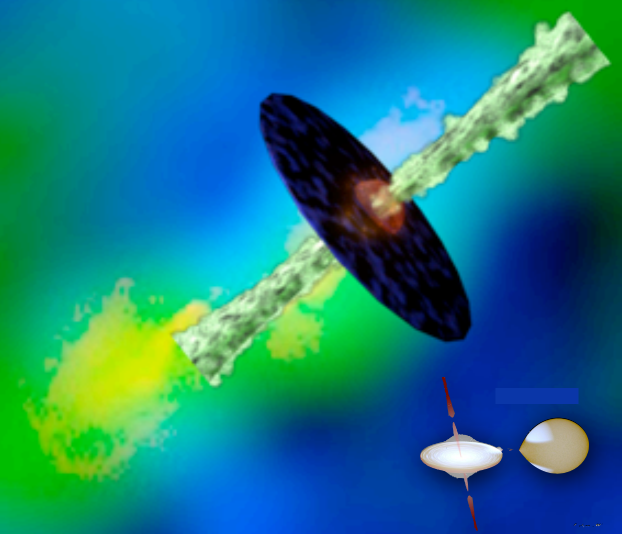
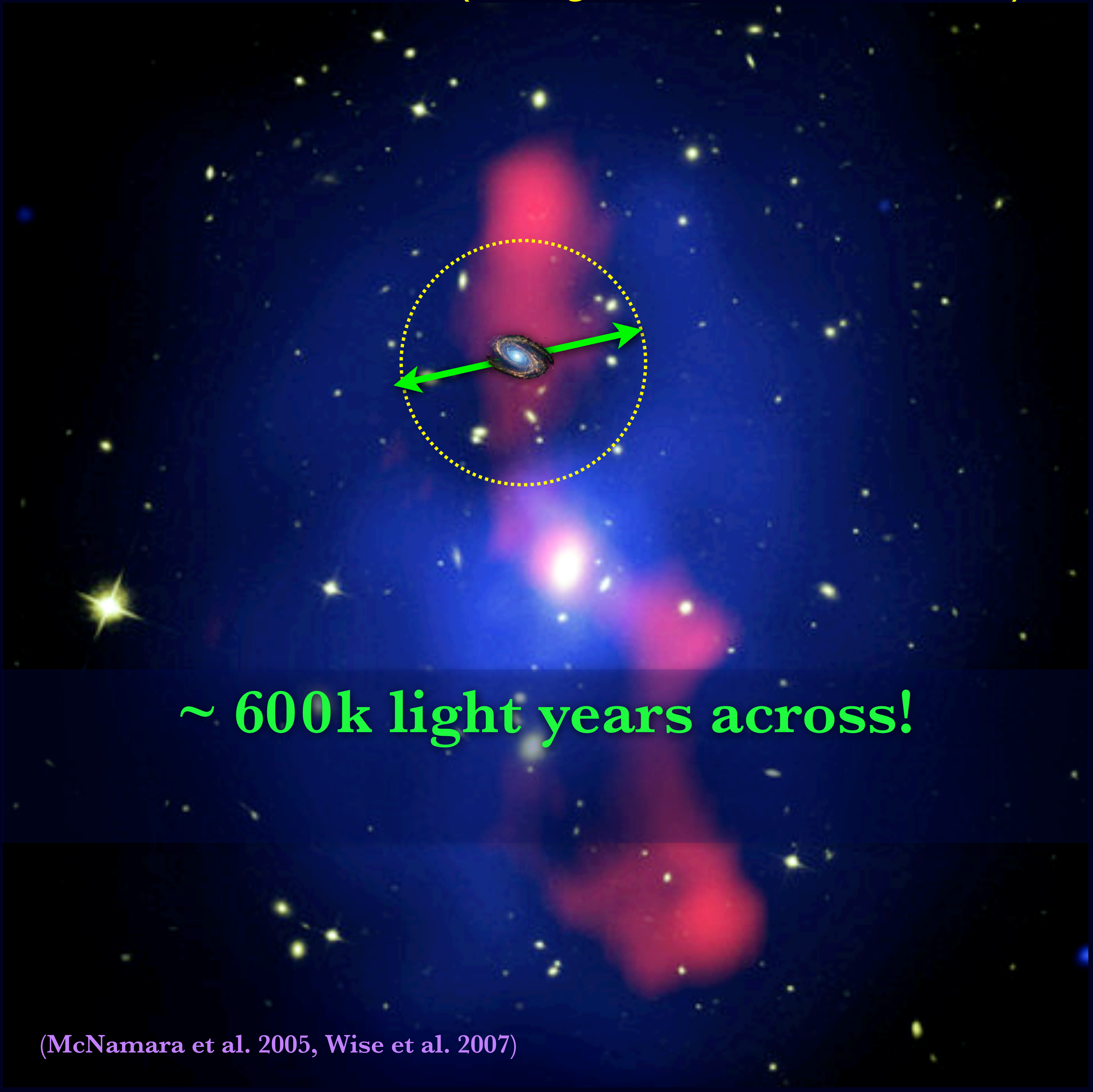
ITN 215212: Black Hole Universe

inflow/outflow connection in accreting black holes: scaling relations and the Fundamental Plane



Sera Markoff
(API, University of Amsterdam)

Black holes have an enormous effect on their local environment (via jets and winds!)



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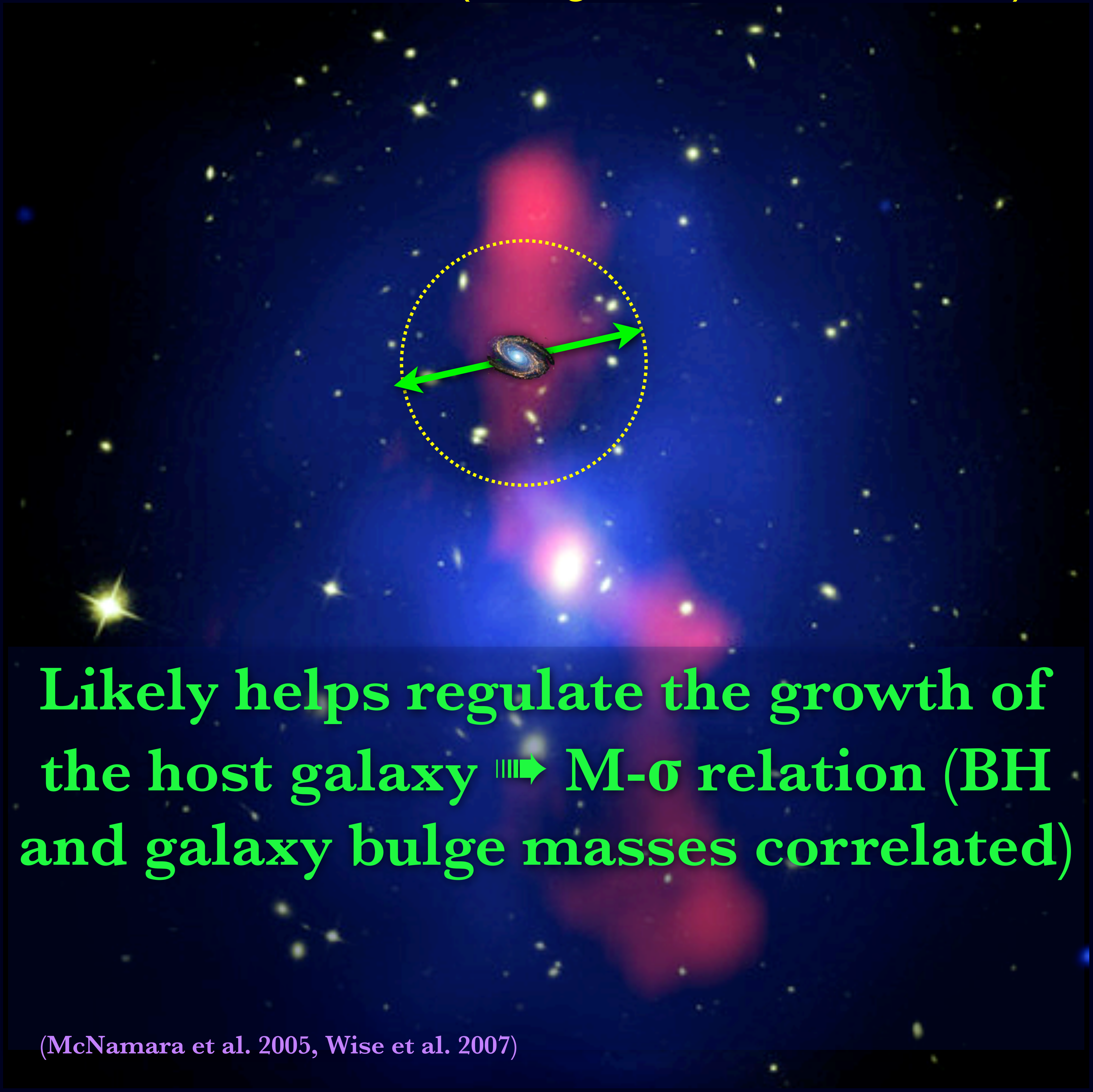


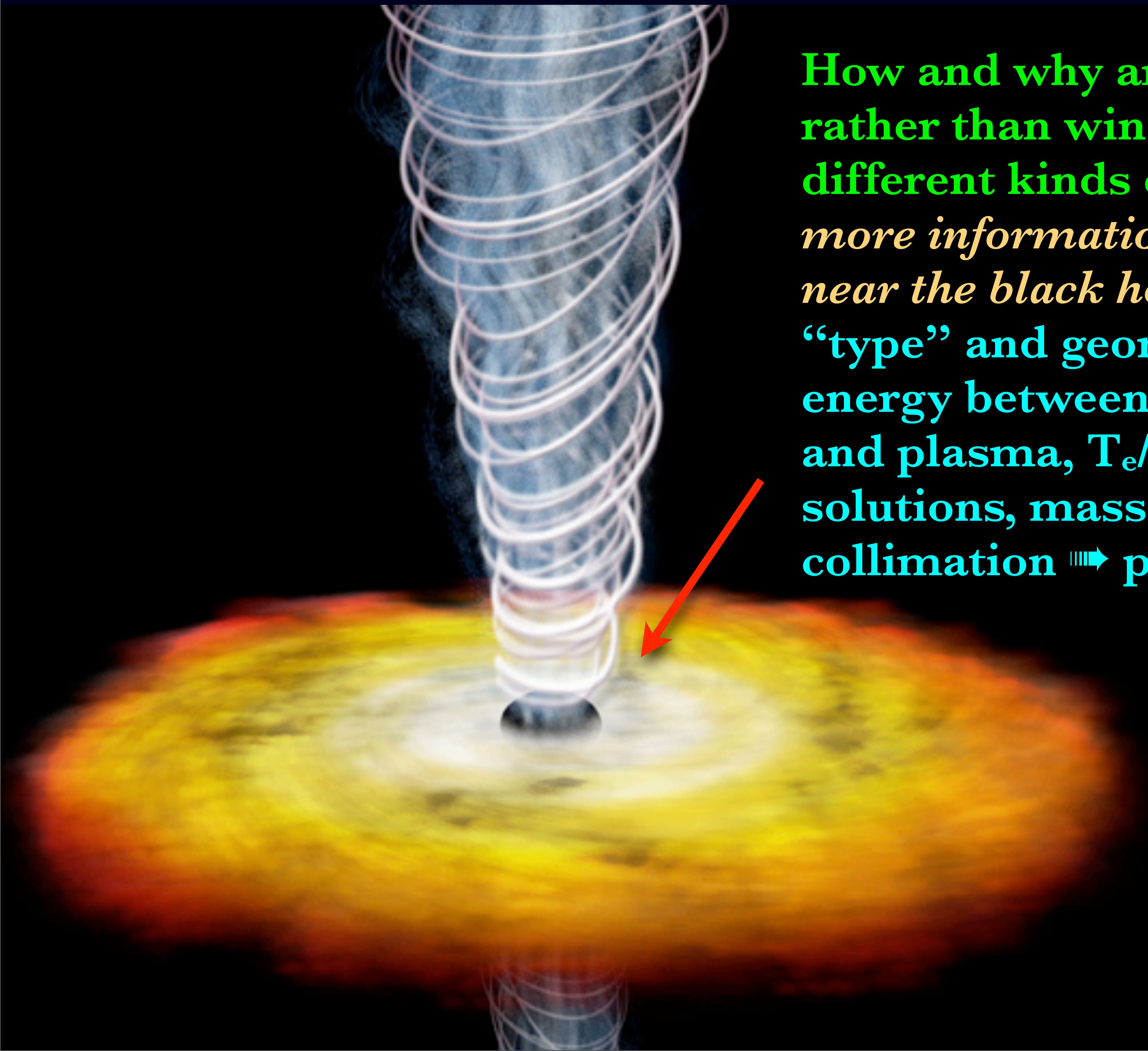
Likely helps regulate the growth of the host galaxy ➠ M-σ relation (BH and galaxy bulge masses correlated)

(McNamara et al. 2005, Wise et al. 2007)

"Big picture questions"

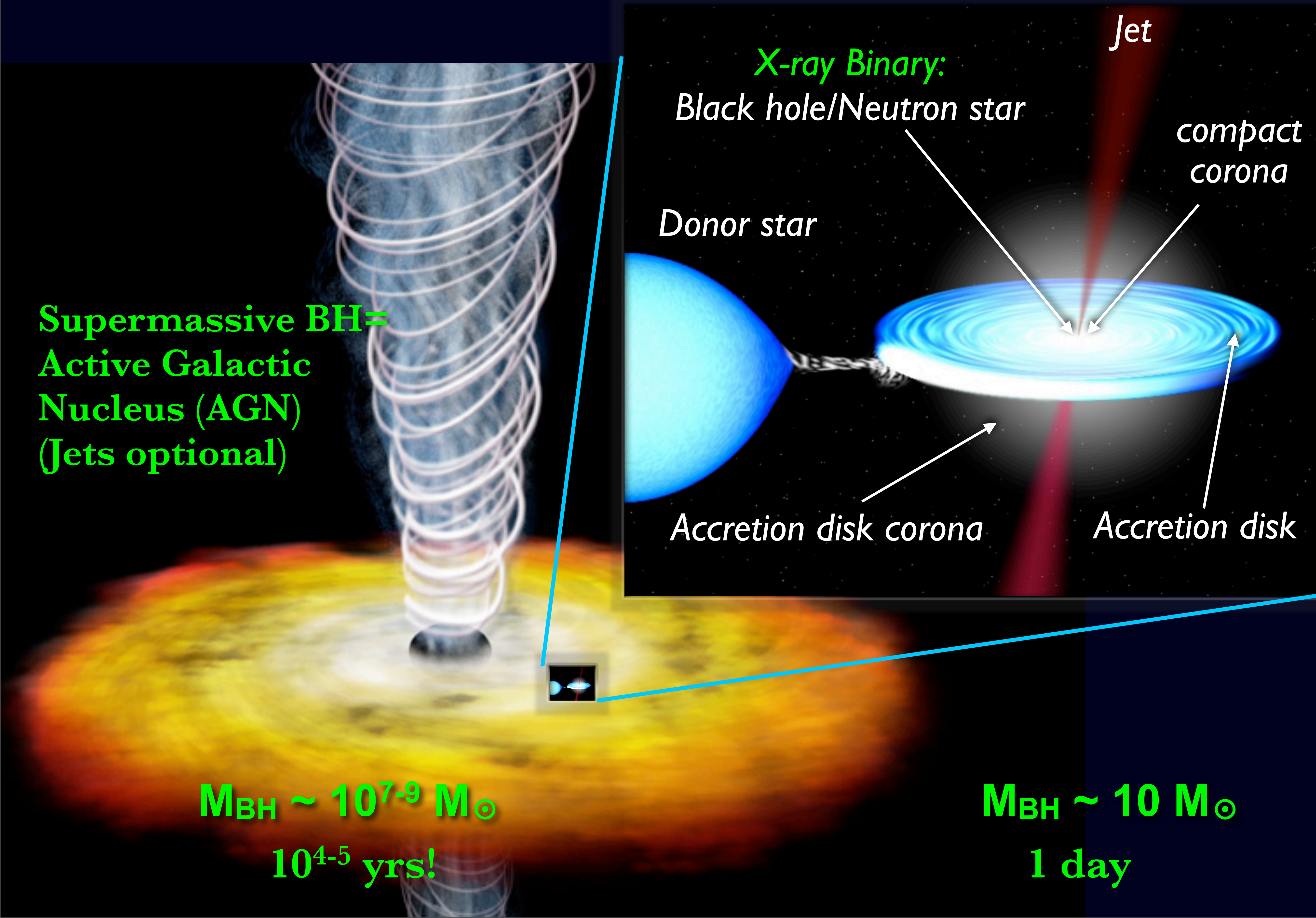
- How do we track $\dot{M}$ onto SMBHs over cosmic time?
  - i.e.: how does what's happening "out there" determine what makes it onto the black hole? Does it determine it at all? (AK)
- What besides $\dot{M}$ determines all the activity/states we see in accreting black holes? Spin? Magnetic fields?
  - Somehow we can get all sorts of combinations (**weak disk + weak jet** or **strong disk + strong jet** or **strong disk + no jet + wind**), often all at similar $\dot{M}$ so other drivers needed
- Assuming we can find a way to know $\dot{M}$, a, B, how do these factors work together to explain all the inflow/outflow phenomenology we see?

We need to know what's going on at $r < 100r_g$

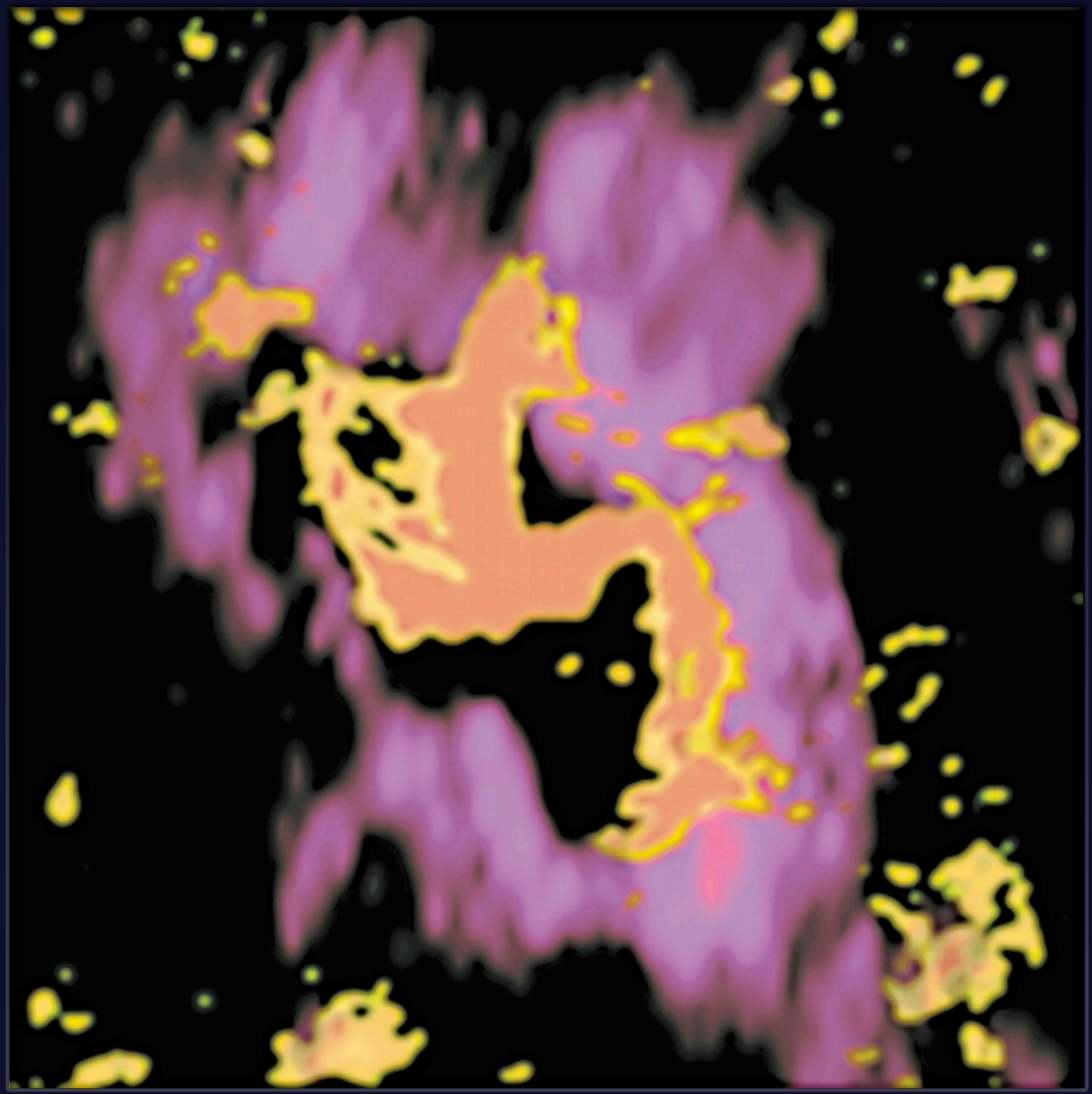


How and why are jets launched rather than winds? Why the different kinds of jets? ***Requires more information about conditions near the black hole:*** **accretion flow "type" and geometry, balance of energy between magnetic fields and plasma, T_e/T_i ➠ launch/flow solutions, mass loading and collimation ➠ particle acceleration**

Can we compare sources across the M_{BH} scale?



AGN fueling example: the Galactic center



(Yusef-Zadeh ea. 93,00; Genzel ea. 03)

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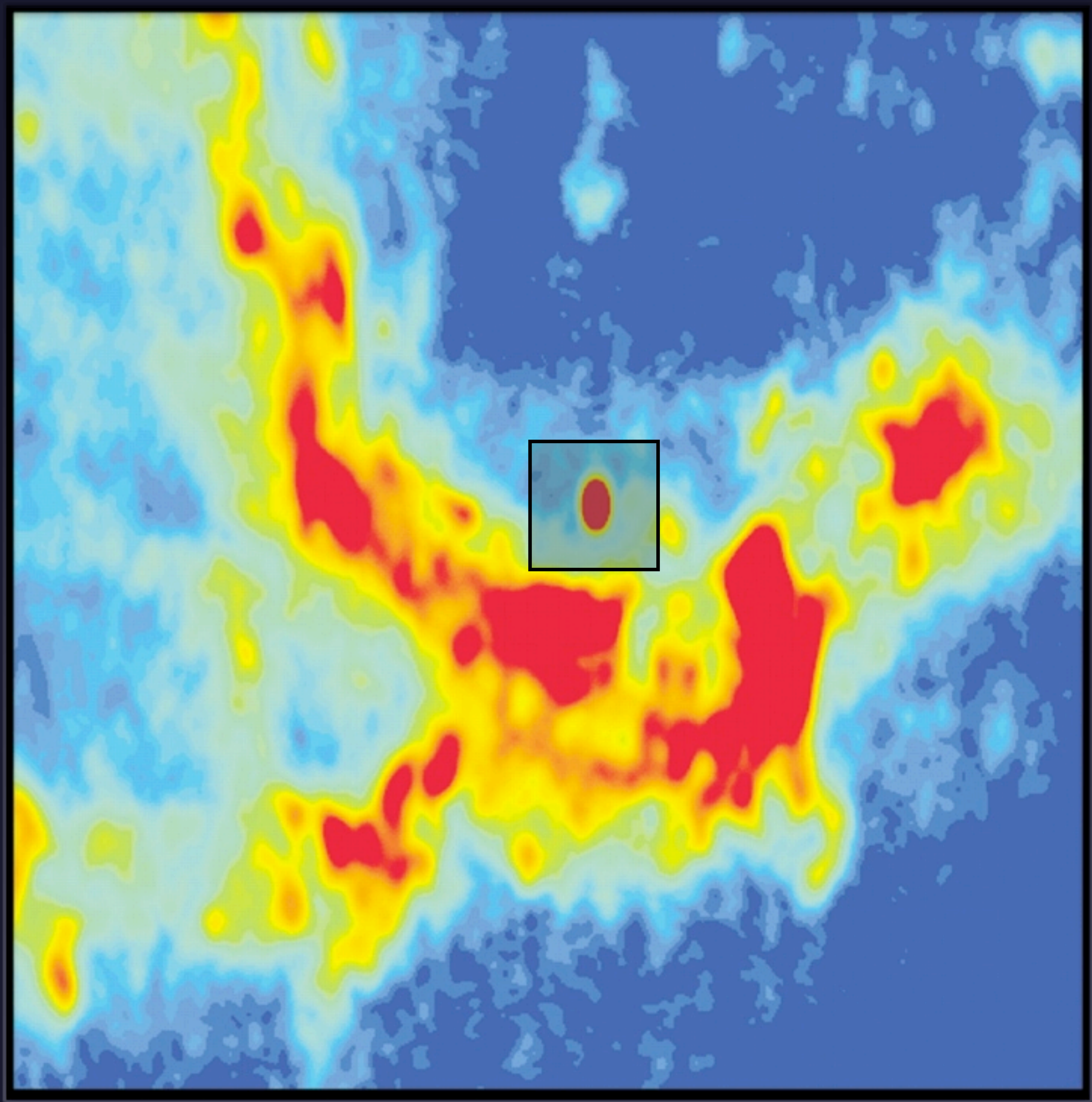

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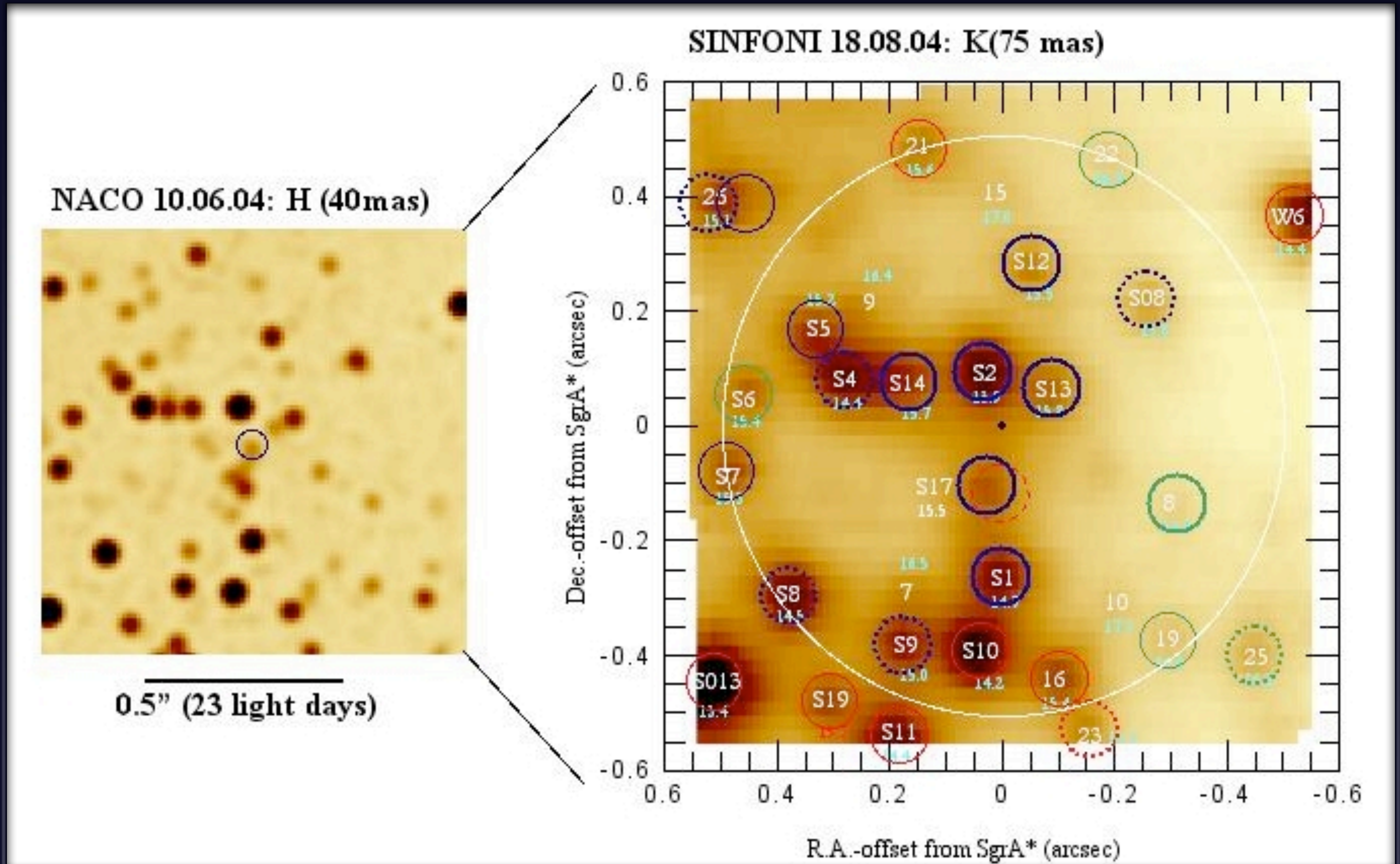


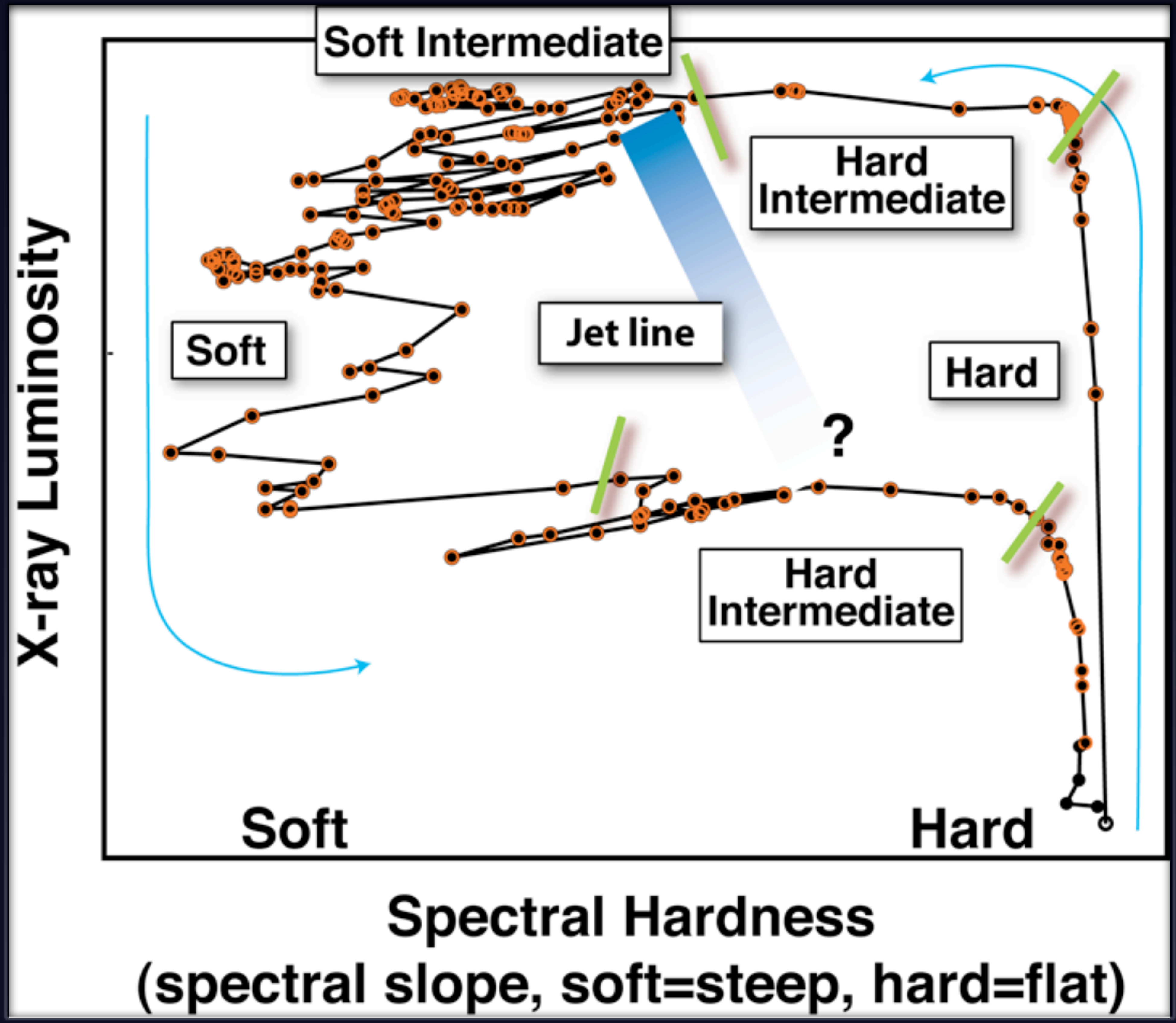
(Yusef-Zadeh ea. 93,00; Genzel ea. 03)

Fundamental Plane: Mass & Power scales in black holes

- What is it?
- What drives it?
- How can we use it as a tool to break “theoretical degeneracies”?

Time variable XRB behavior: The HID

Real data with states indicated

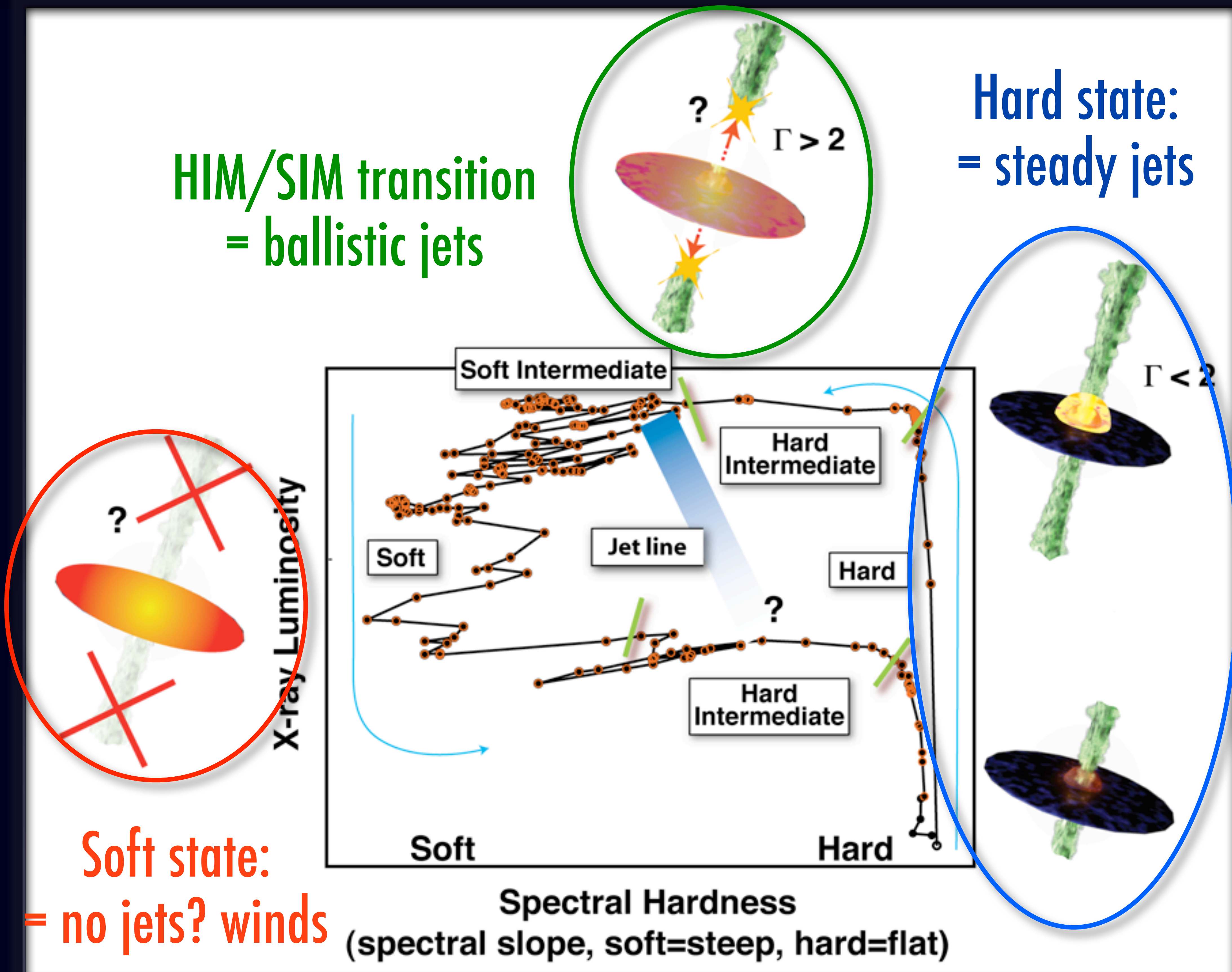


~10-30% L_{Edd}

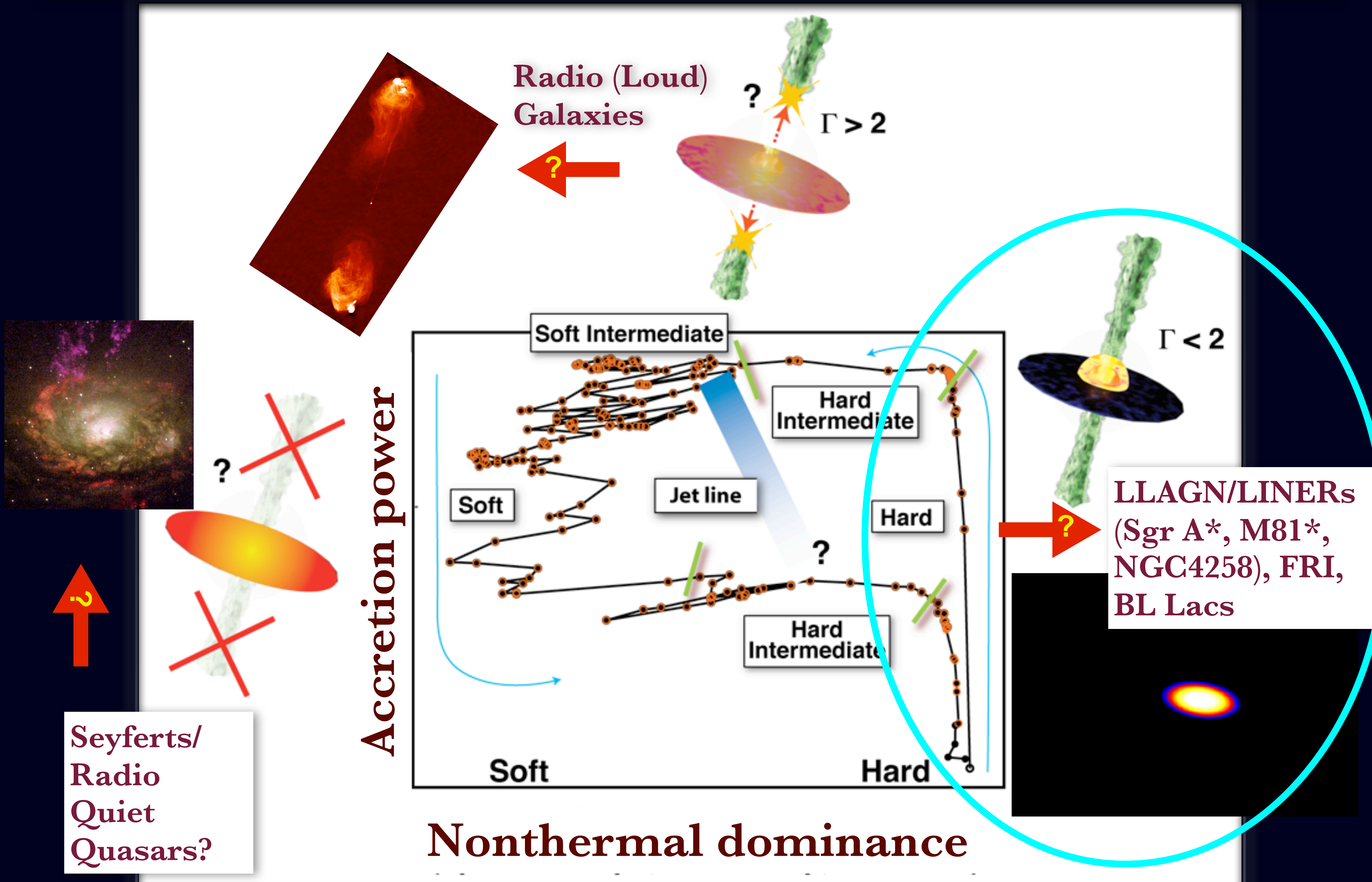
~1% L_{Edd}

$\ll 10^{-5}$ L_{Edd}

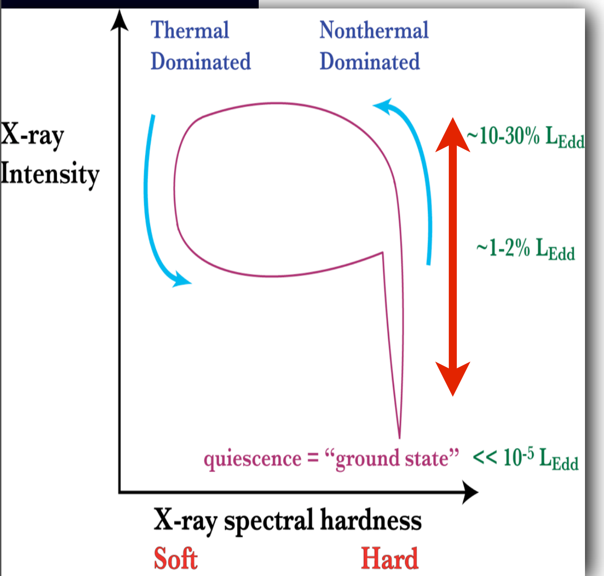
Time variable XRB behavior: The HID
What are the jets doing?

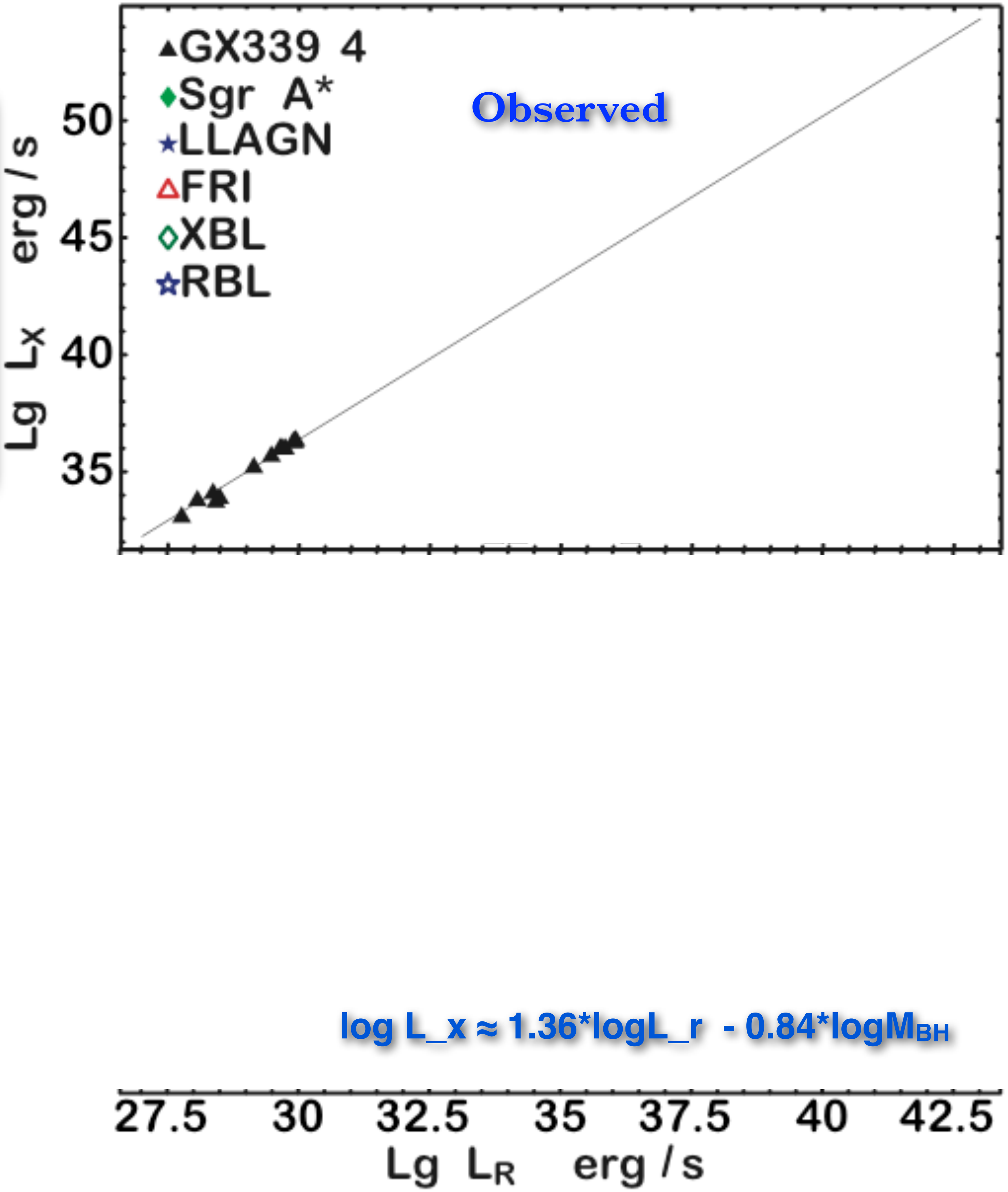


Mapping XRB states ⇔ AGN classes?



Fundamental plane of BH accretion





$\log L\_x \approx 1.36*\log L\_r - 0.84*\log M_{BH}$

(SM et al. 2003, Merloni,Heinz & diMatteo 2003, Falcke, Körding & SM 2004, SM 2005, Merloni et al. 2006, Körding et al. 2006)

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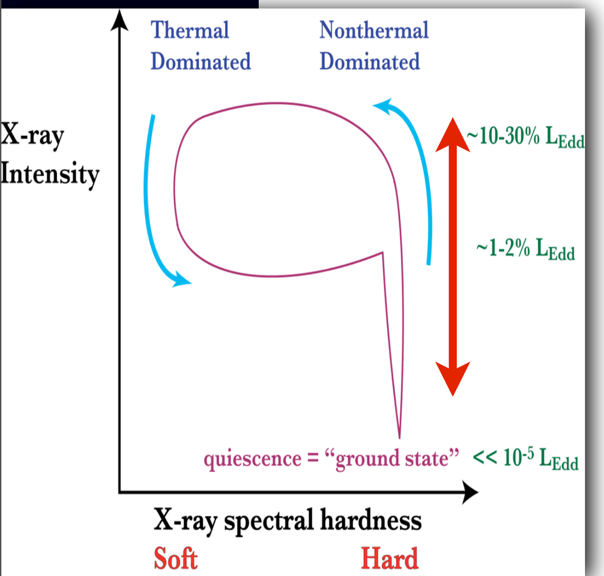

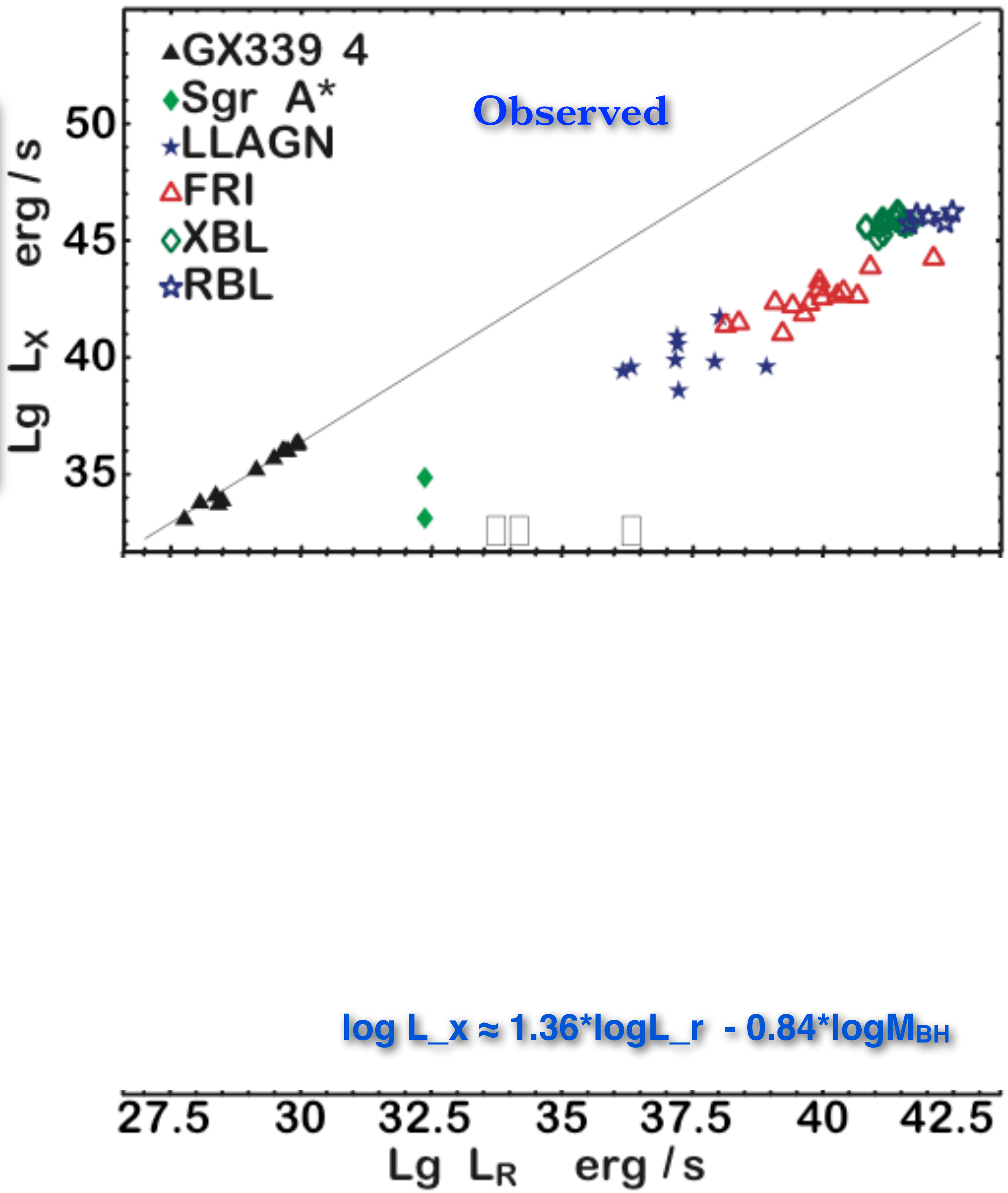

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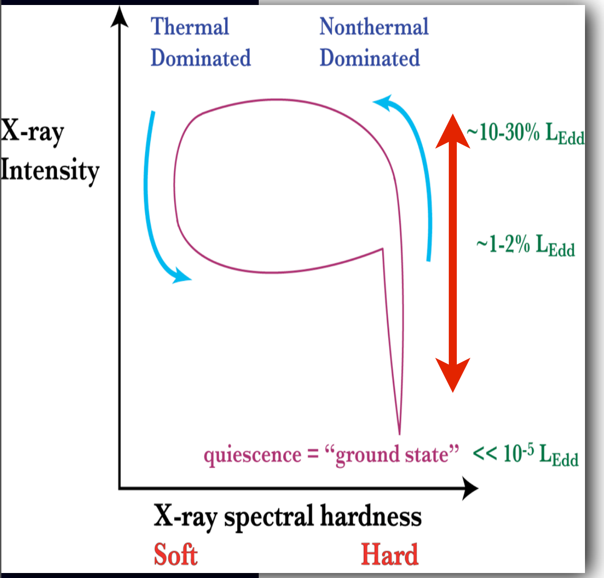

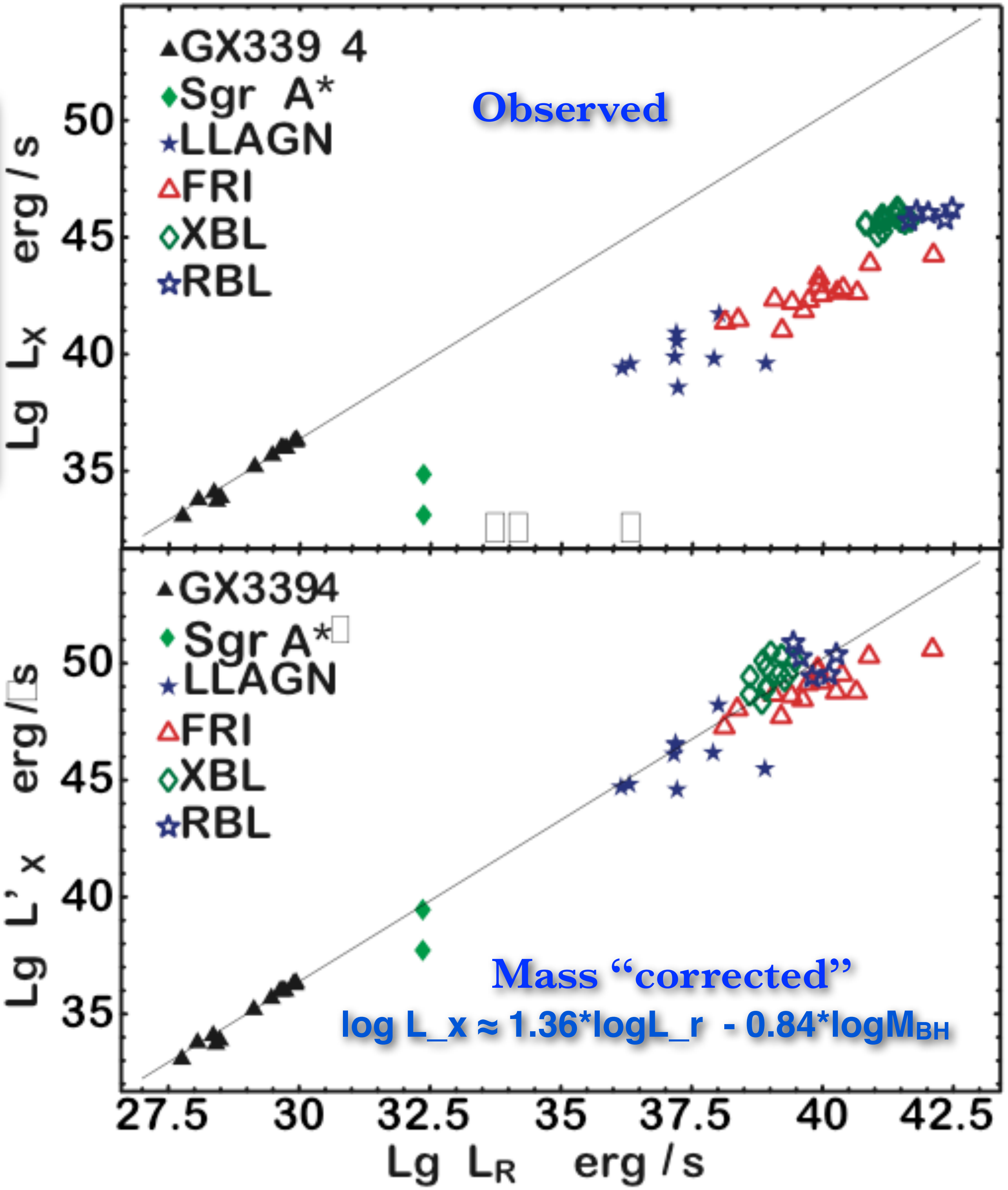

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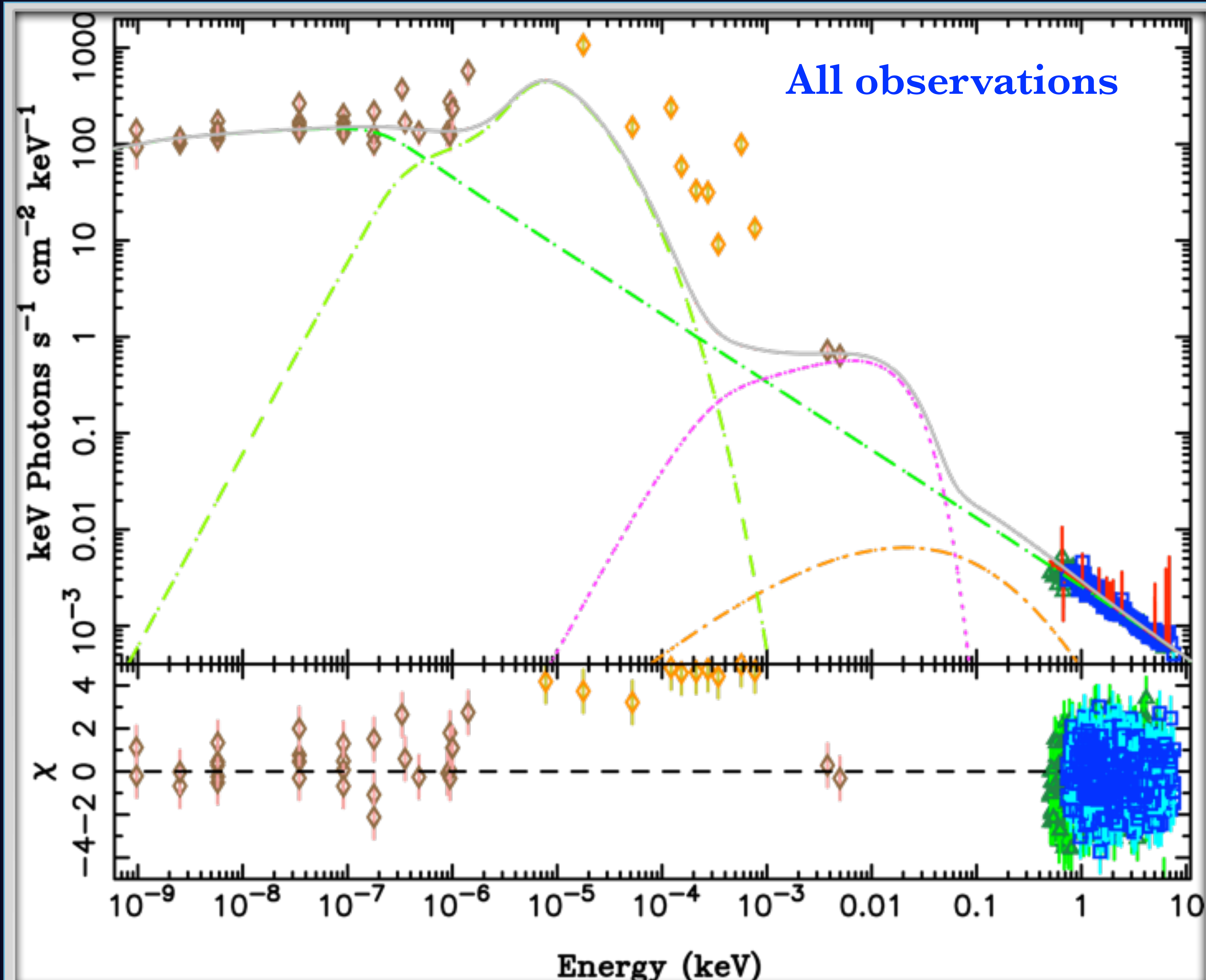
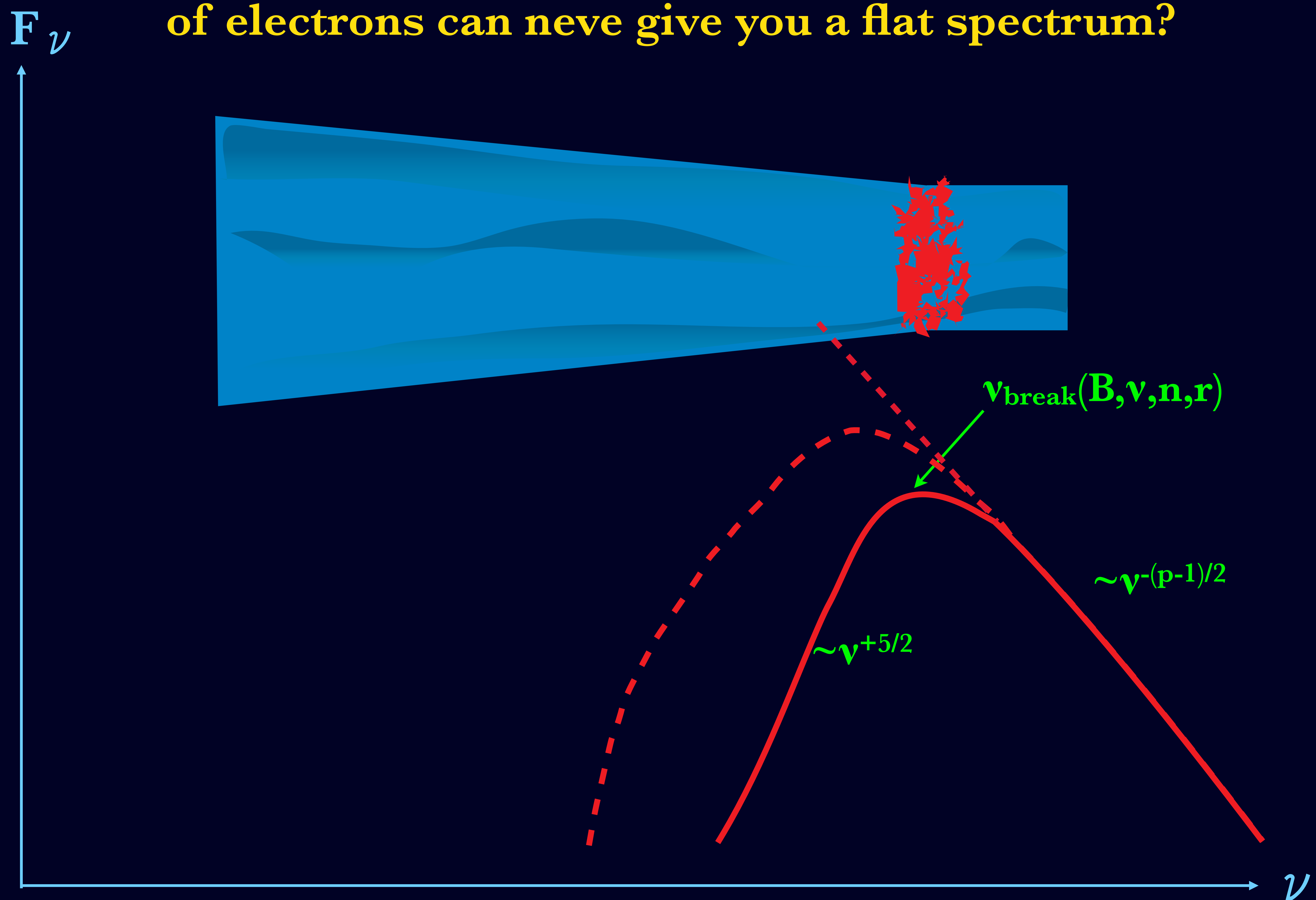
M81*: simultaneous campaign

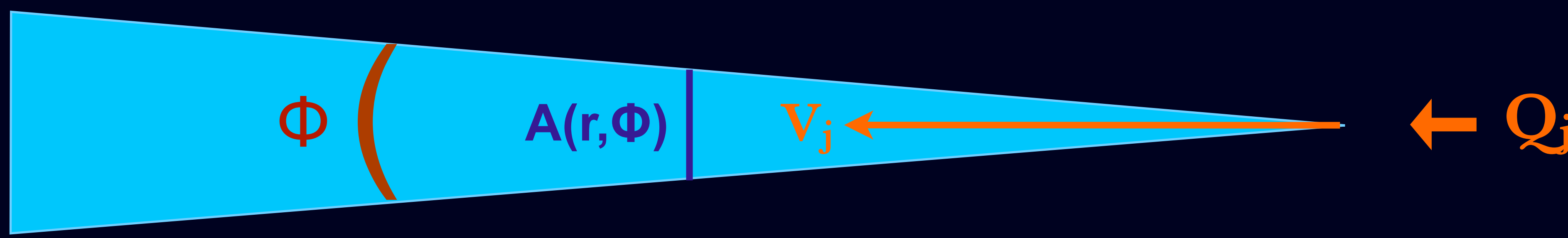


(SM et al. 2008)

But synchrotron emission from a single distribution of electrons can neve give you a flat spectrum?



How does the flat synchrotron spectrum arise?



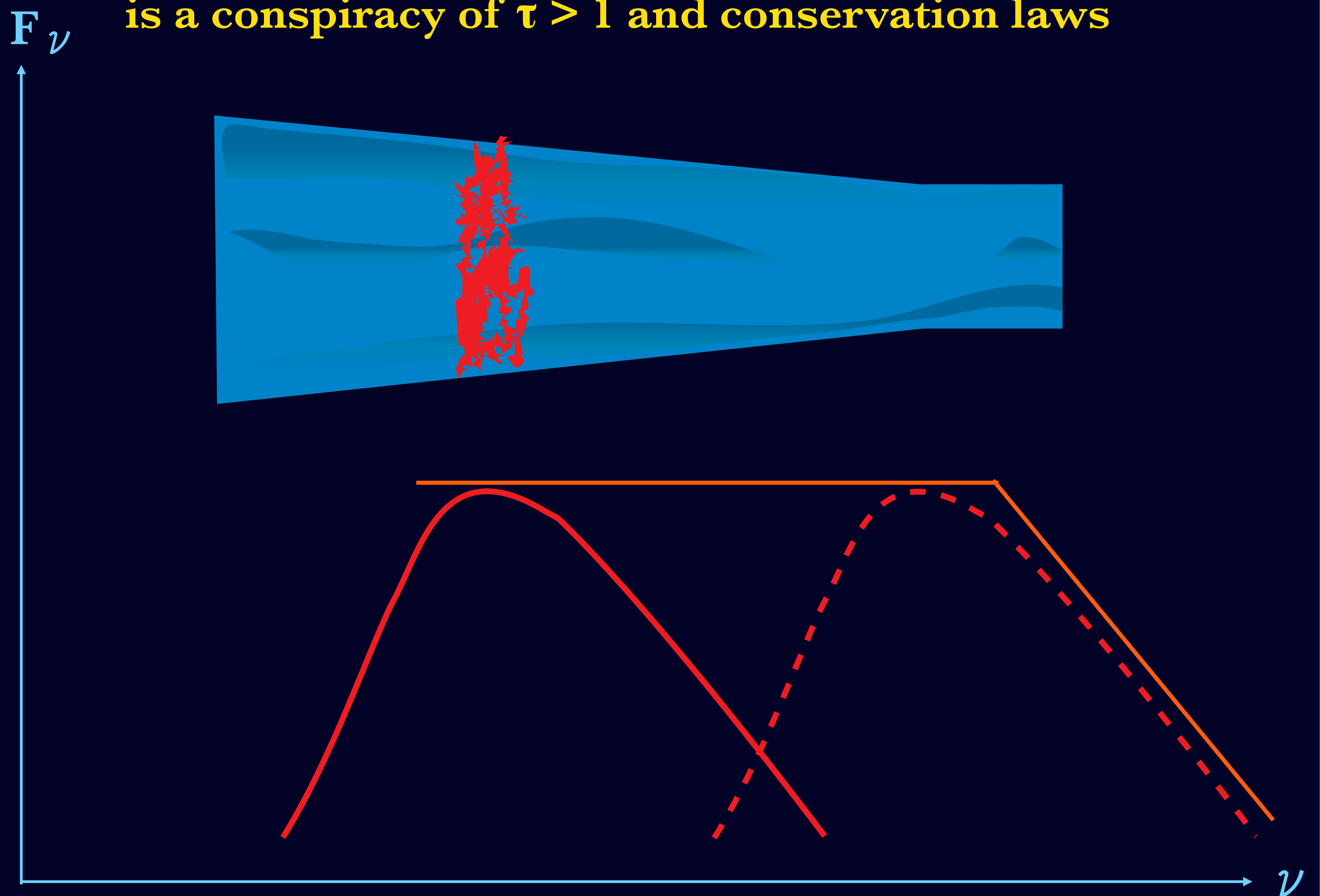
- Convert input power into energy density: $\frac{Q_j}{\pi r_0^2 \beta_j \gamma_j c} = U_B + U_p + U_e$
- Make a choice about energy partition (and fix it, e.g.): $U_p = U_B + U_e$
  - Conservation of particle and magnetic fluxes ➠ $B \propto r^{-1}$, $n \propto r^{-2}$
  - Assume particles have PL: $n(\gamma) \sim C\gamma^{-p}$, fixed energy partition ➠ $C \propto n \propto B^2$
- Assume optically thick, for PL of electrons: $\alpha_\nu \propto C B^{(p+2)/2} \nu^{-(p+4)/2}$
- The part we see is at photosphere where $\tau \sim \alpha_\nu r = 1 \Rightarrow \alpha_\nu \propto 1/r$
- Assume "canonical" PL index p=2, substitute C, B in α_ν in terms of r:

$$\frac{1}{r} \propto \left(\frac{1}{r}\right)^2 \left(\frac{1}{r}\right)^2 \nu^{-3} \Longrightarrow r \propto \nu^{-1}$$

☛ $$F_\nu \propto C B \left(\frac{\nu}{B}\right)^{-(p-1)/2} r^3 \propto (r\nu)^{-0.5} \propto \text{constant!}$$

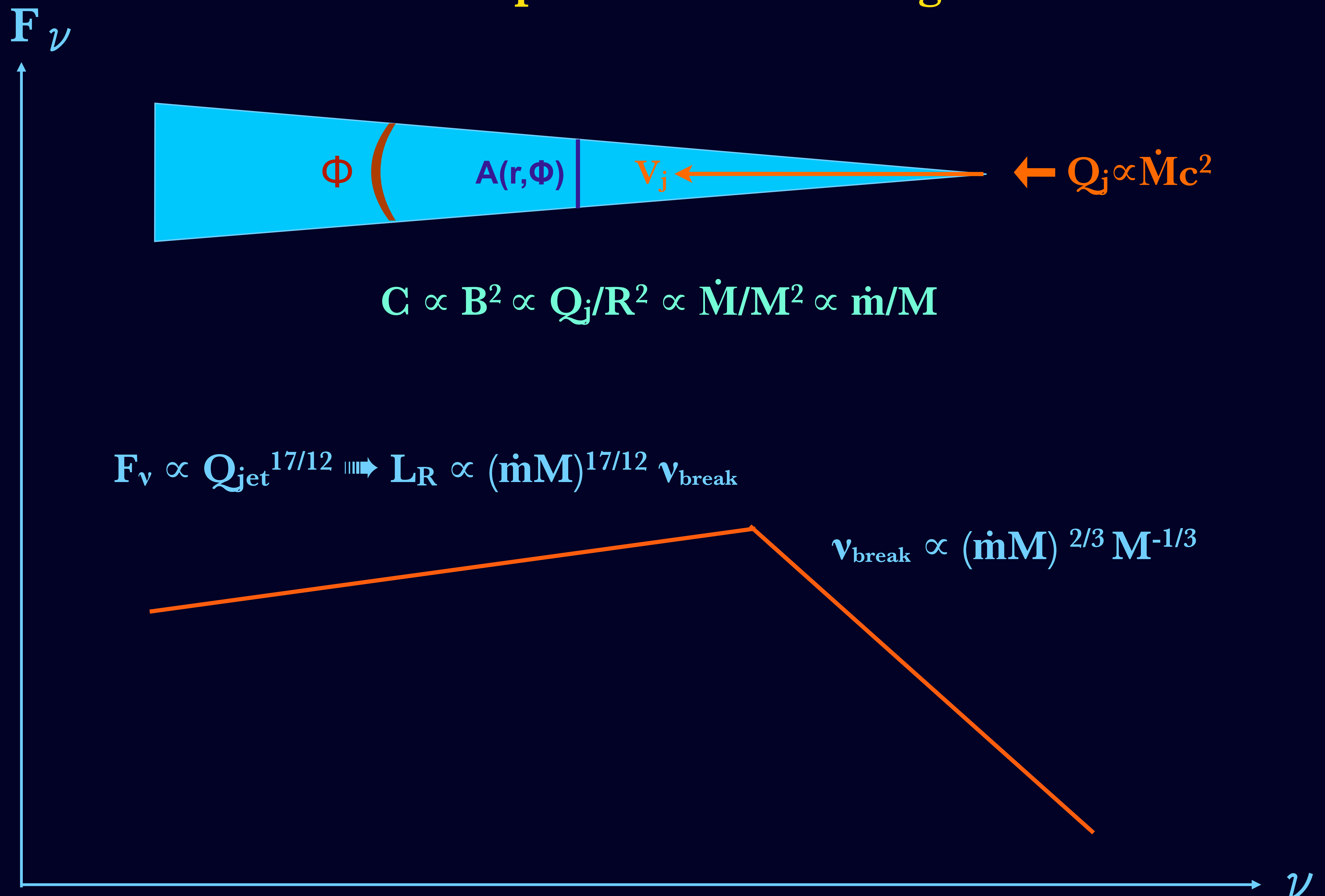
(Blandford & Königl 1979; Rybicki & Lightman 1979)

"Signature" flat(ish) emission of compact jets ("cores") is a conspiracy of $\tau > 1$ and conservation laws

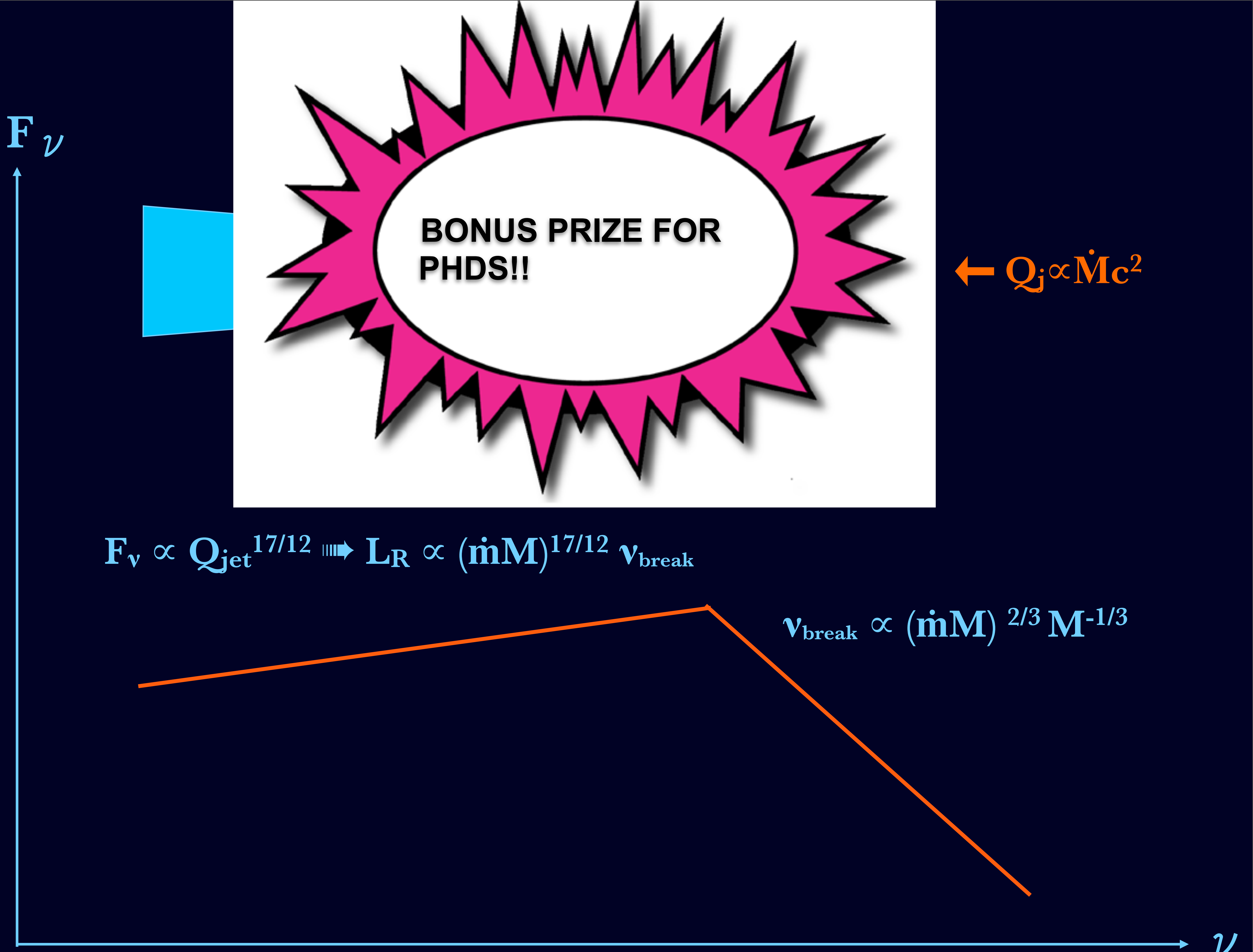


(Blandford & Königl 1979)

“Generic” power/mass scalings



(Blandford & Königl 1979, Falcke & Biermann 1995, SM et al. 2003, Heinz & Sunyaev 2003)



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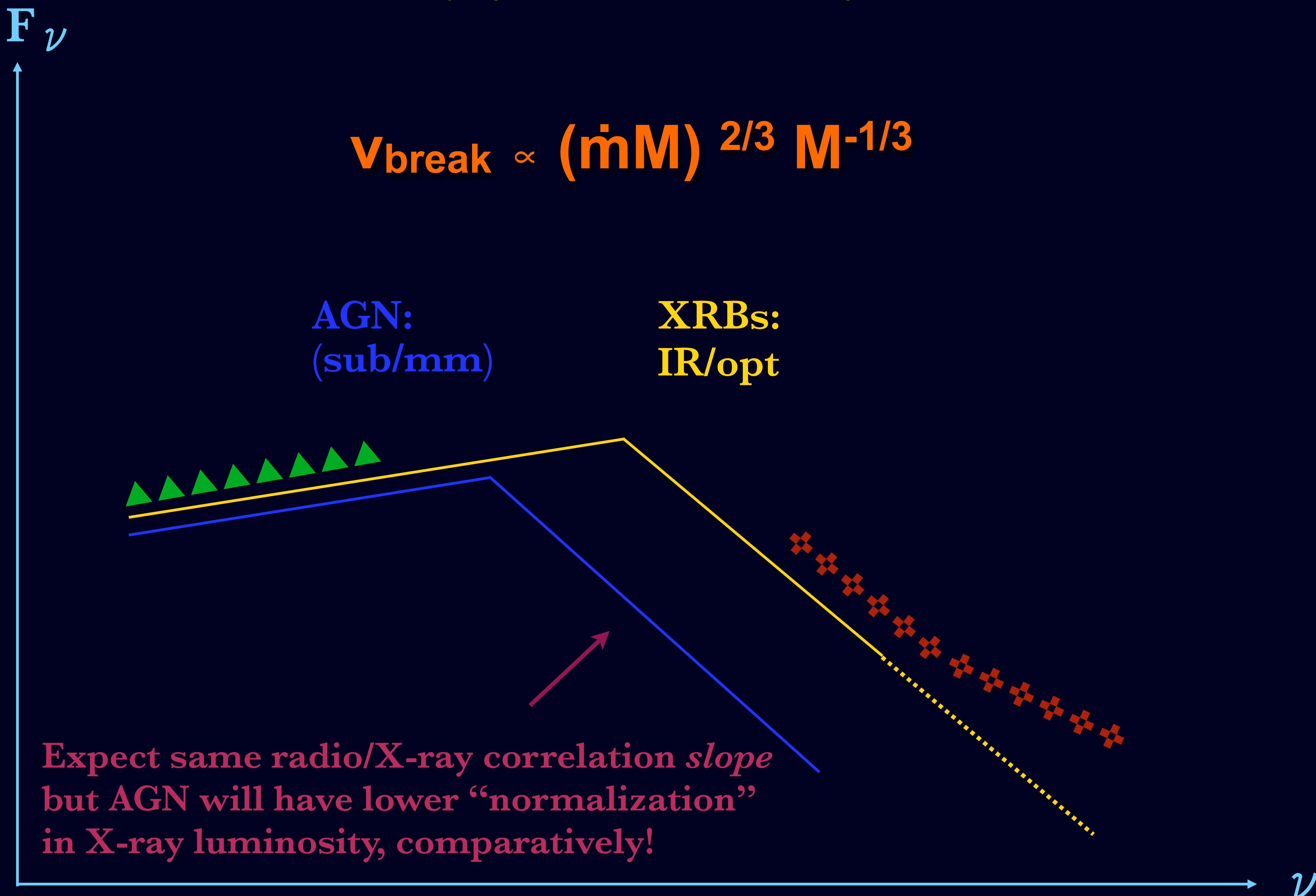
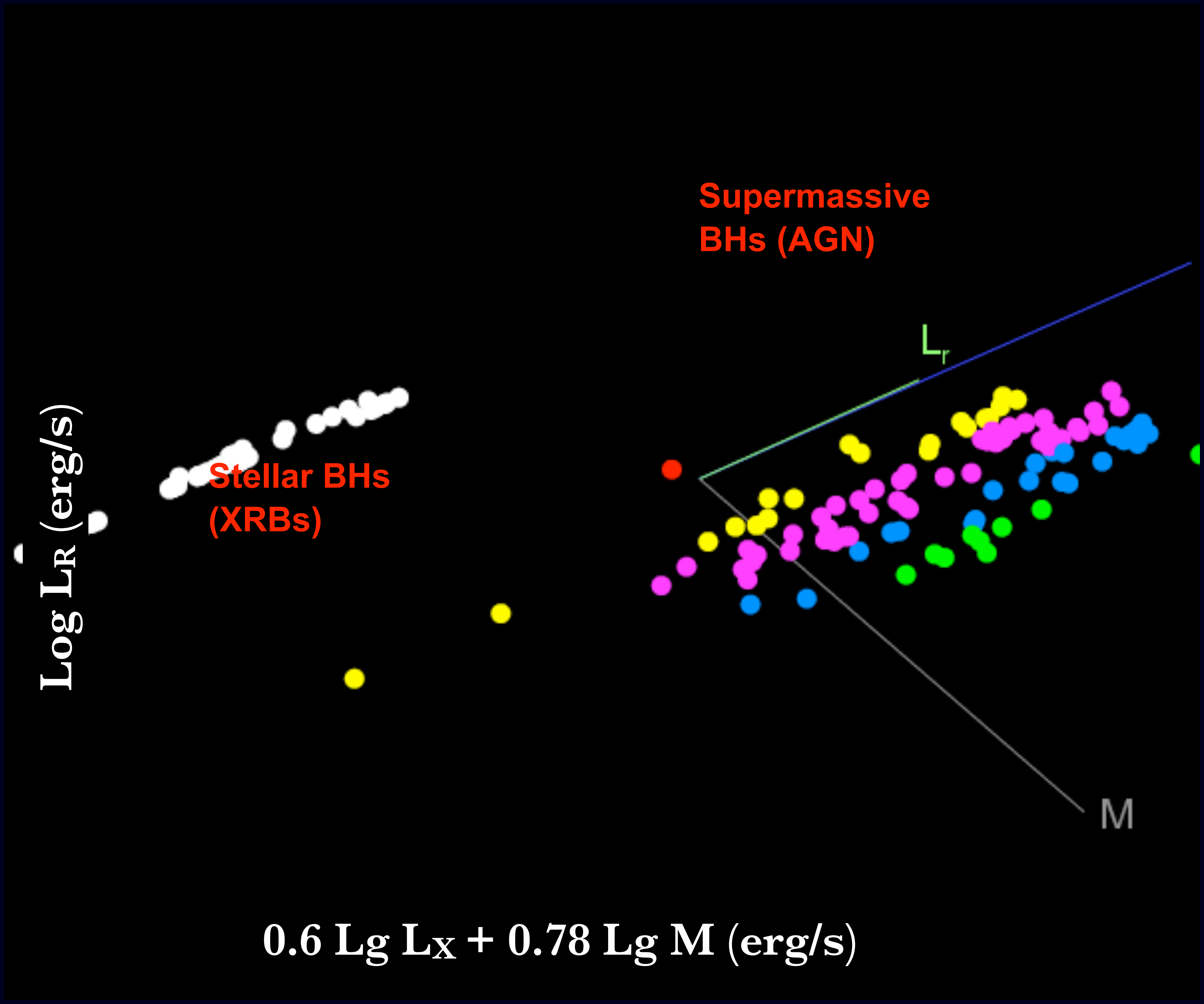
Break frequency (normalization) scales with mass



Fundamental plane of BH accretion



(movie courtesy of S. Heinz)

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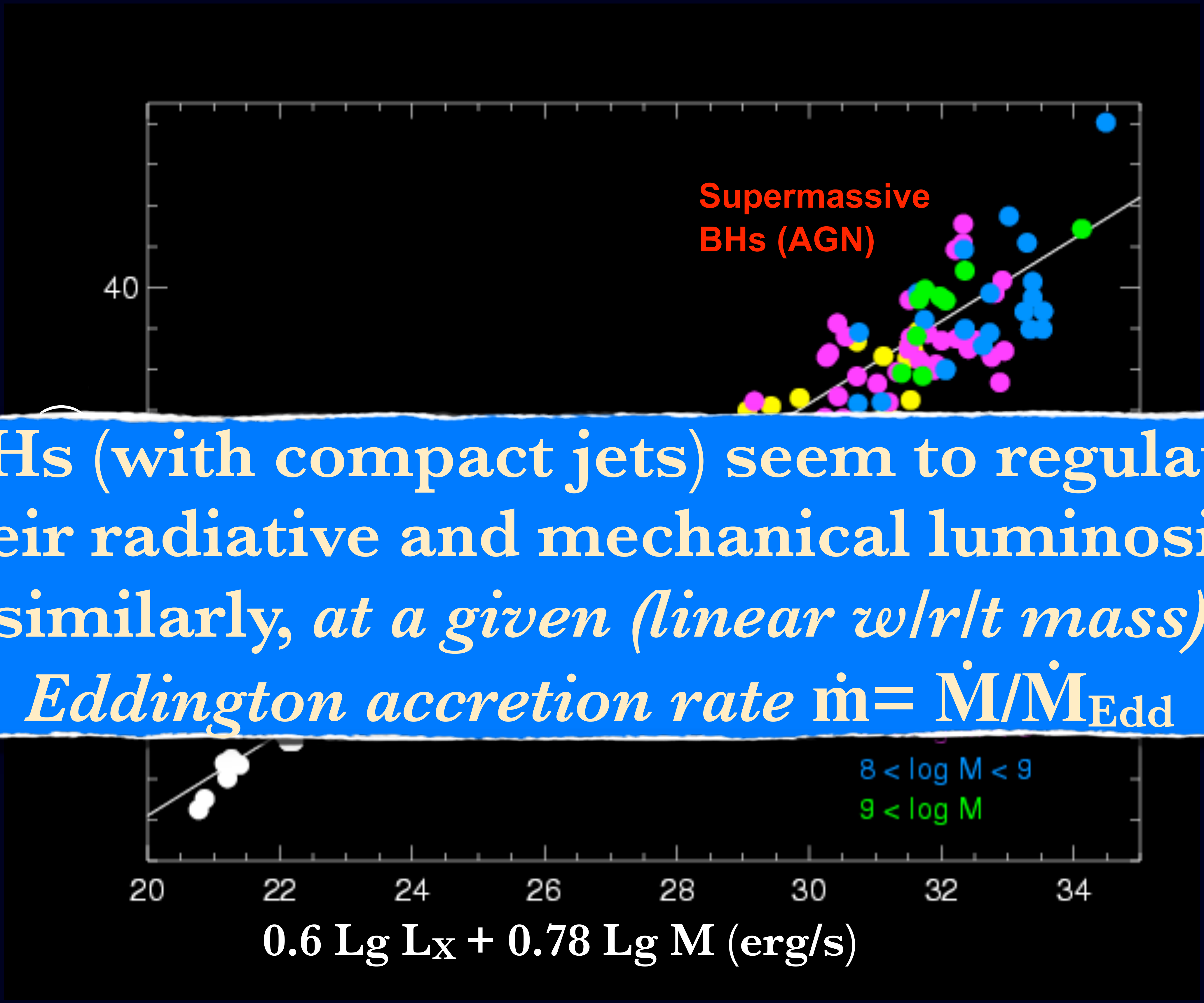
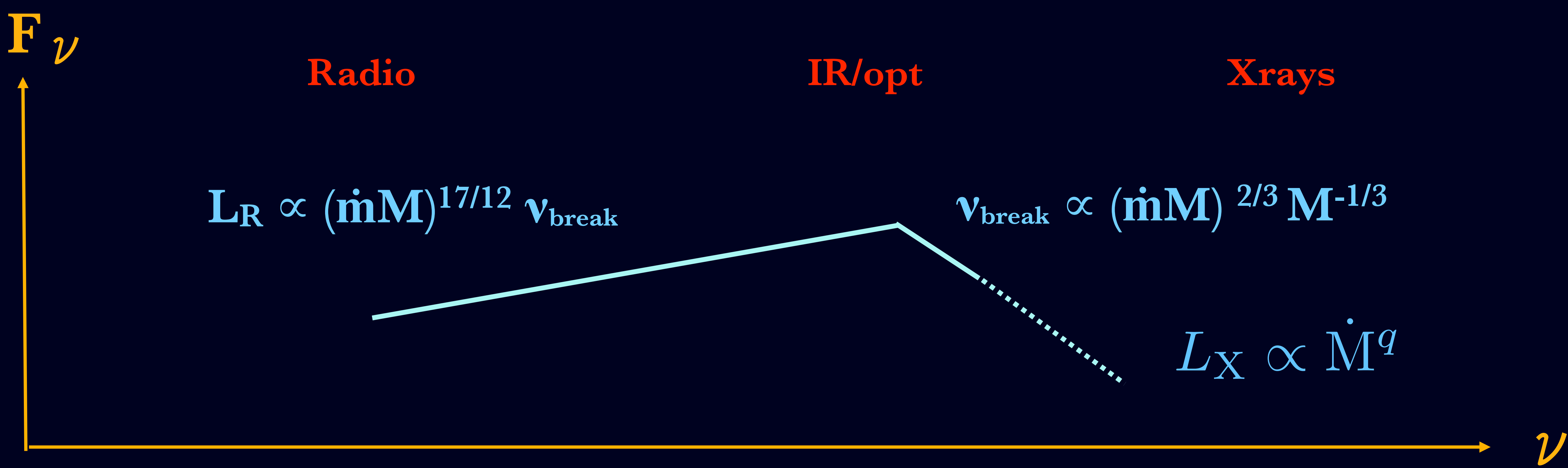


BHs (with compact jets) seem to regulate their radiative and mechanical luminosity similarly, *at a given (linear w/r/t mass) Eddington accretion rate* $\dot{m} = \dot{M}/\dot{M}_{Edd}$

(movie courtesy of S. Heinz)

Constraining accretion physics with radio/X-ray correlations



For objects with the *same* mass:

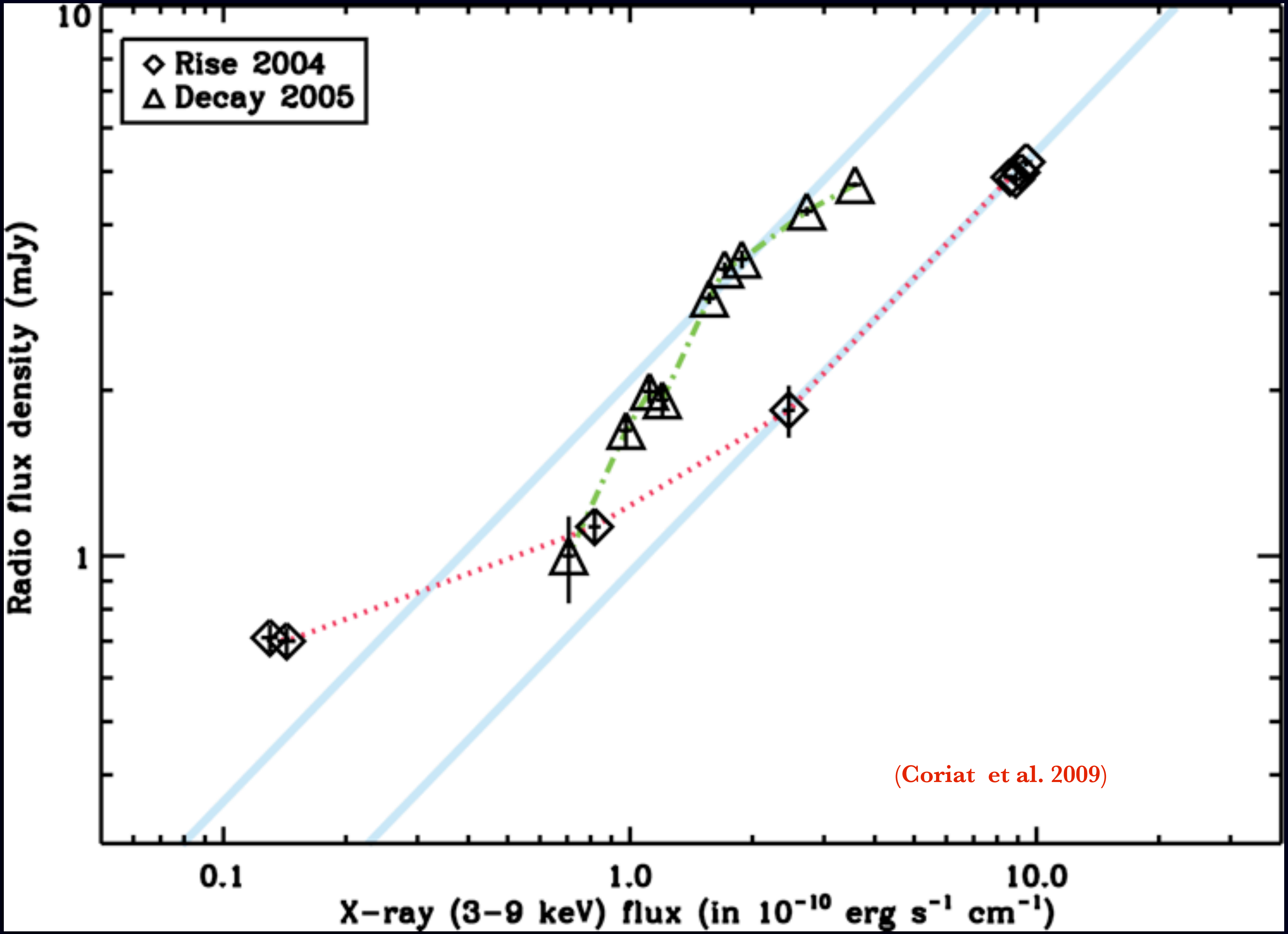
$$L_R \propto L_X^m \qquad m = \frac{\frac{17}{12} - \frac{2}{3}\alpha_R}{q} \approx \frac{1.4}{q}$$

Synchrotron: q=2, ADAF/RIAF: q=2-2.3,

Radiatively efficient disk/corona: q=1 ➠ problematic

(Falcke & Biermann 1995, SM et al. 2003, Heinz & Sunyaev 2003, Merloni, Heinz & diMatteo 2003, Falcke, Körding & SM 2004)

Some complications to simple correlations



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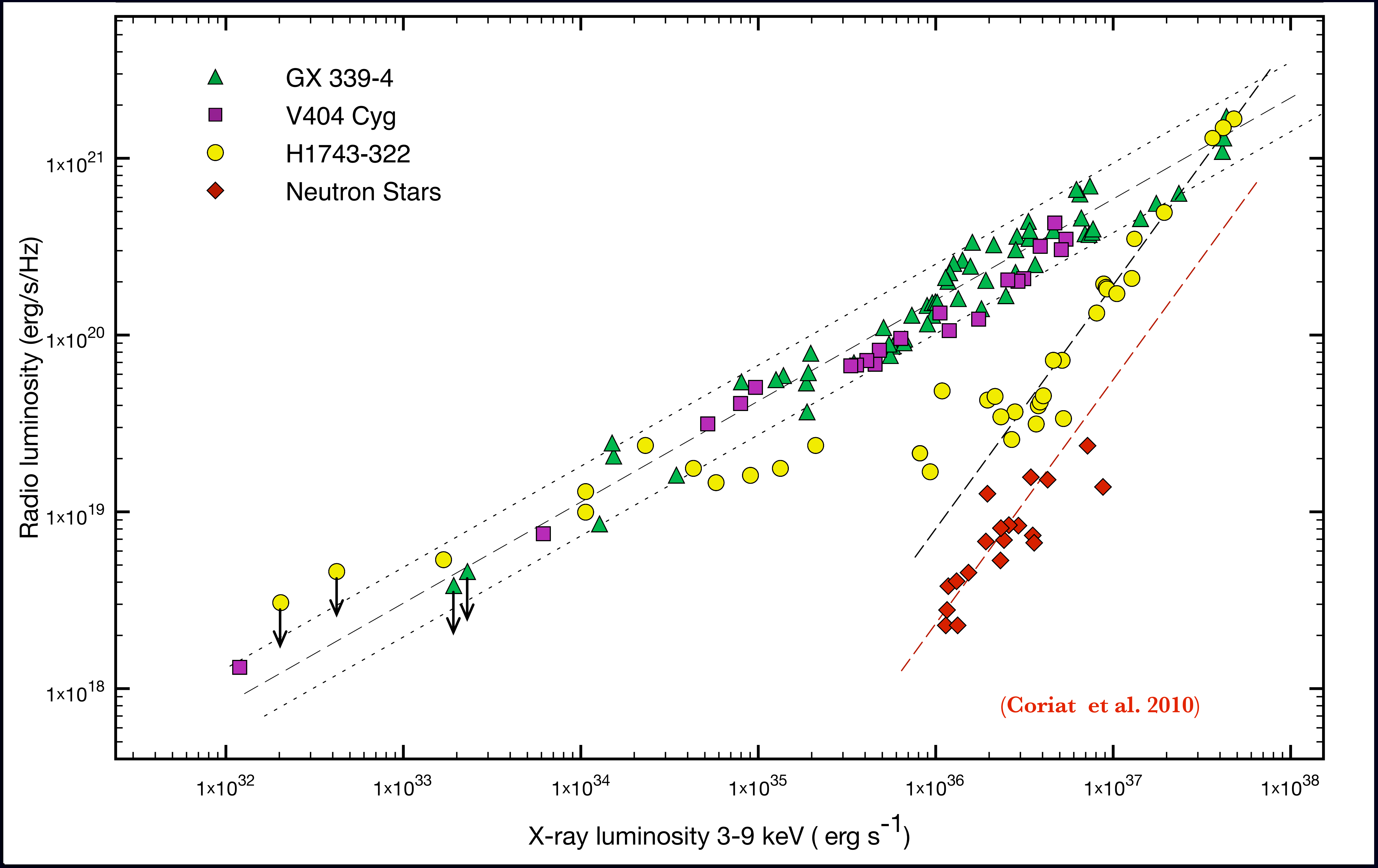
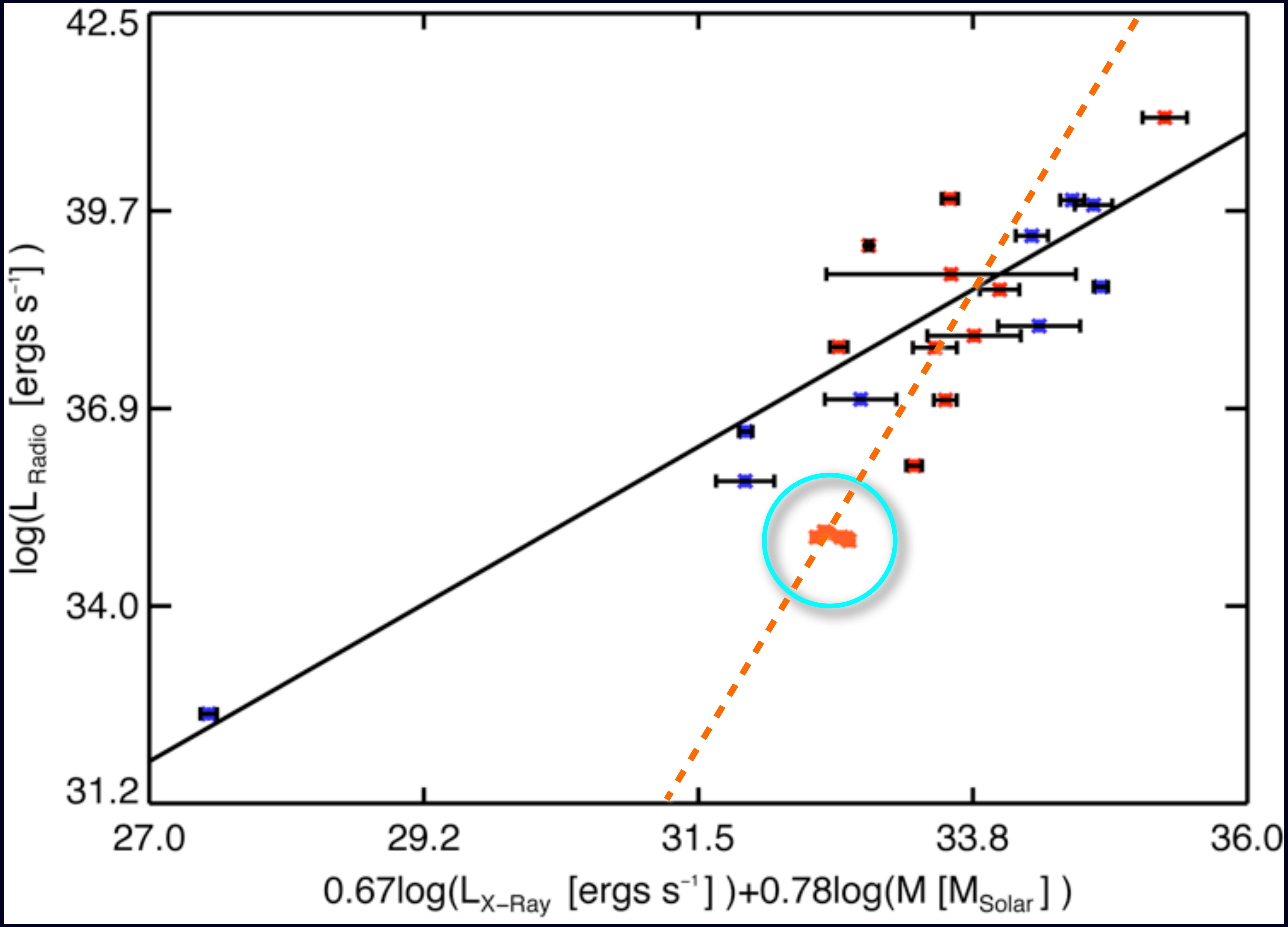


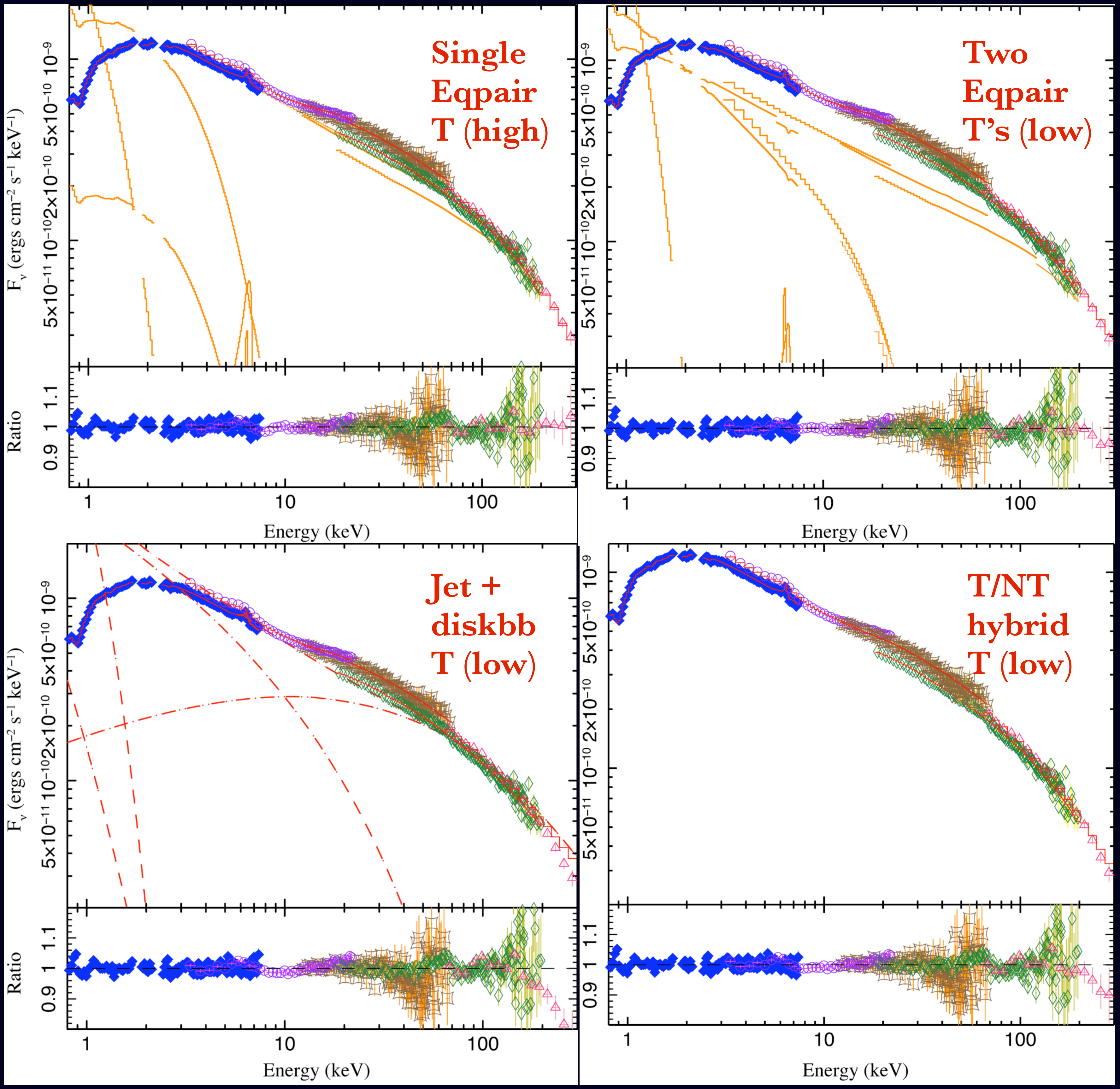
Scatter from error in masses, or by including Seyferts? M-σ sources only:



(Gültekin et al. 2009, King et al. 2011)

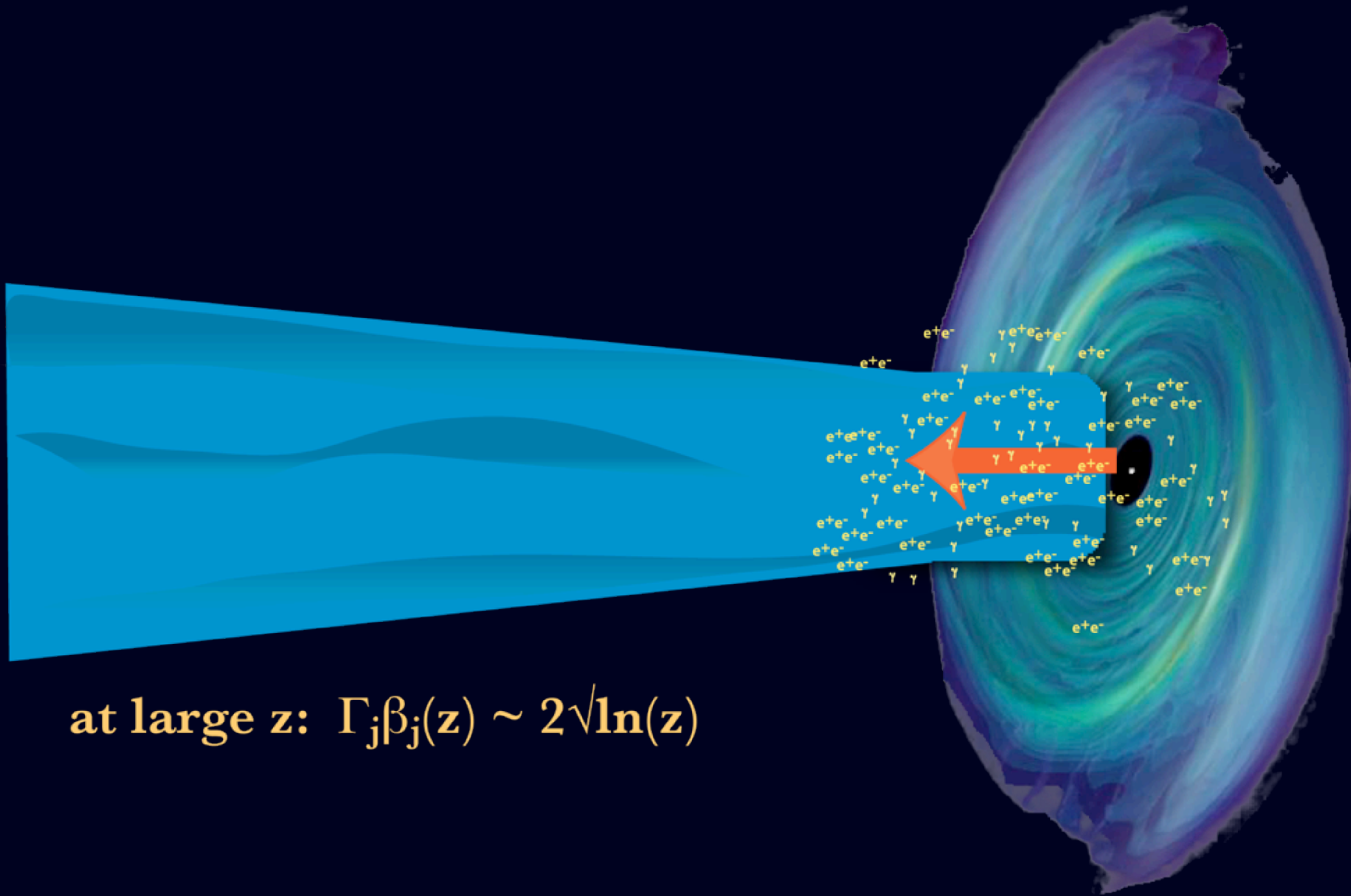
Using FP to break "theoretical degeneracies" in models, and constrain actual physics

Quality of data is not determining factor



(Nowak et al. 2011)

Modeling compact jets 1.0: HD model

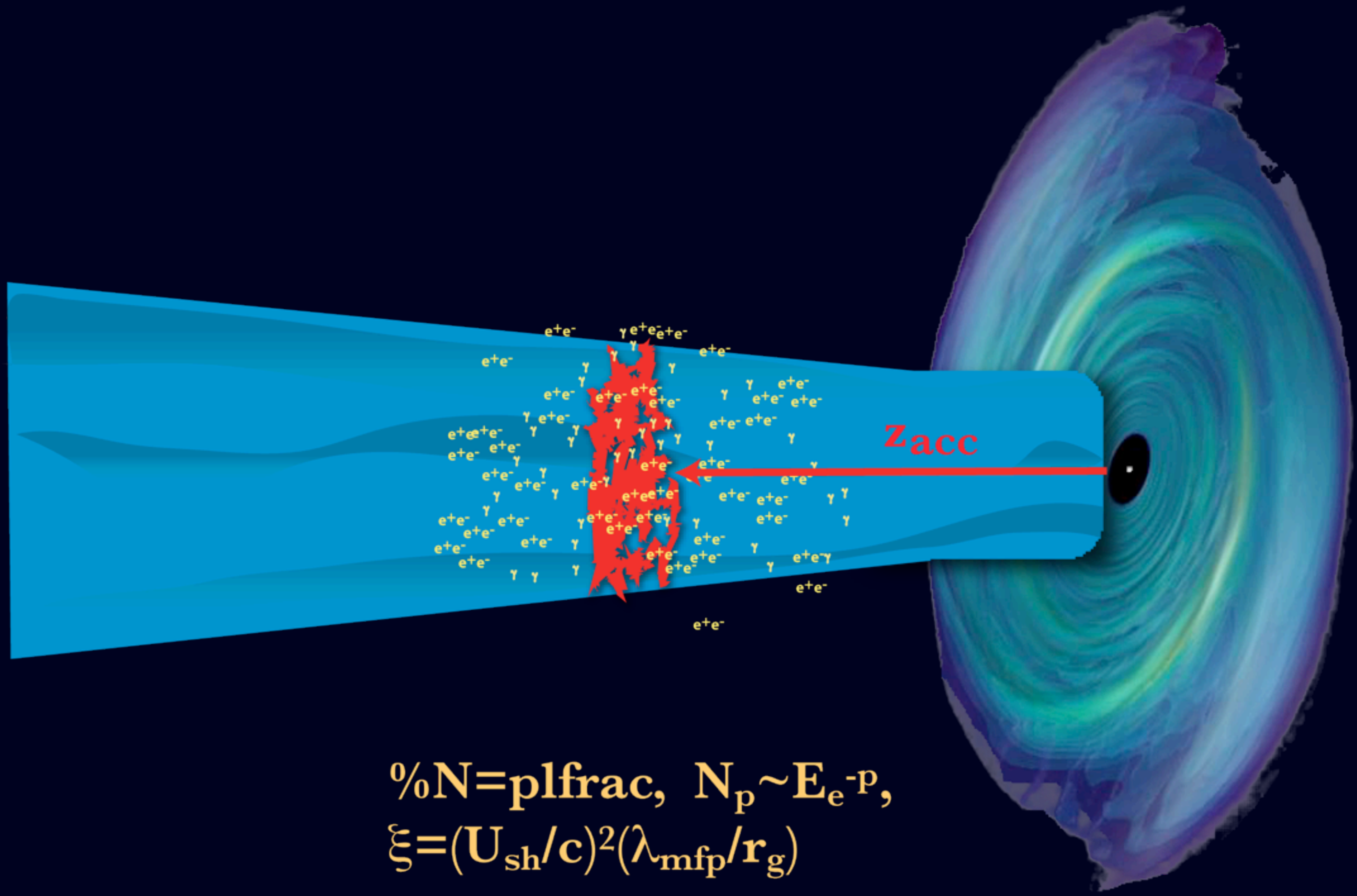


at large z: $\Gamma_j\beta_j(z) \sim 2\sqrt{\ln(z)}$

$Q_j=\eta\dot{M}c^2=(U_e+U_B+U_p)/(\pi R^2\Gamma_j\beta_j c)$

$n_p=n_e$, $U_B/U_e=k$, $N(\gamma_e)=$MW-J(T_e)

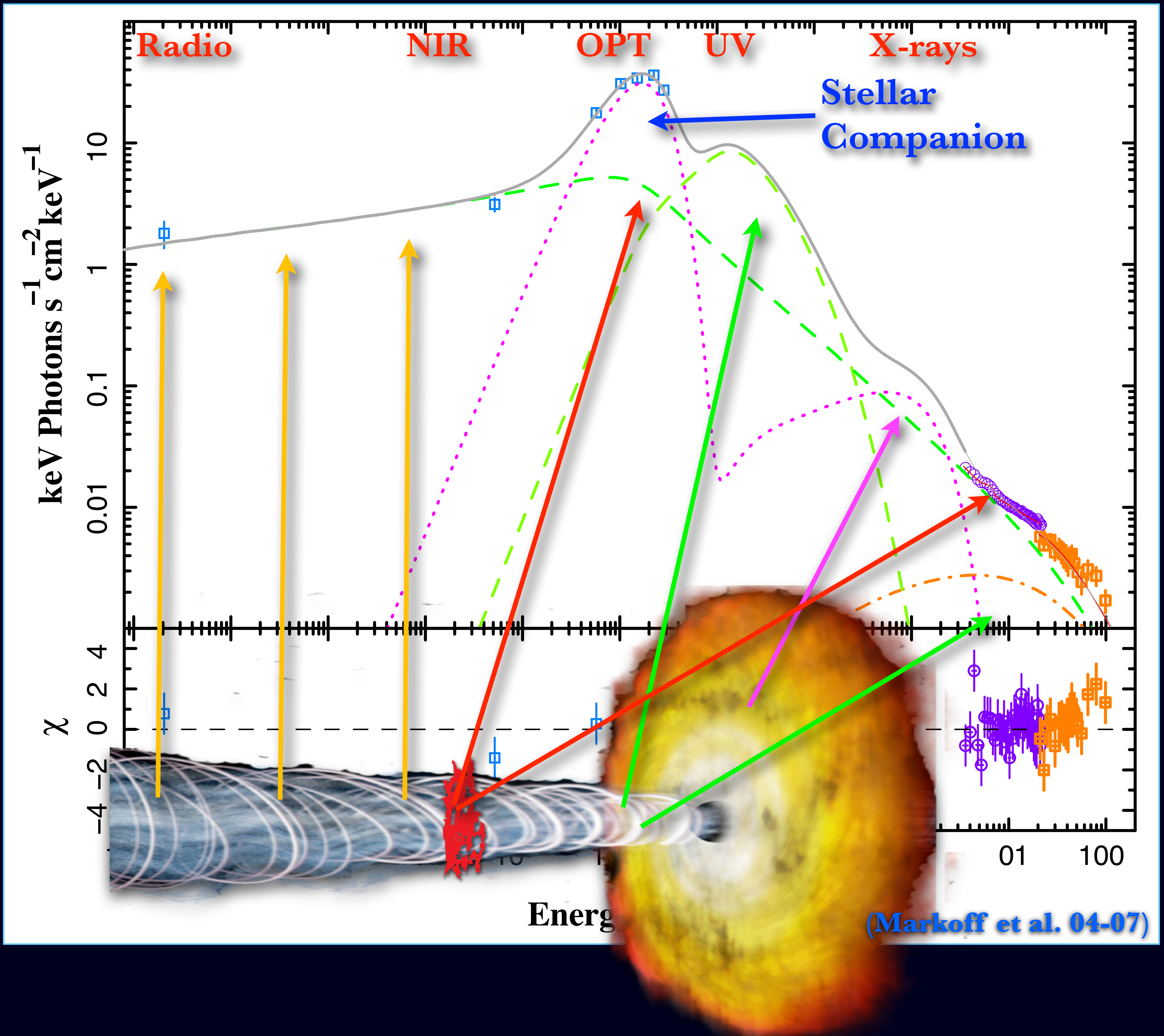
Modeling compact jets 1.0: HD model



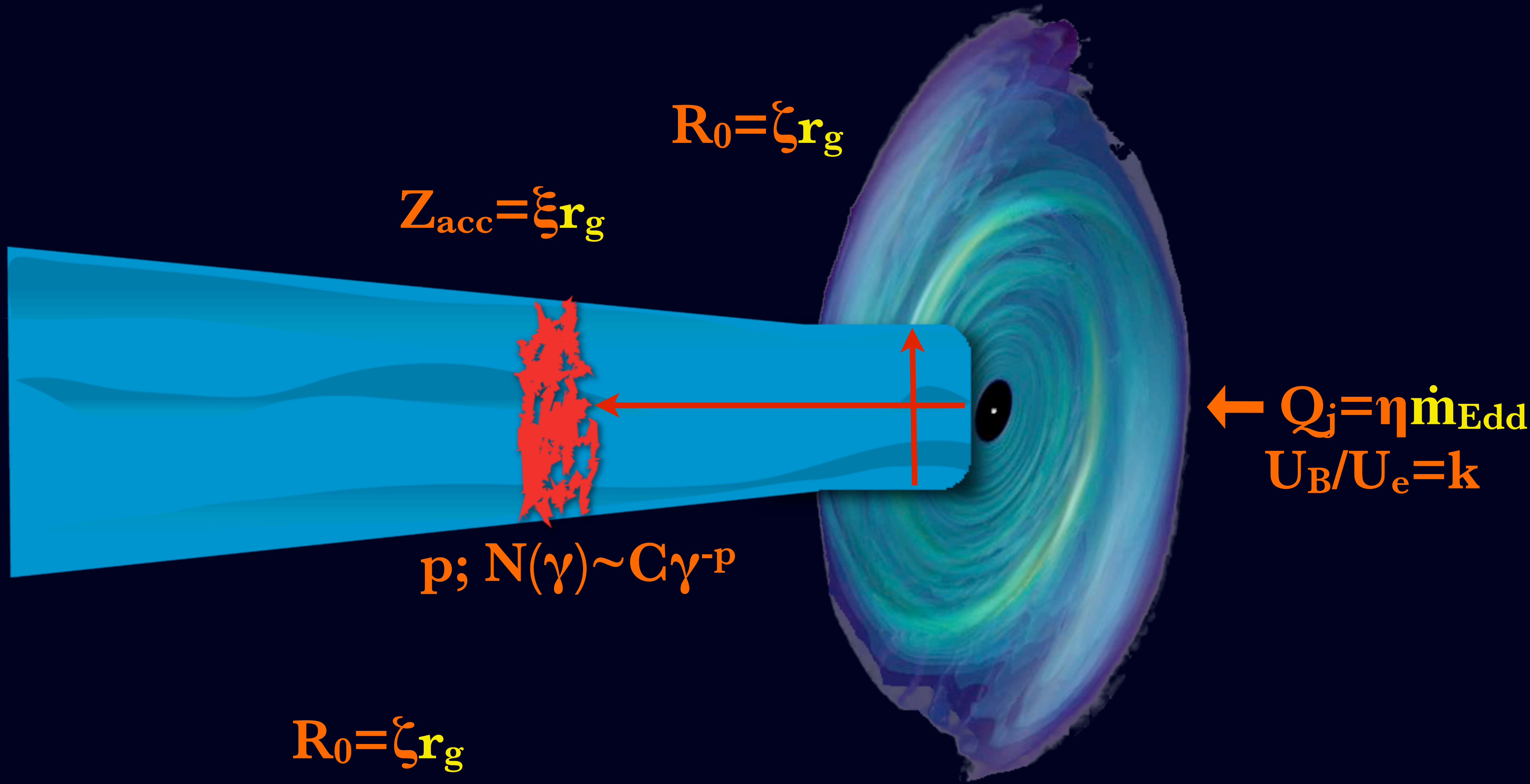
$\%N$=plfrac, $N_p \sim E_e^{-p}$,

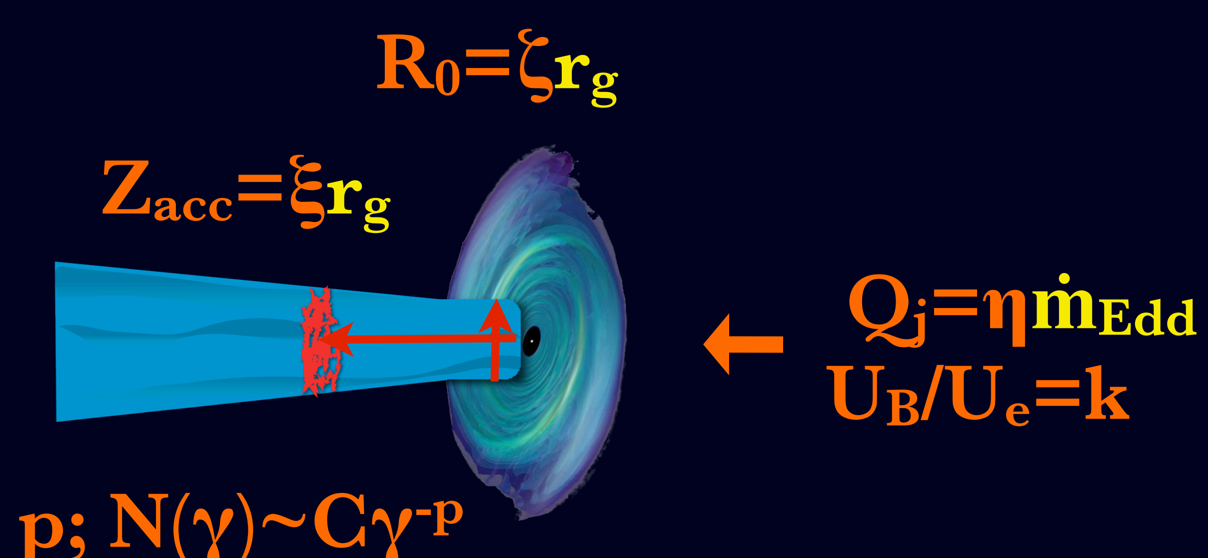
$\xi = (U_{sh}/c)^2(\lambda_{mfp}/r_g)$

Modeling weakly accreting black holes



Joint simultaneous fitting: requiring self-similarity

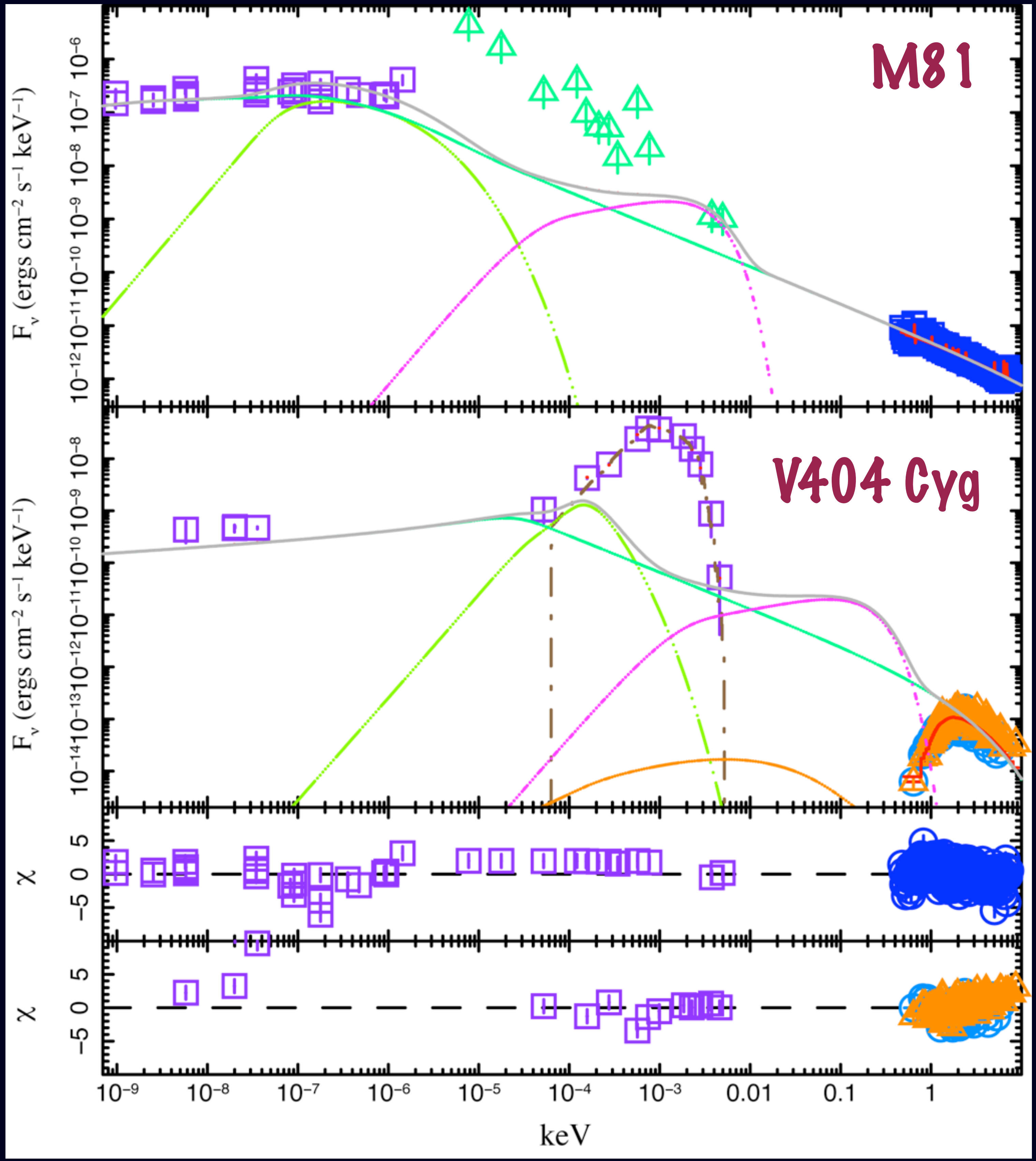




R_d, T_d,
T_e, ξ_{acc}

First joint model: M81⇔V404 Cyg ($L_x \sim 10^{-7}$ - 10^{-6} L_{Edd})

- Tied parameters:
  - R_{in} (disk)
  - R_0 ("corona")
  - z_{acc}
  - p (e^- PL)
  - U_B/U_{e-}



(SM, Nowak, Gallo, Hynes et al., in prep.)

Why is this so interesting?

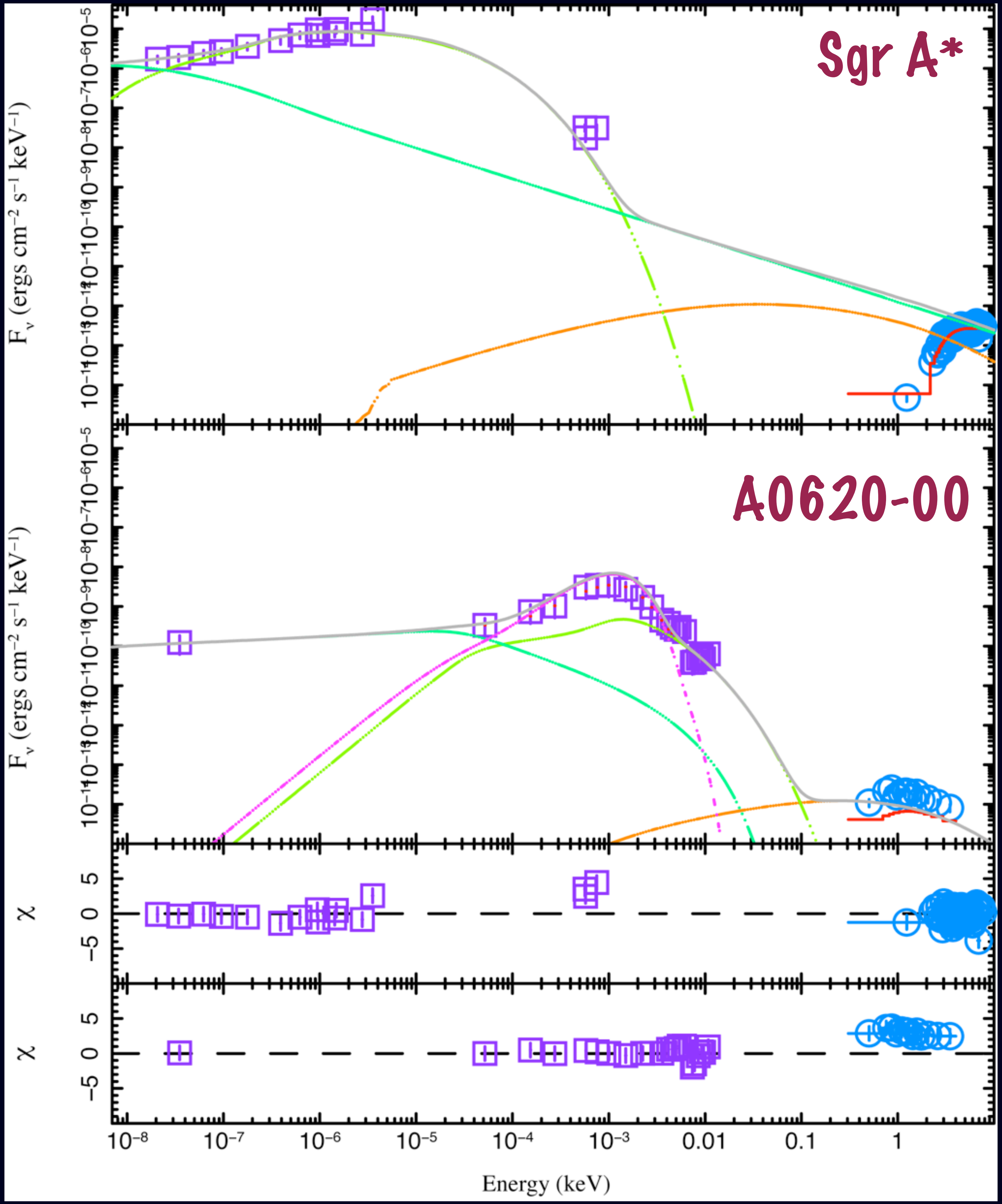
$L < 10^{-7} L_{Edd}$ (A0620 and Sgr A*)

Parameter	HS-XRBs	M81	A0620	Sgr A*
M ($M_\odot$)	~10	7×10^{7}	~10	4×10^{6}
Q_{jet} (L_{Edd})	$10^{-5} - 10^{-1}$	10^{-5}	10^{-7}	10^{-9}
R_0 (R_g)	2–20	2.4	2–7	2.5
z_{acc} (R_g)	10–400	144	1250	$>10^{4}$
p_{elec}	2.4–2.9	2.4	3.4	>3.8
PL frac	0.6*	0.6*	<0.6	<0.01
T_e (K)	$2–5\times10^{10}$	1×10^{11}	2×10^{10}	1×10^{11}
equip ($1/\beta$)	1–5	1.4	1.5	>10

(SM, Nowak & Wilms 2005, Migliari et al. 2007, Gallo et al. 2007, SM, Bower & Falcke 2007, SM et al. 2008, Maitra et al. 2009., van Oers, SM et al., 2010, Nowak et al. 2011)

Quiescence joint model: Sgr A* (flare) ⇔ A0620-00 ($L_x \sim 10^{-10}$ - 10^{-9} L_{Edd})

- Tied parameters:
  - R_{in} (disk)
  - R_0 ("corona")
  - z_{acc}
  - p (e^- PL)
  - U_B/U_{e-}



(SM, Nowak, Nip, Froning, Baganoff et al., in prep.

Summary

- ✷ Accretion states in XRBs seem to correspond to AGN classes in *some* cases. Entire HID? Role of spin? Still incomplete.
- ✷ Fundamental Plane most robust for hard state/LLAGN, we think we understand the physical drivers:
  - ➠ scaling: $\dot{m}/M$ dependence of energy densities, compact jets plus radiative inefficiency in X-rays
  - ➠ Synchrotron/IC: both possible, increasing evidence for oddly smooth transition between them ➠ states within our states?
- ✷ Reproducing scaling relations is not enough! To constrain physics, need models that can also explain SEDs across M_{BH} scale
  - ➠ Joint fitting: Break degeneracies especially at low-luminosity. Supports that HS XRBs $\Leftrightarrow$ LLAGN, and that Sgr A* during flares $\Leftrightarrow$ quiescent BHBs [NEW! 3Msec with Chandra HETG]
  - ➠ AGN fueling: supports scenario where larger ($>R_c$) environment not driving AGN phenomenology, at least at low-lum
- ✷ Outlook: different states; *compact jets vs ballistic jets vs winds!*