Unification of accretion: from black hole binaries to Active Galactic Nuclei

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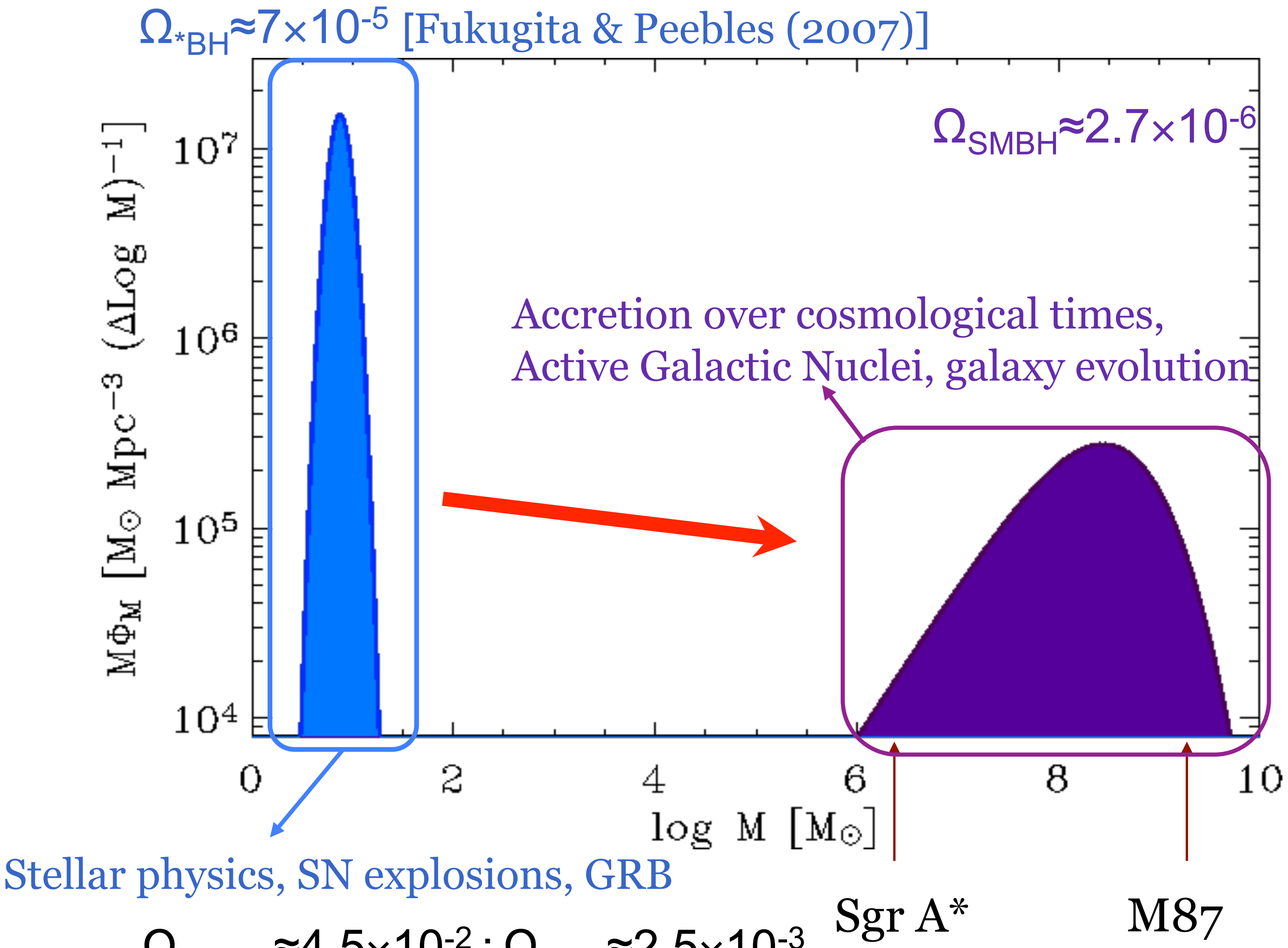
Outline

1. AGN evolution and the history of accretion
2. From AGN SED to AGN physics
   - Accretion discs and X-ray coronae in AGN
3. Do AGN reveal accretion mode changes? The fundamental plane of BH activity
   - Accretion state of LLAGN
   - Jet power measures in radio galaxies

Black Holes in the local Universe



$\Omega_{baryon} \approx 4.5\times10^{-2}$; $\Omega_{stars} \approx 2.5\times10^{-3}$

AGN as accreting BH: the Soltan argument

- Soltan (1982) first proposed that the mass in black holes today is simply related to the AGN population integrated over luminosity and redshift

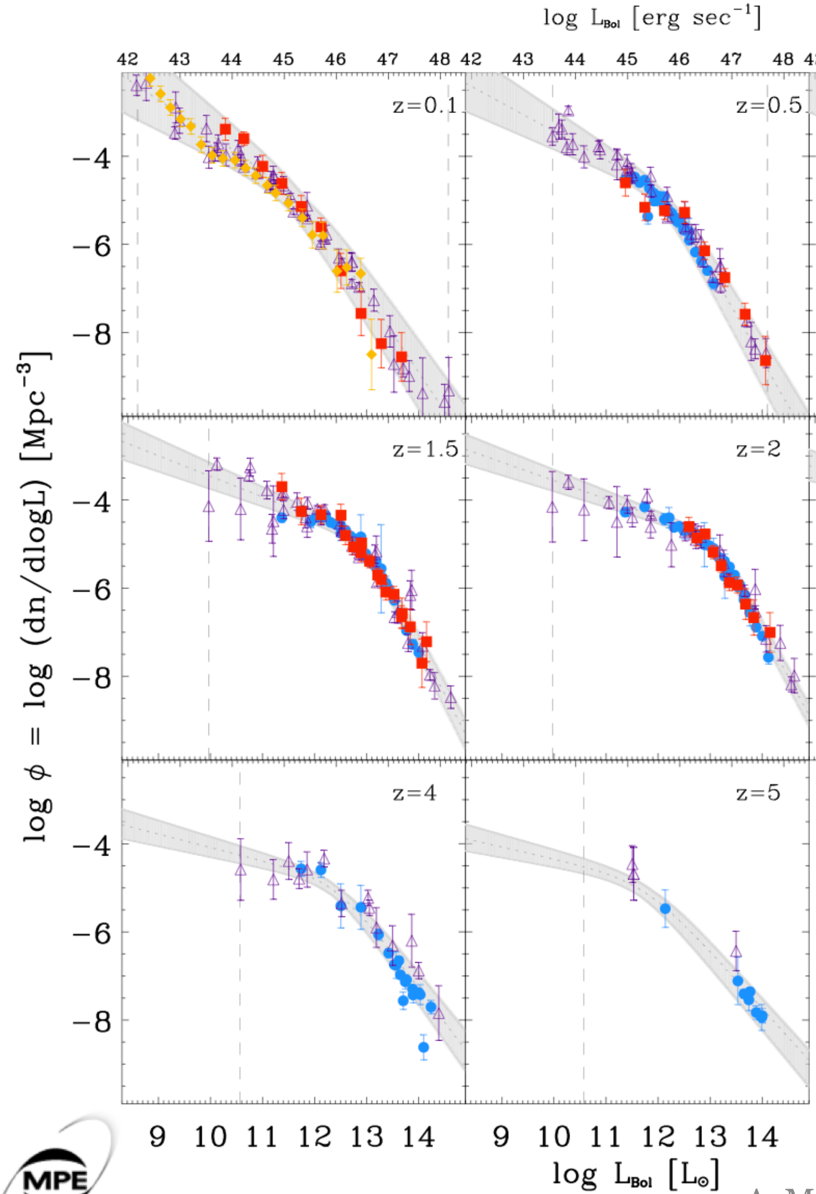
$$L_{\rm bol} = \epsilon_{\rm rad} \dot{M} c^2$$

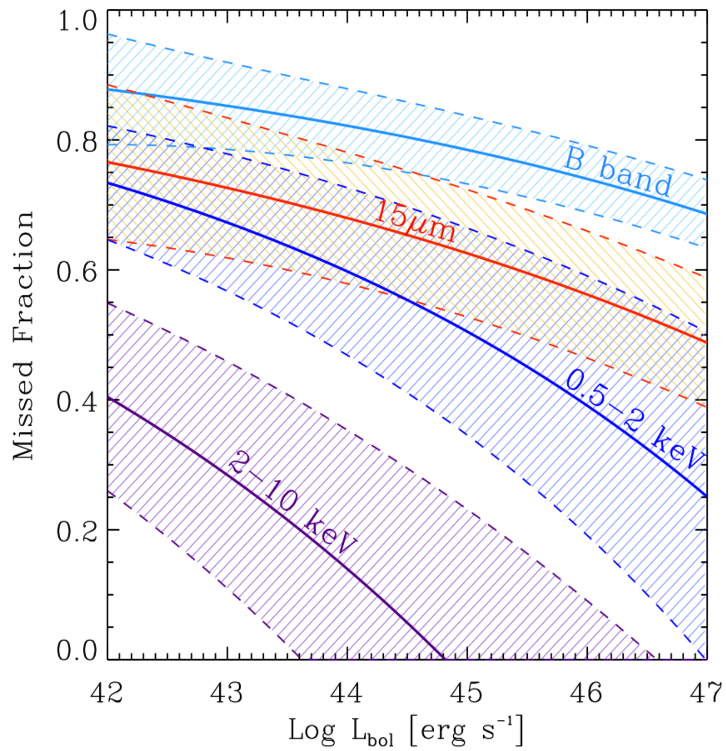
$$\mathrm{BHAR}(z) \equiv \Psi_{\rm BH} = \int_0^\infty \frac{(1-\epsilon_{\rm rad}) L_{\rm bol}}{\epsilon_{\rm rad} c^2} \phi(L_{\rm bol}, z) dL_{\rm bol}$$

$$\frac{\rho_{\rm BH}(z)}{\rho_{\rm BH,0}} = 1 - \int_0^z \frac{\Psi_{\rm BH}(z')}{\rho_{\rm BH,0}} \frac{dt}{dz'} dz'$$

Fabian and Iwasawa (1999) ε~0.1; Elvis, Risaliti and Zamorani (2002) ε >0.15;
Yu and Tremaine (2002) ε>0.1; Marconi et al. (2004) 0.16> ε >0.04;
Merloni, Rudnick, Di Matteo (2004) 0.12> ε >0.04; Shankar et al. (2007) ε ~0.07

Panchromatic Luminosity Functions

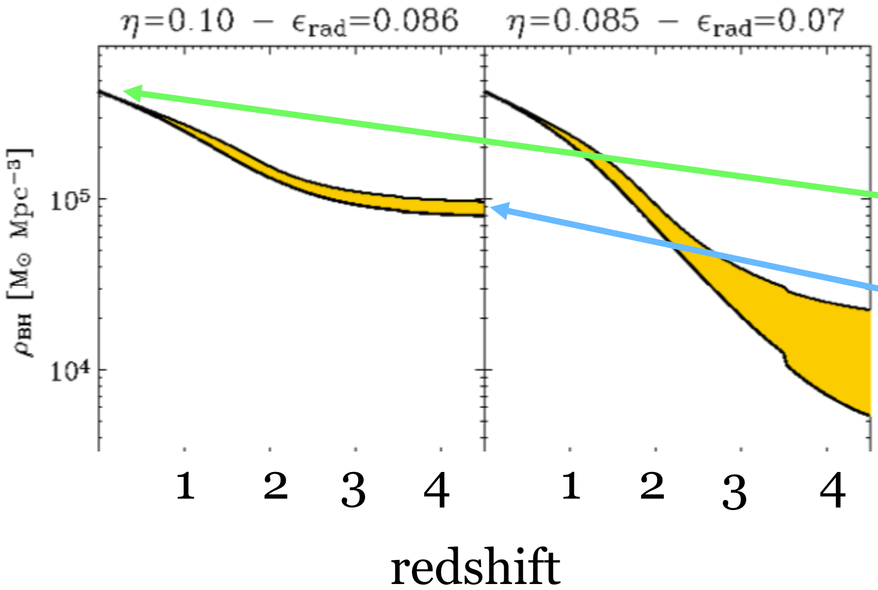




Hard X-rays provide by far the most complete census of AGN activity

See Hopkins et al. (2007);
Marconi et al. (2004);
Merloni & Heinz (2013)

Constraints on radiative efficiency $\langle \varepsilon_{rad} \rangle$



$\xi_o = \rho_{BH,o}/(4.2\text{x}10^5)$

$\xi_i = \rho_{BH}(z=z_i)/\rho_{BH,o}$

(Input from seed BH formation models needed!)

$\xi_{lost} = \rho_{BH,lost}/\rho_{BH,o}$

(Mass density of SMBH ejected from galactic nuclei due to GW recoil after mergers)

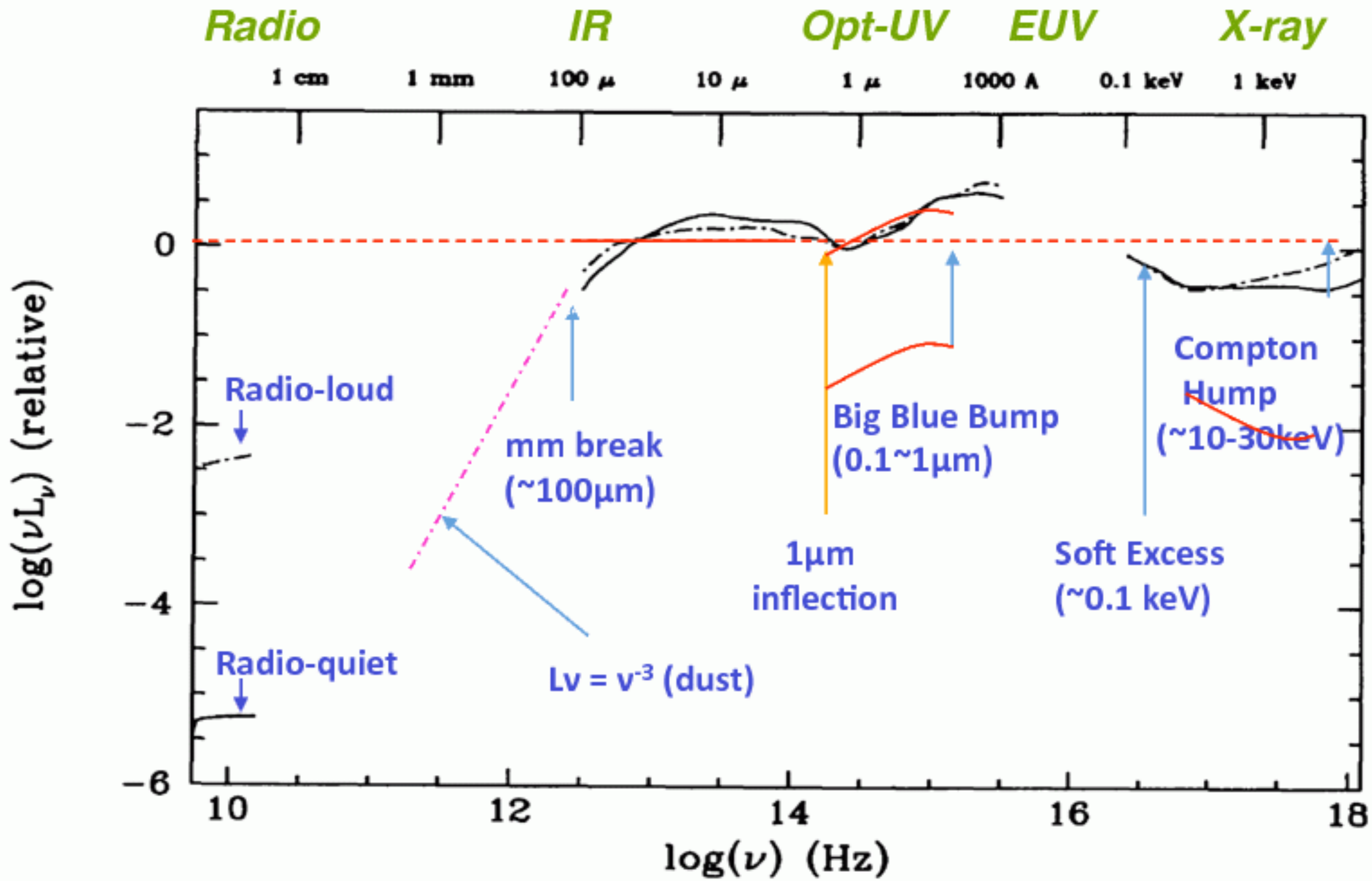
$\xi_{CT} = \rho_{BH,CT}/\rho_{BH,o}$

(Fractional Mass density of SMBH grown in a Compton Thick, heavily obscured phase)

$$\boxed{\langle \varepsilon_{rad} \rangle \approx 0.07/[\xi_o (1-\xi_{CT}-\xi_i + \xi_{lost})]}$$

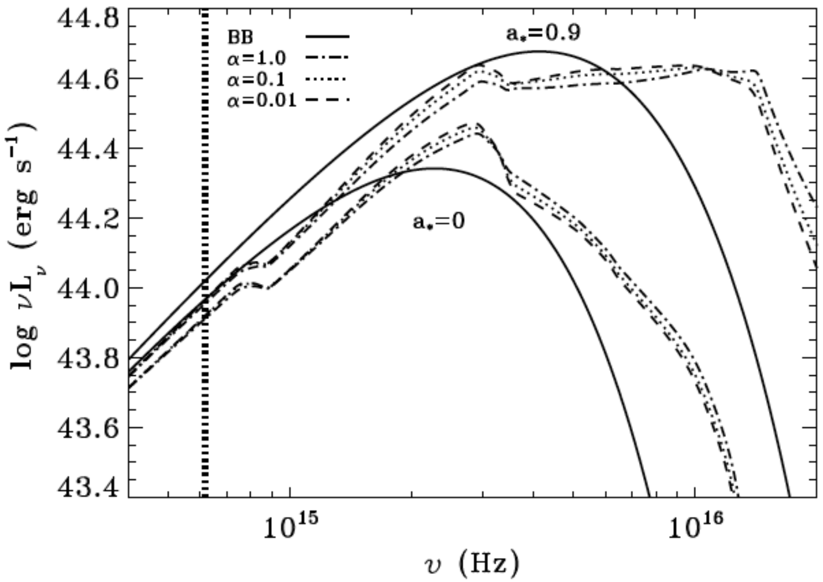
Merloni and Heinz 2008

Spectral Energy Distribution (SED)



Elvis et al., 1994, ApJS, 95, 1

Disk continuum fitting in AGN



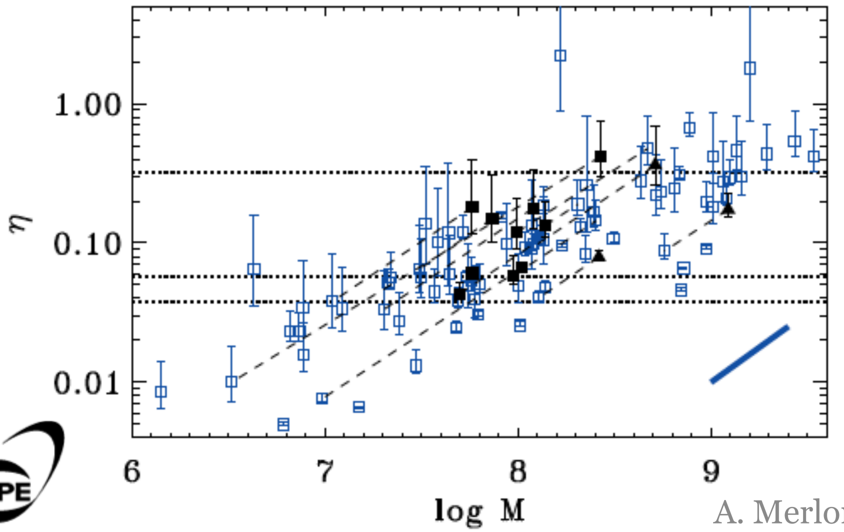
$$L_\nu = \frac{160}{\pi^3}\left(\frac{6\pi^2 h G^2 c^2}{5}\right)^{1/3} \Theta \nu^{1/3} \dot{M}^{2/3} M^{2/3} \cos i,$$

where

$$\Theta(\nu, r_{\rm in}, r_{\rm out}) \equiv \int_{x_{\rm in}}^{x_{\rm out}} dx \frac{x^{8/3-1}}{\exp(x)-1}.$$

$$\dot{M} = 2.6 M_\odot \ {\rm yr}^{-1} \left(\frac{L_{\rm opt,45}}{\cos i}\right)^{3/2} M_8^{-1},$$

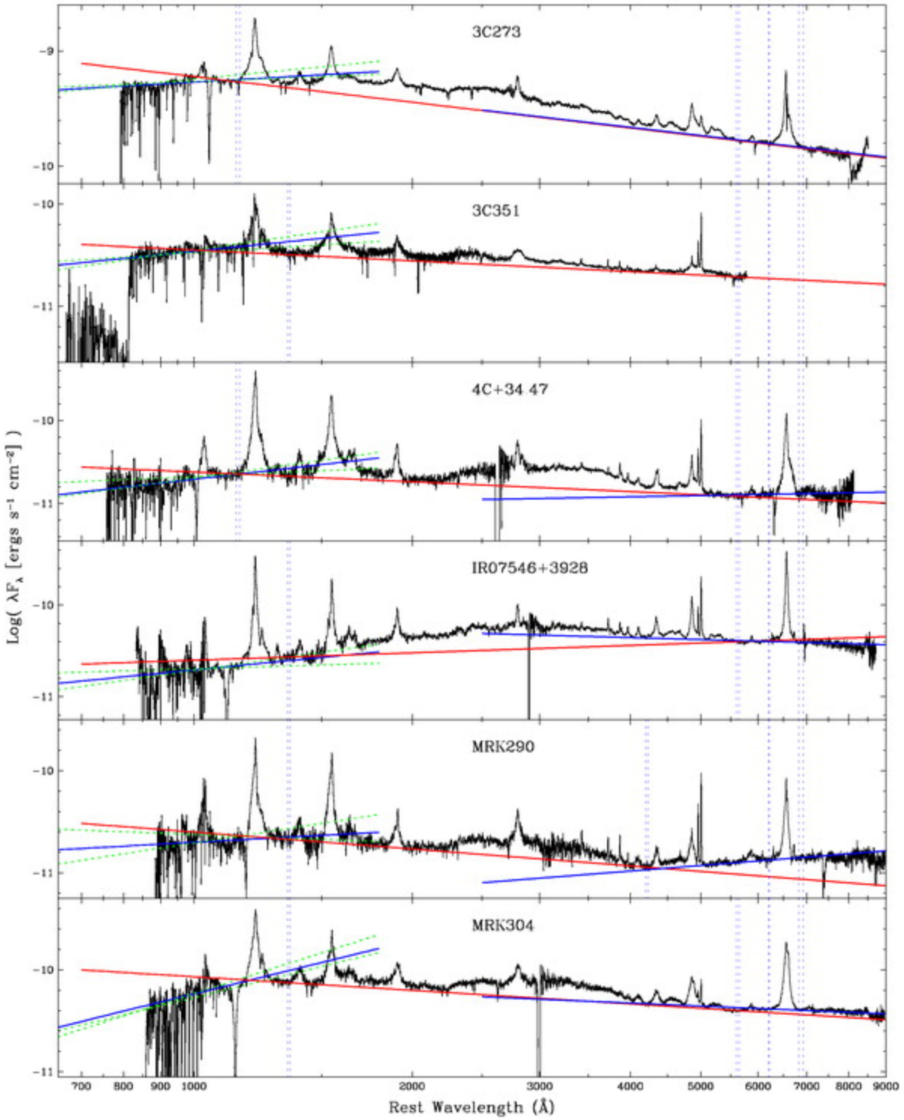
Once Mass and luminosity is known, we can
Measure accretion efficiency (or BH spin)!



Analogous to disk continuum fitting in BHXRB (Zahng, Cui, McClitock, Davis, Narayan etc.)

Davis and Laor, 2010

Optical-FUV SED: a closer look



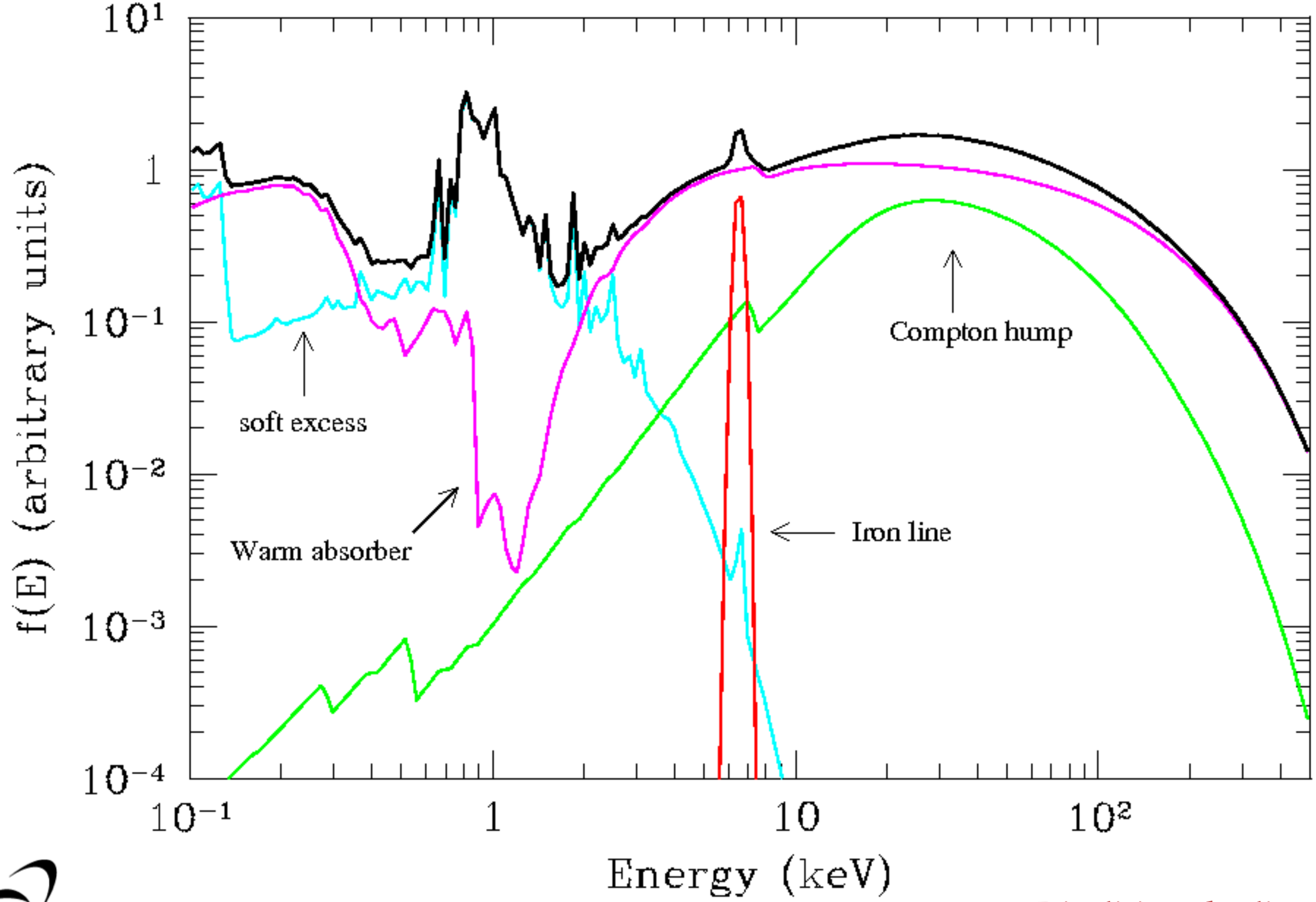
Shang et al. 2005

- Spectral UV peak at ~1100 AA does not scale with M_{BH} as expected ("Temperature problem")
- Uncertain FUV shape: is there enough flux to ionize BLR? (see Binette's talk)
- UV variability faster than viscous, and happening in phase

➔Lawrence 2012: inhomogeneous disc atmospheres at few tens of R_S

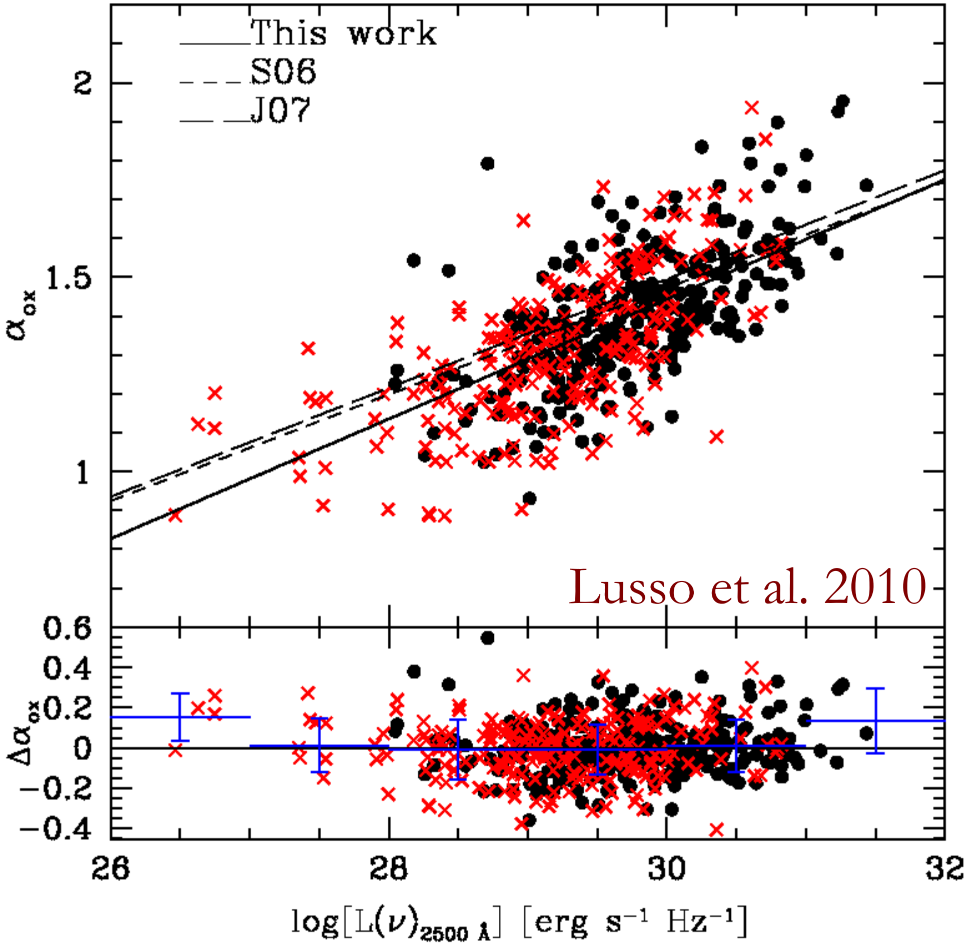
(Analogous solutions have been proposed for the X-ray "soft excess"; Merloni et al. 2006)

X-ray spectra



Risaliti and Elivs 2004

X-ray loudness and corona production



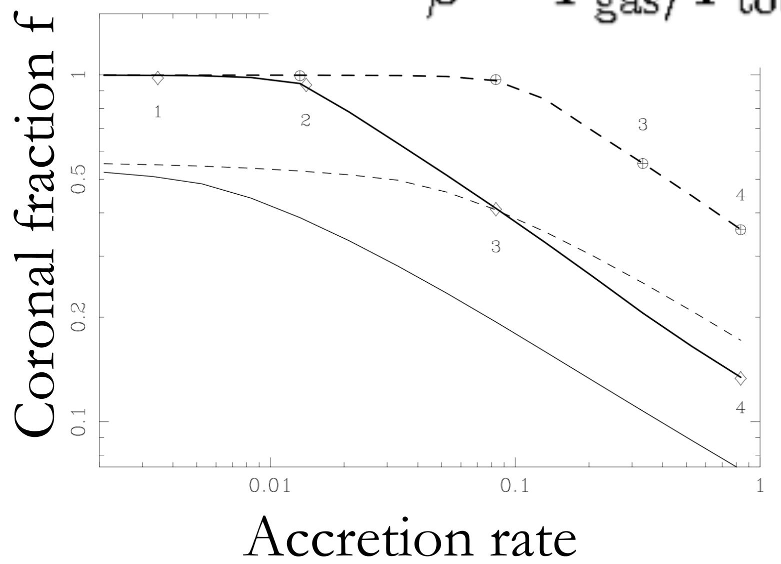
X-ray loudness decreases with increasing luminosity [but little agreement on slope, non-linearity, etc.]

$$t_{r\phi} = \alpha_0 P_{\rm tot}^{1-\mu/2} P_{\rm gas}^{\mu/2}$$

Viscous stresses $t_{r\phi} \propto P_{\rm mag}$

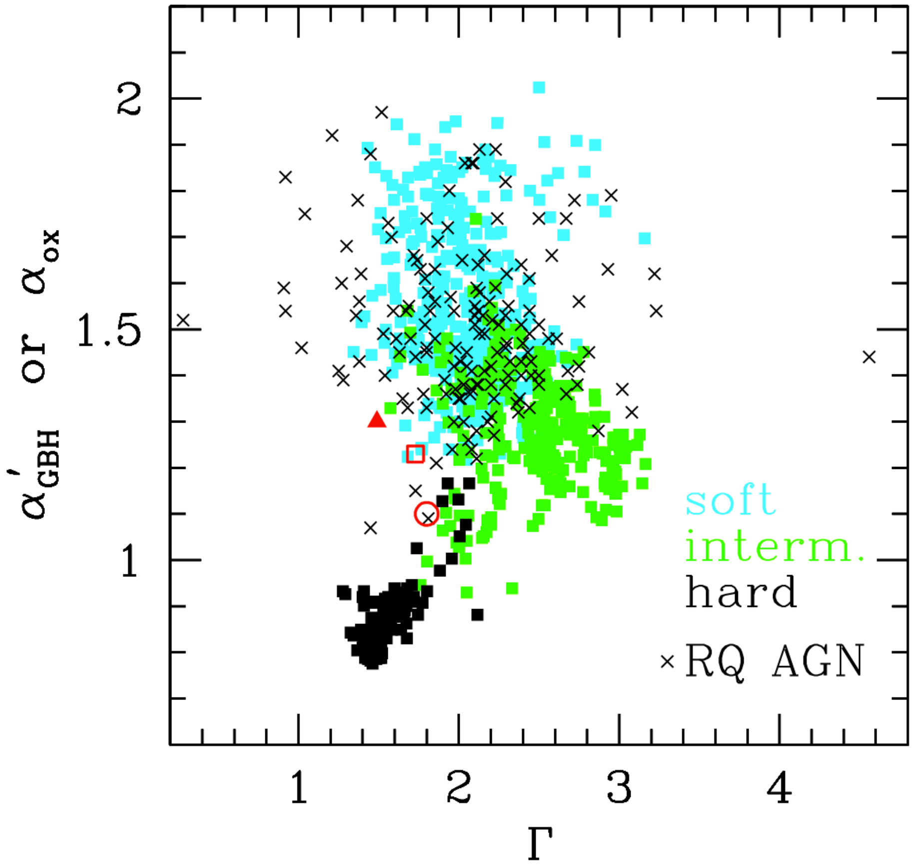
Coronal fraction $f \simeq \dfrac{v_{\rm A}}{c_{\rm s}} = \sqrt{2\alpha_0 \beta^{\mu/2}}$

$$\beta = P_{\rm gas}/P_{\rm tot}$$

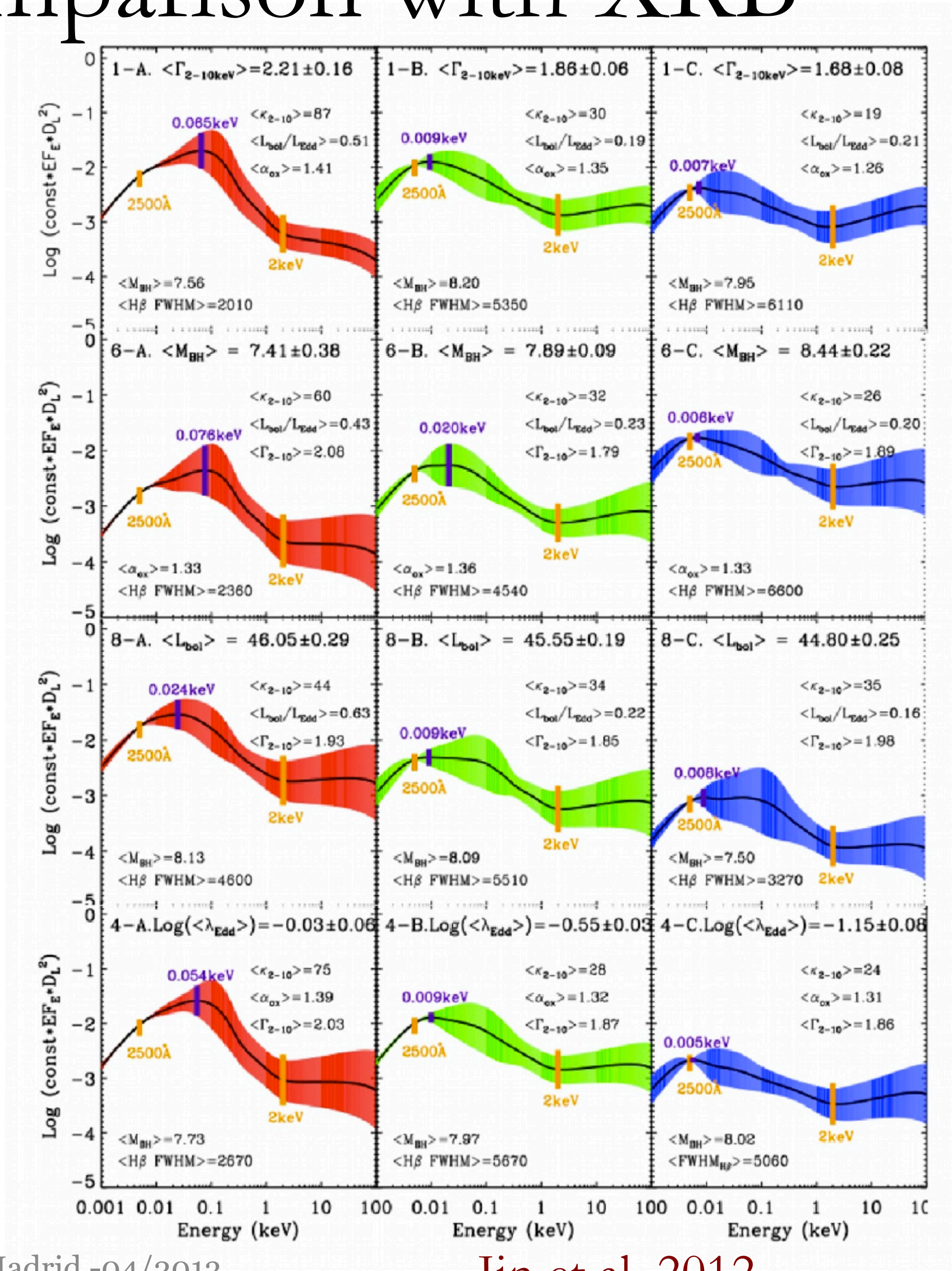


Merloni & Fabian 2002;2003

X-ray loudness: comparison with XRB



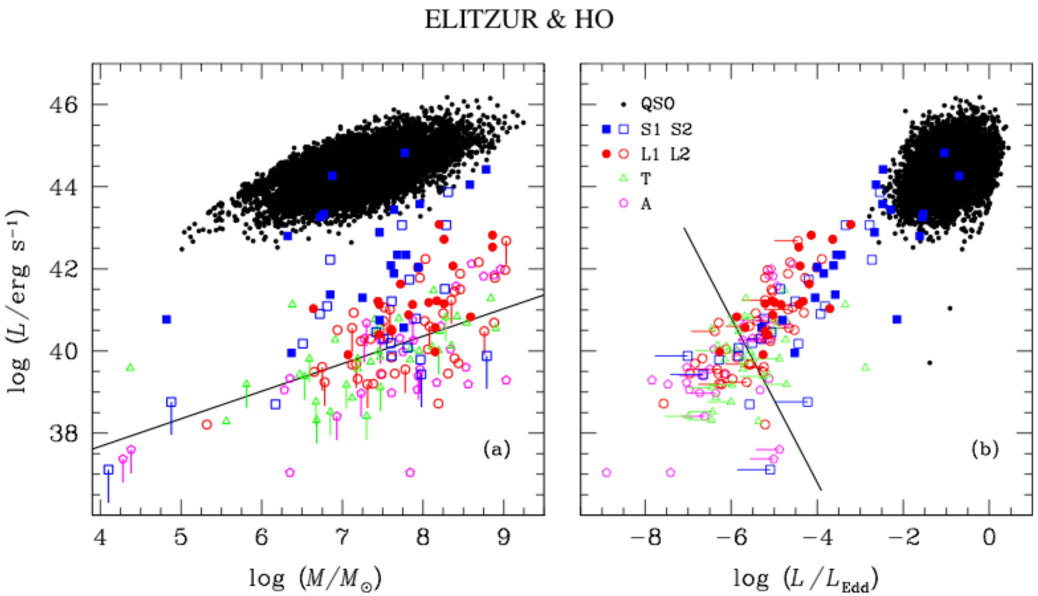
Sobolewska et al. 2010



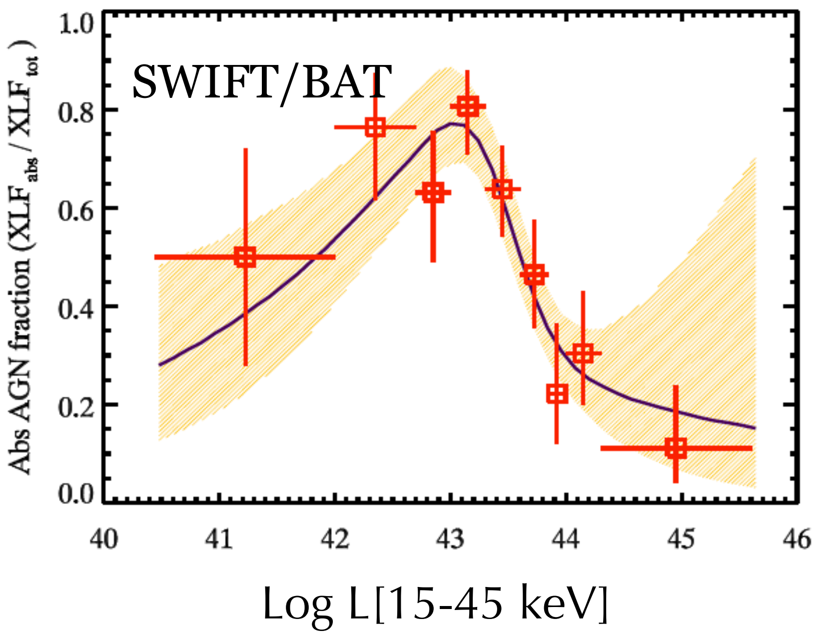
Jin et al. 2012

AGN in the low/hard state: disappearance of torus/disc?

- Do "naked" type-2 AGN exist at low Eddington ratio?
- Can we put limits on the disappearance of BLR/torus?
- Statistics of AGN with and without broad lines at low luminosity



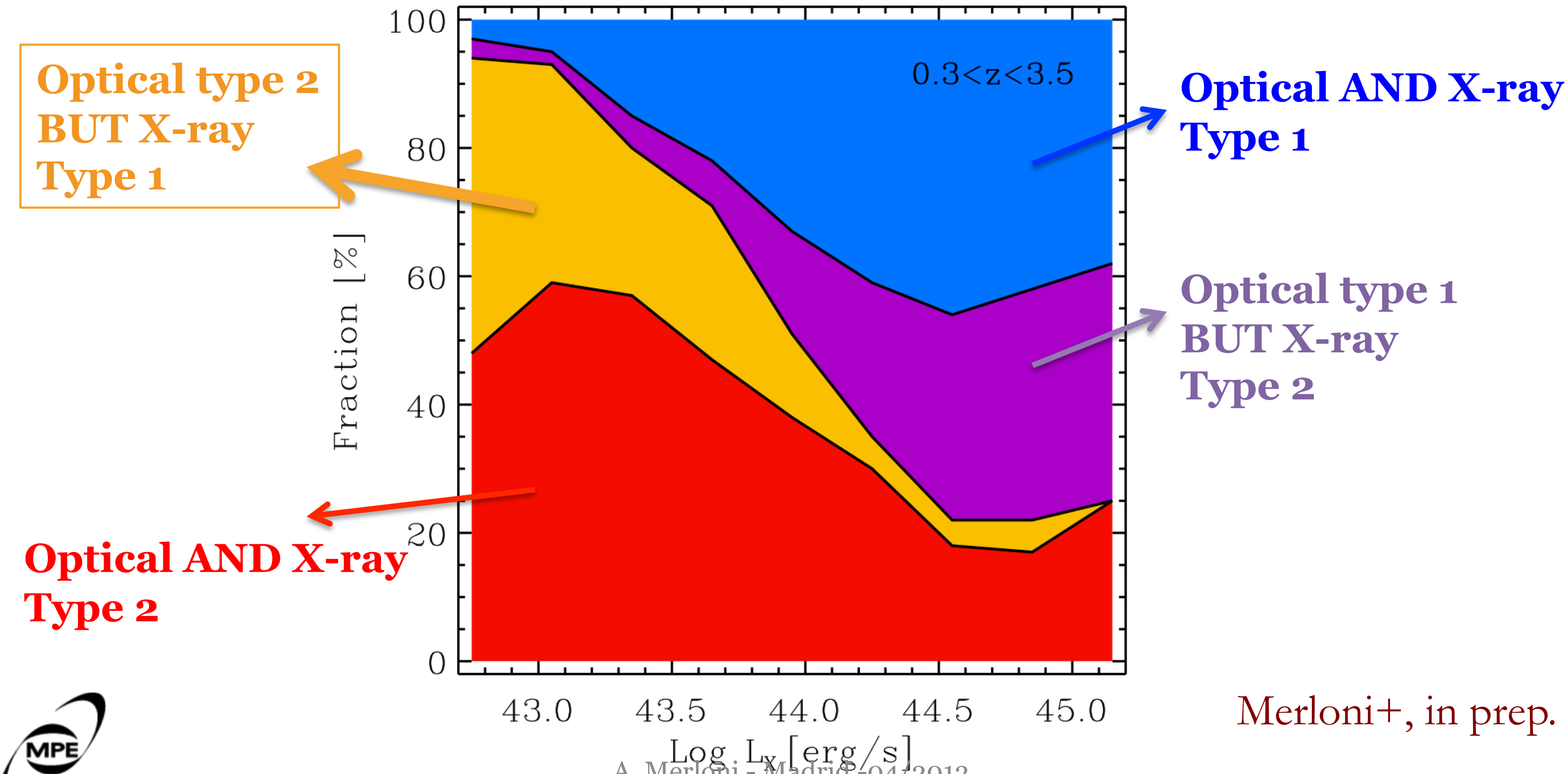
Elitzur and Ho 2009



Burlon et al. 2011
Brightman et al. 2011

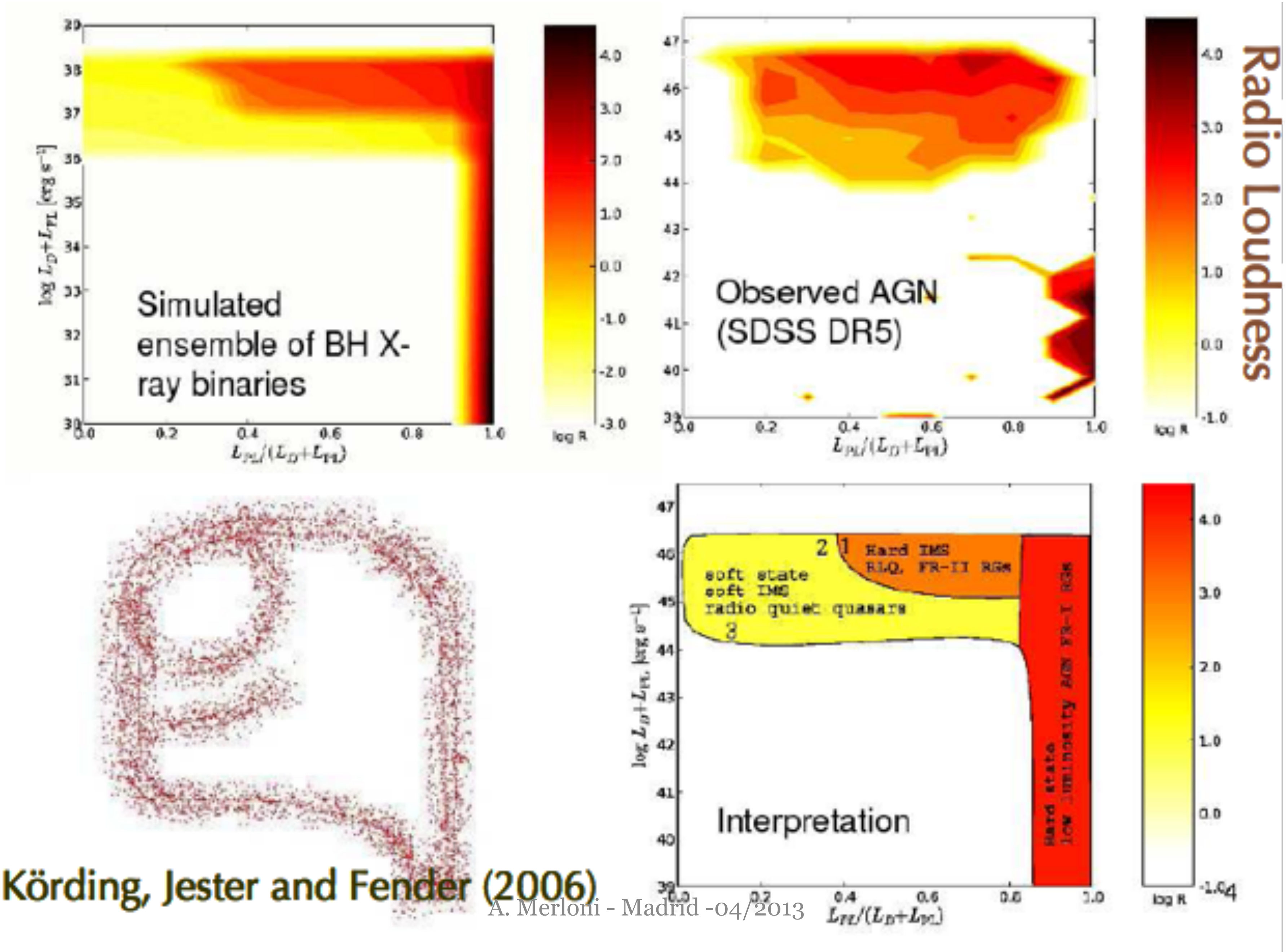
Do “naked” type 2 AGN exist at low L?

- A COMPLETE sample of ~1300 AGN selected from rest-frame 2-10 keV flux in XMM-COSMOS
- Optical classification based on spectroscopy (~50%) and full SED modelling
- X-ray classification based on (rest-frame) Hardness ratios



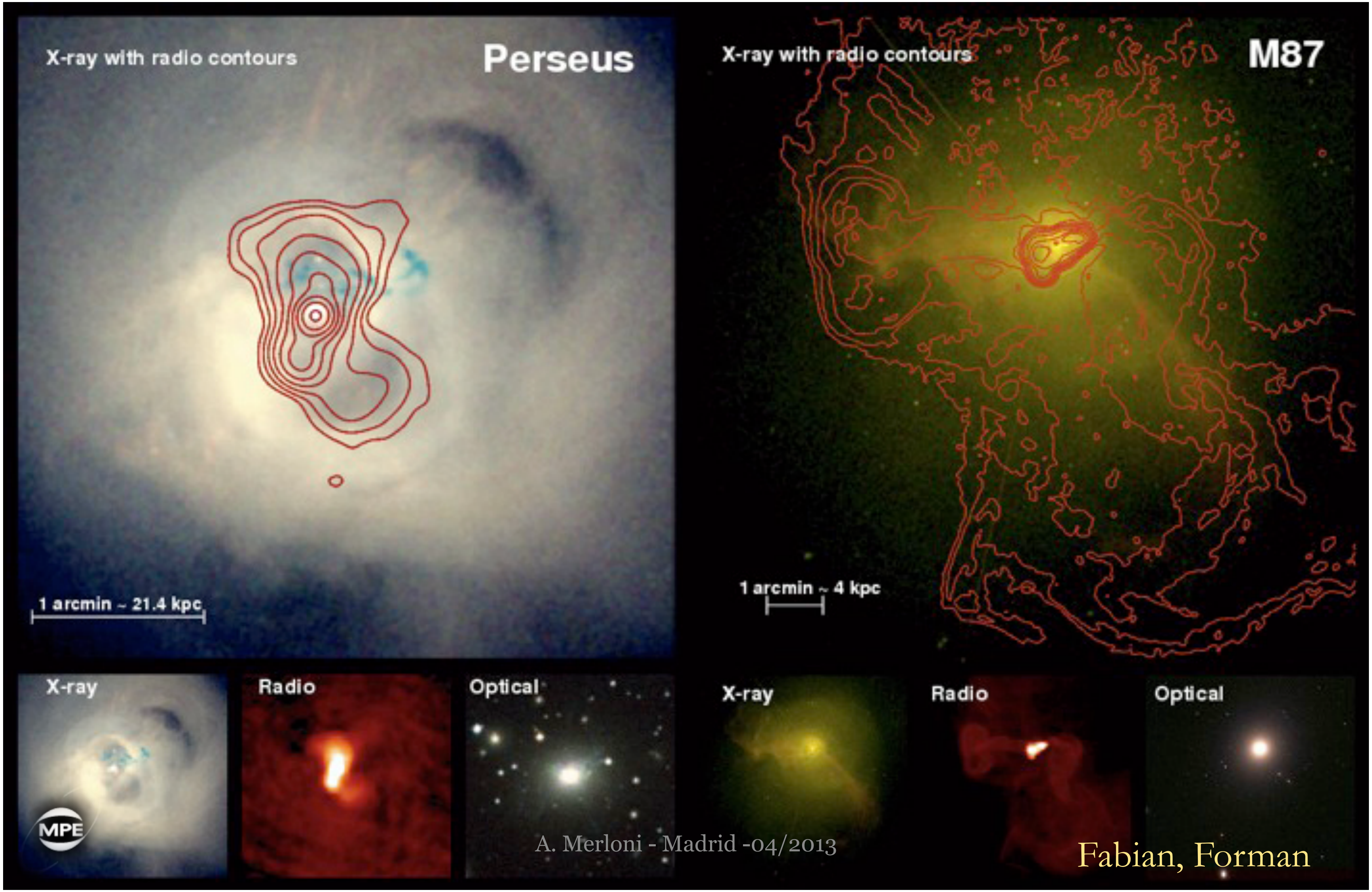
Merloni+, in prep.

The AGN/XRB analogy: spectra



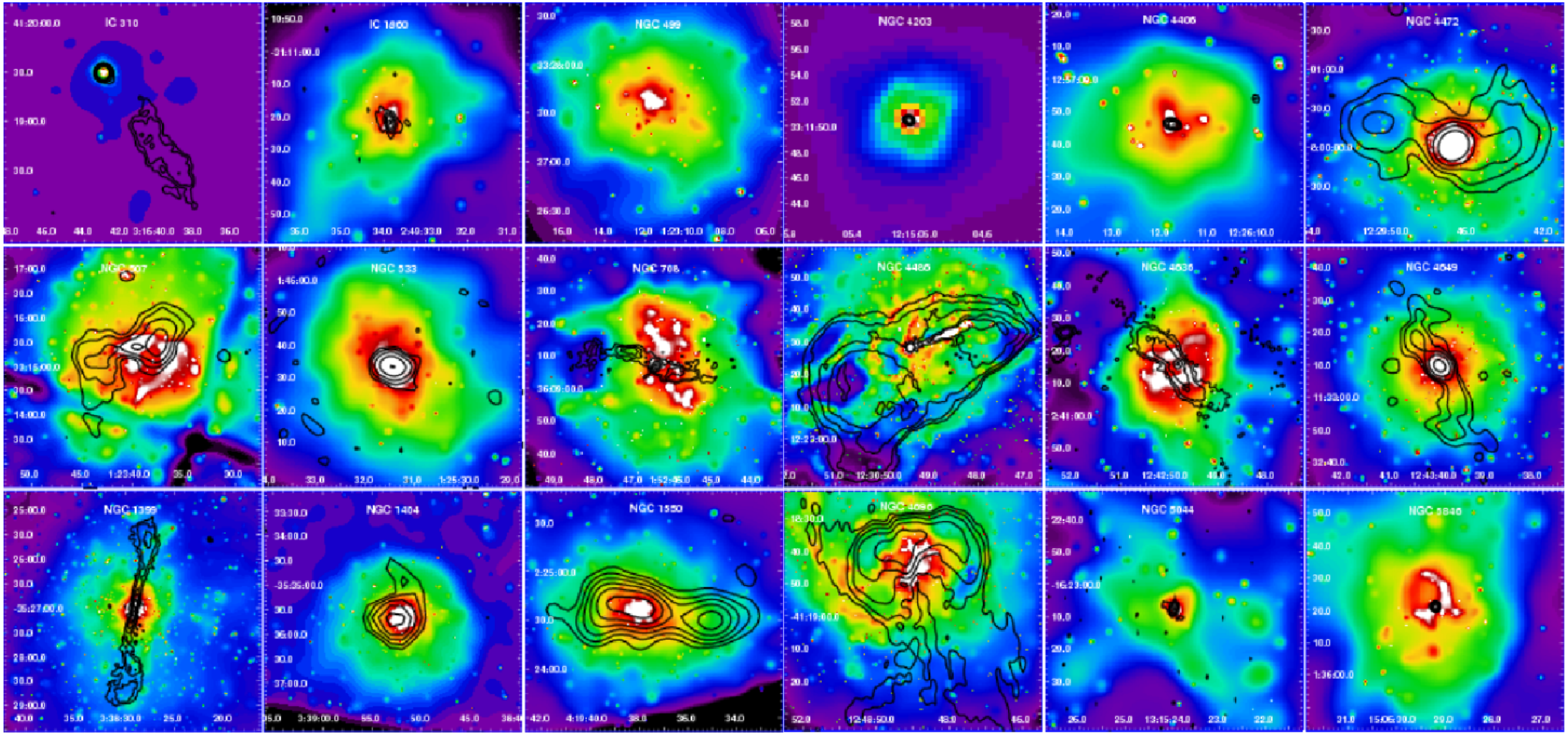
Körding, Jester and Fender (2006)

Low-luminosity AGN: jet-disc connection



Fabian, Forman

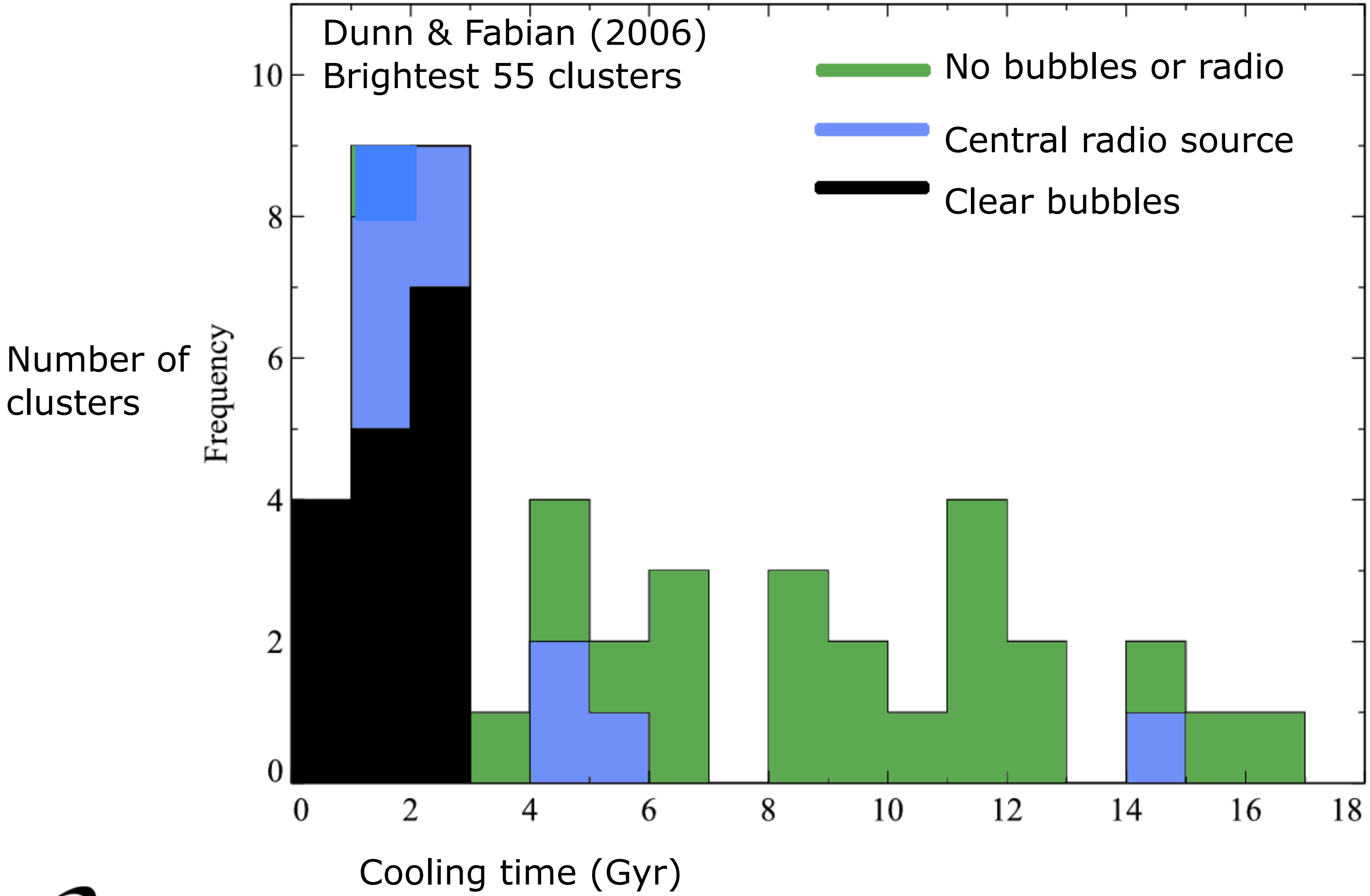
LLAGN in cluster/group cores



A complete, X-ray selected sample of nearby, massive elliptical galaxies

Dunn et al. 2010

Duty cycle is ~100%



See also Birzan+04, Rafferty+06+08, Dunn+07

Estimating the kinetic power of jets

$$E_{\rm cavity} = \frac{\gamma p V}{(\gamma - 1)} \sim 4pV$$

γ=4/3

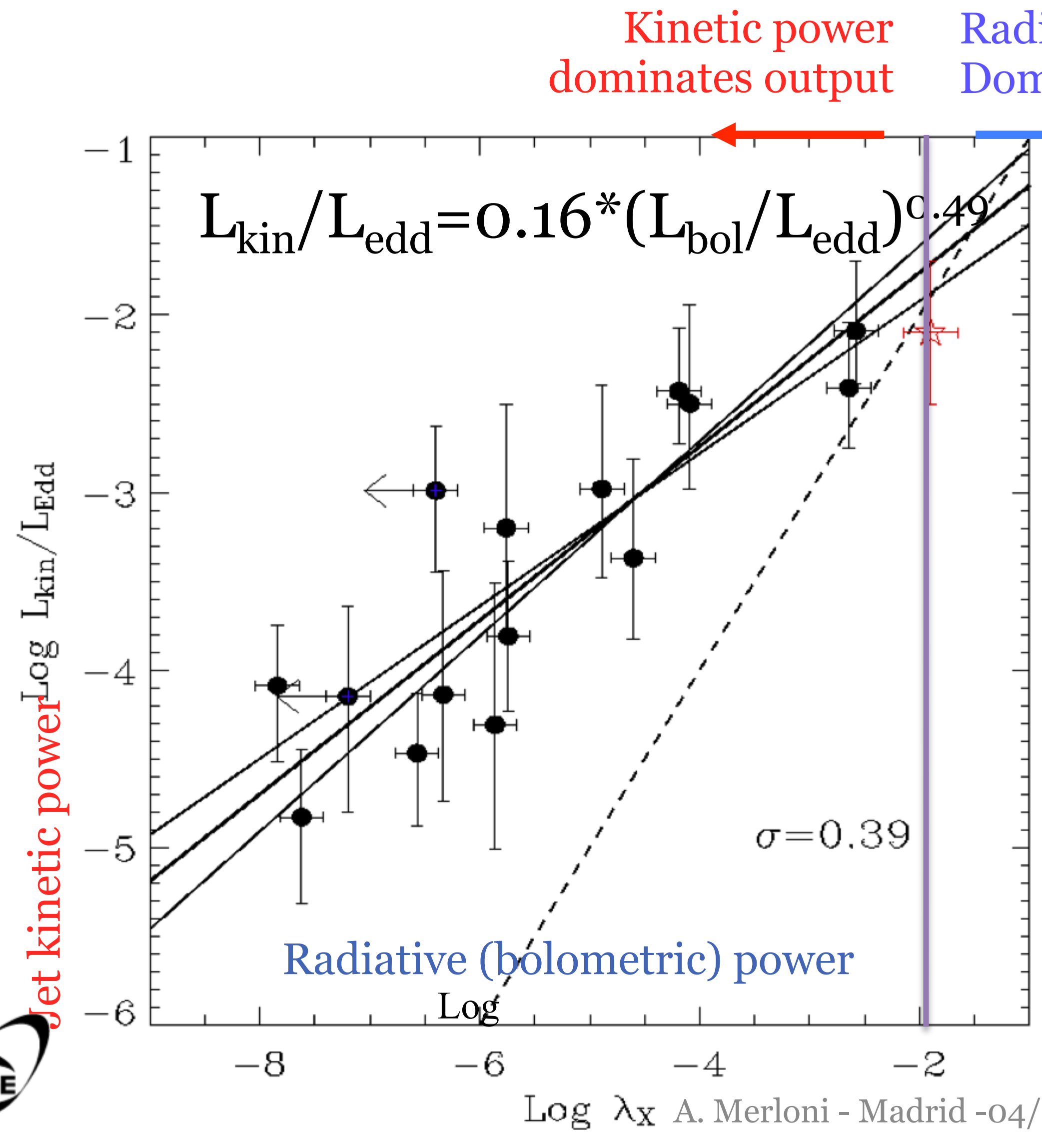
$$t_{\rm cavity} \geq \tau_{\rm sonic} = \frac{R_{\rm cavity}}{c_{\rm s}}$$

$$t_{\rm cavity} \leq \tau_{\rm buoy} \sim \frac{2R_{\rm cavity}}{v_{\rm buoy}} \sim \frac{2R_{\rm cavity}}{c_{\rm s}\sqrt{\frac{4}{3}\frac{d\ln(P)}{d\ln R}\frac{1}{C_{\rm W}}}} = 2\tau_{\rm sonic}\sqrt{\frac{3C_{\rm W}}{4}\frac{d\ln(R)}{d\ln(P)}} \sim 2\tau_{\rm sonic}$$

$$\frac{E_{\rm cavity}}{\tau_{\rm buoy} + \tau_{\rm sonic}} \sim \frac{E_{\rm cavity}}{3\tau_{\rm sonic}} \lesssim P_{\rm jet} \lesssim \frac{E_{\rm cavity}}{\tau_{\rm sonic}}$$

Nulsen 2007; Allen et al. 2006;
Rafferty et al. 2006
Merloni & Heinz 2013

How do AGN work?
Low Power ones are jet dominated

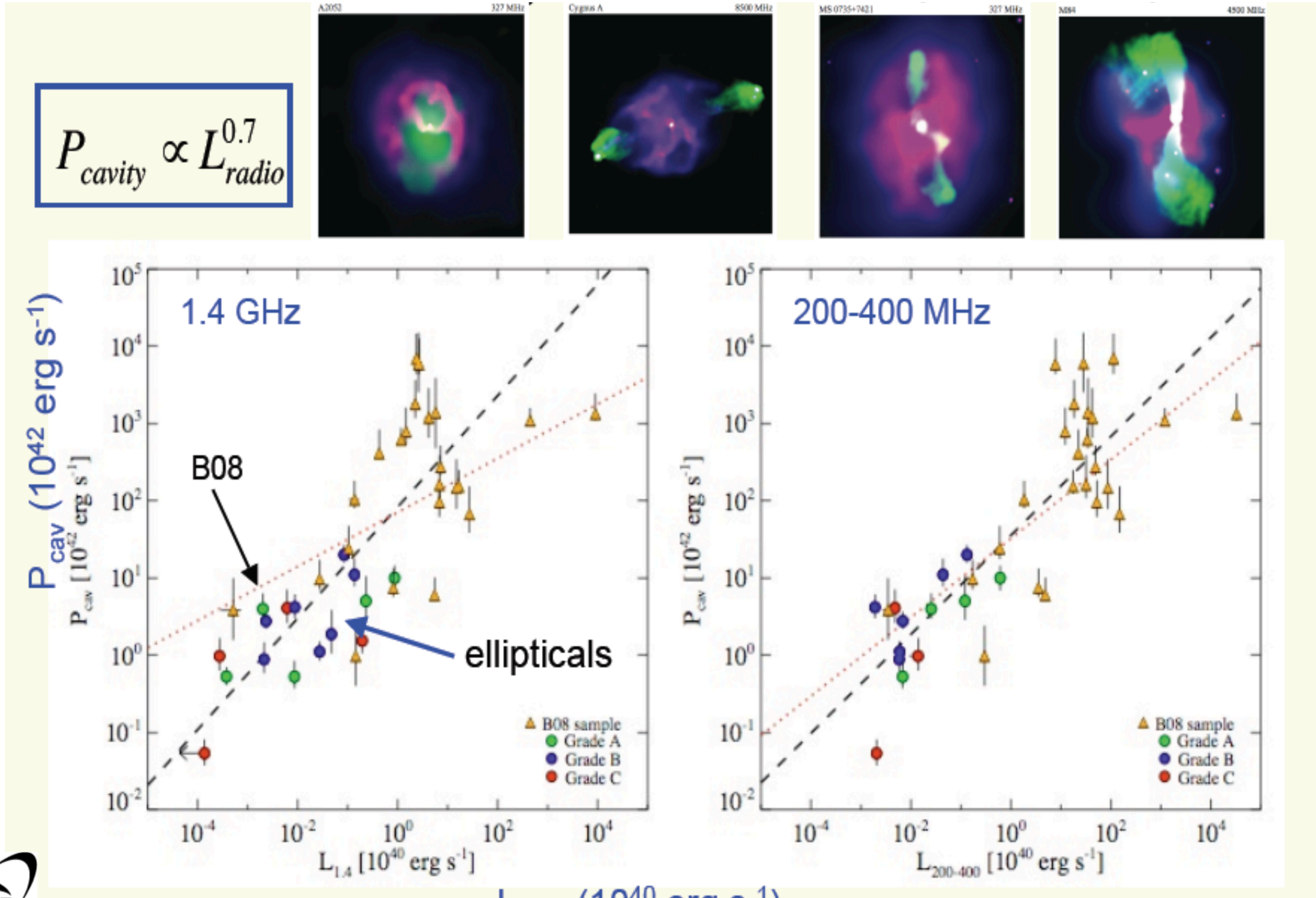


- By studying the nuclear properties of the AGN we can establish a link between jet power and accretion power
- The observed slope (0.49±0.045) is perfectly consistent with radiatively inefficient "jet dominated" models

Merloni et al. 2003
Merloni & Heinz 2007

Extended Radio/L_{Kin} relation

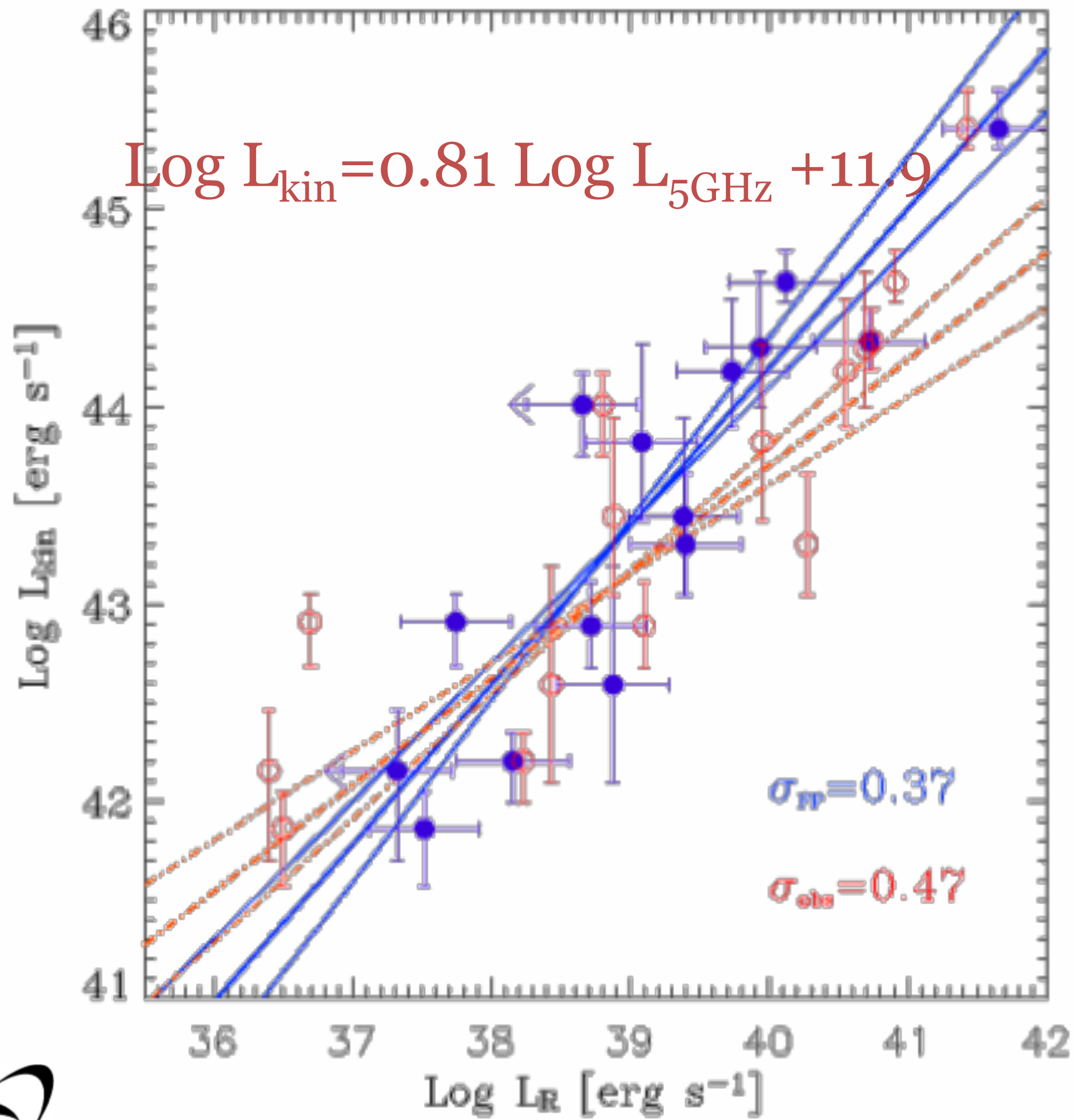
$$P_{cavity} \propto L_{radio}^{0.7}$$



Cavagnolo + 10, Birzan + 08

Core Radio/L_{Kin} relation

Log L_{kin}=0.81 Log L_{5GHz} +11.9



Observed L_R (beaming)
Derived from FP relation

Monte Carlo simulation:
Statistical estimates of
mean Lorentz Factor Γ~7

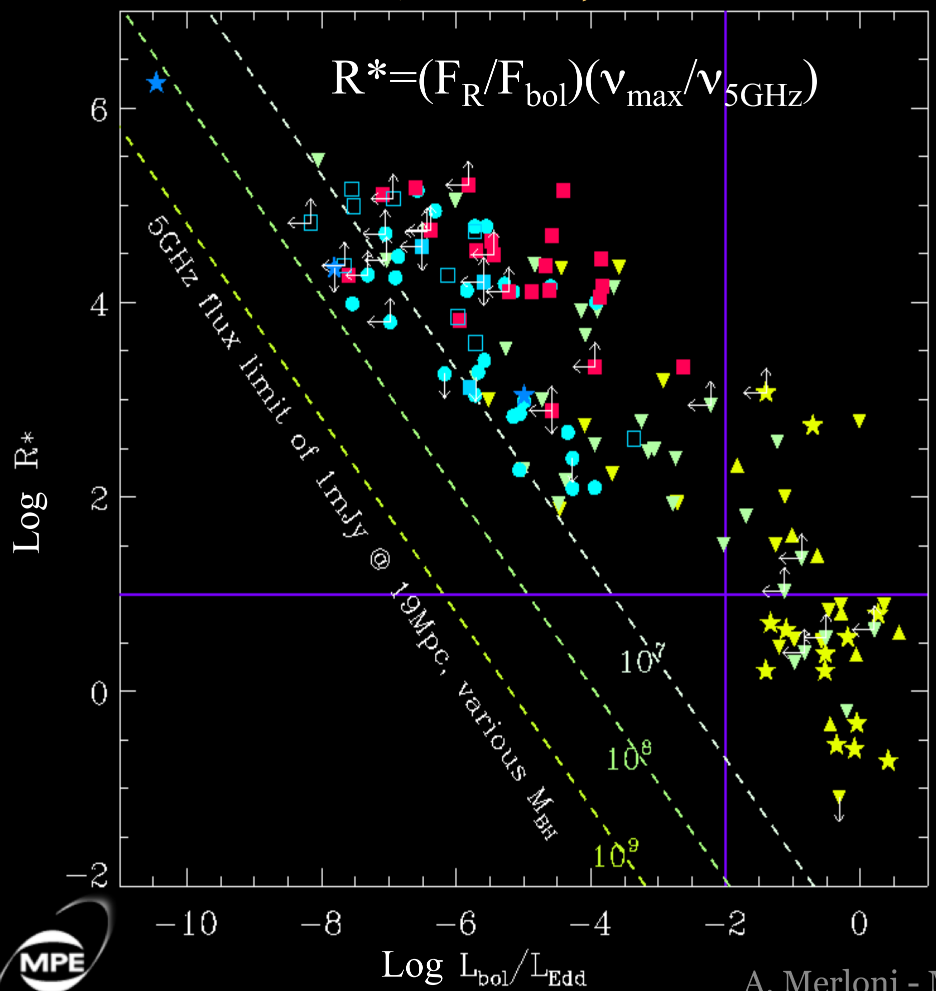
Merloni and Heinz (2007)

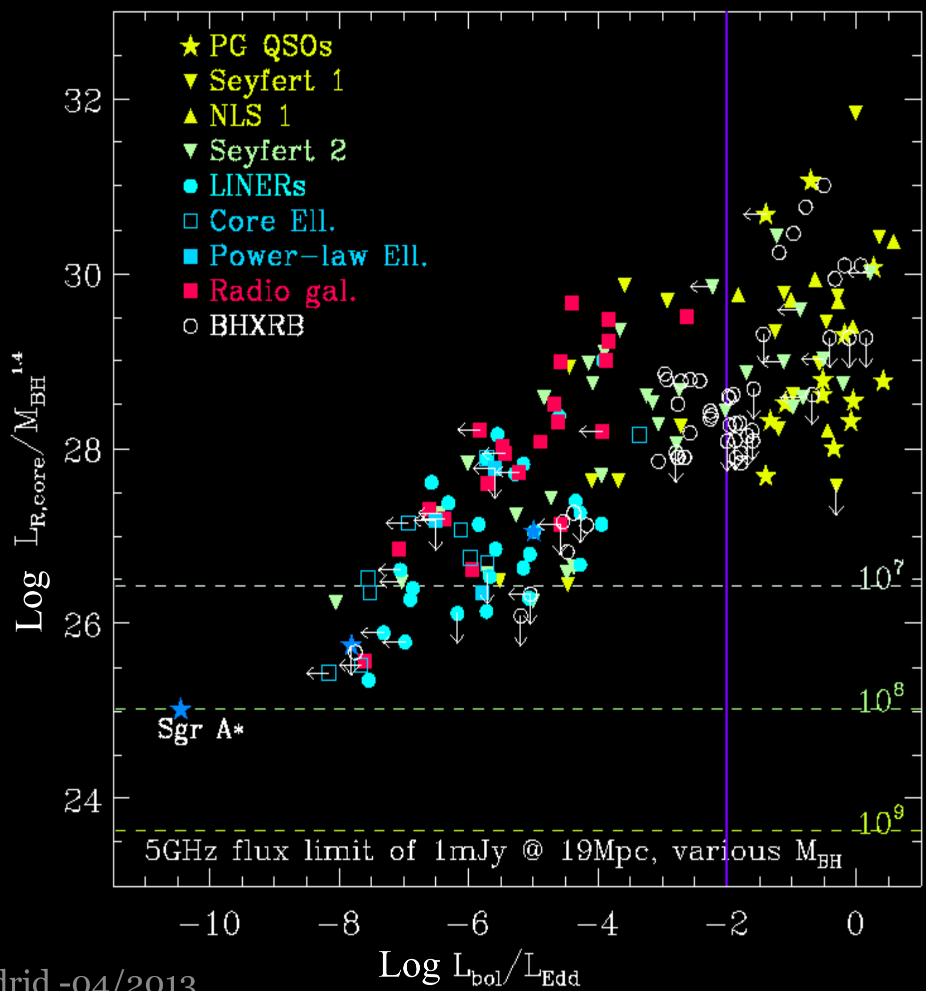
Radio cores scaling with M and mdot

A "fundamental plane" of active BHs

[Merloni et al. 2003; Falcke et al. 2004; Guterlkin et al. 2009]

See also Ho 2002; Greene, Ho and Ulvestad 2003





Basic scaling laws for the Jet Kinetic power

LLAGN ($L/L_{edd}<0.01$); No BLR

$$L_R \propto L_X^{0.6-0.7} M^{0.7-0.8}$$

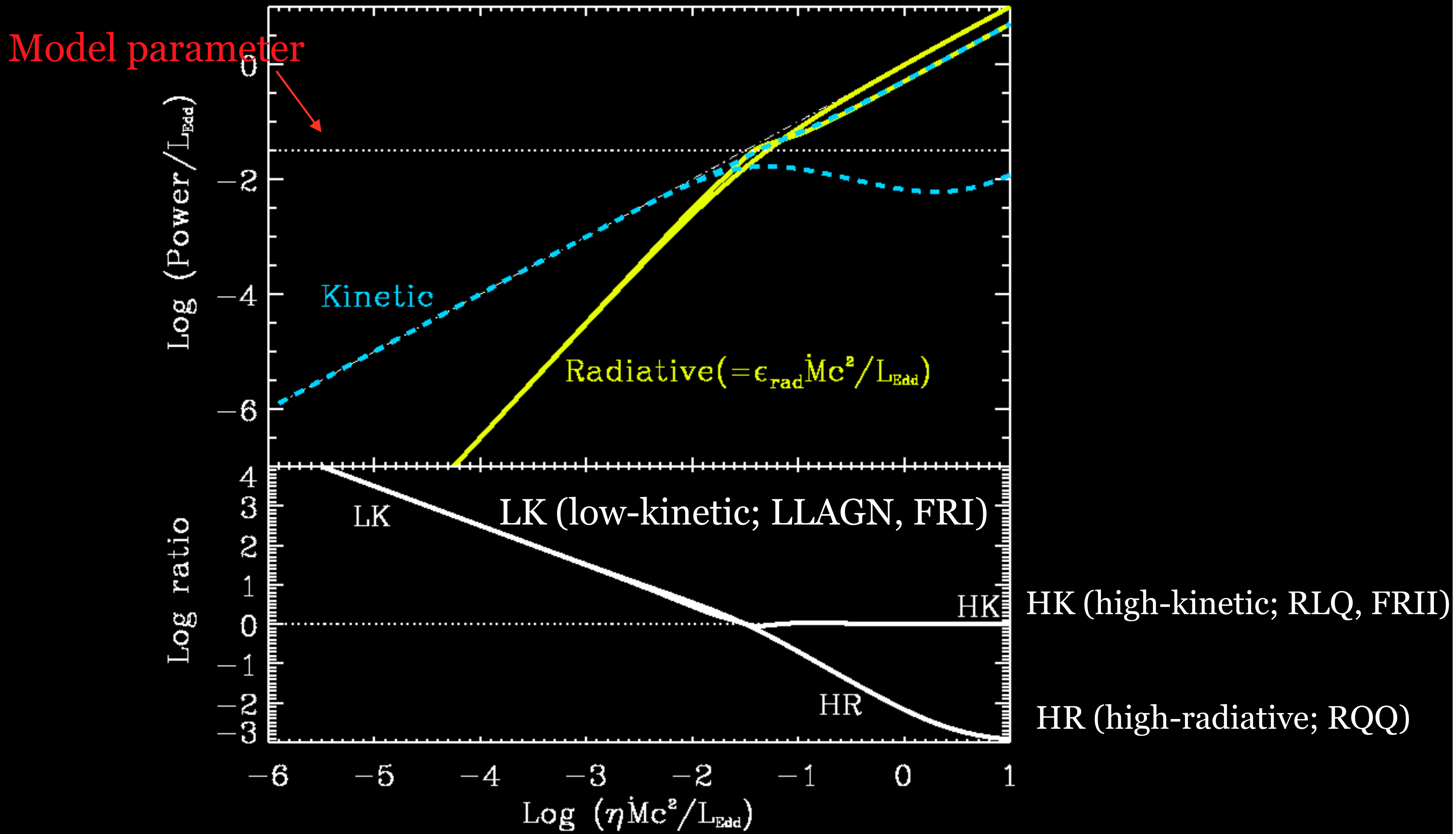
$$L_{KIN} \propto L_R^{0.7-0.8}$$

$$L_{KIN}/L_{EDD} \propto L_X/L_{EDD}^{0.5}$$

Powerful Jets ($L/L_{edd}>0.01$)

$$L_{KIN,Jet} \sim L_{bol}$$

BH Accretion/ejection diagram



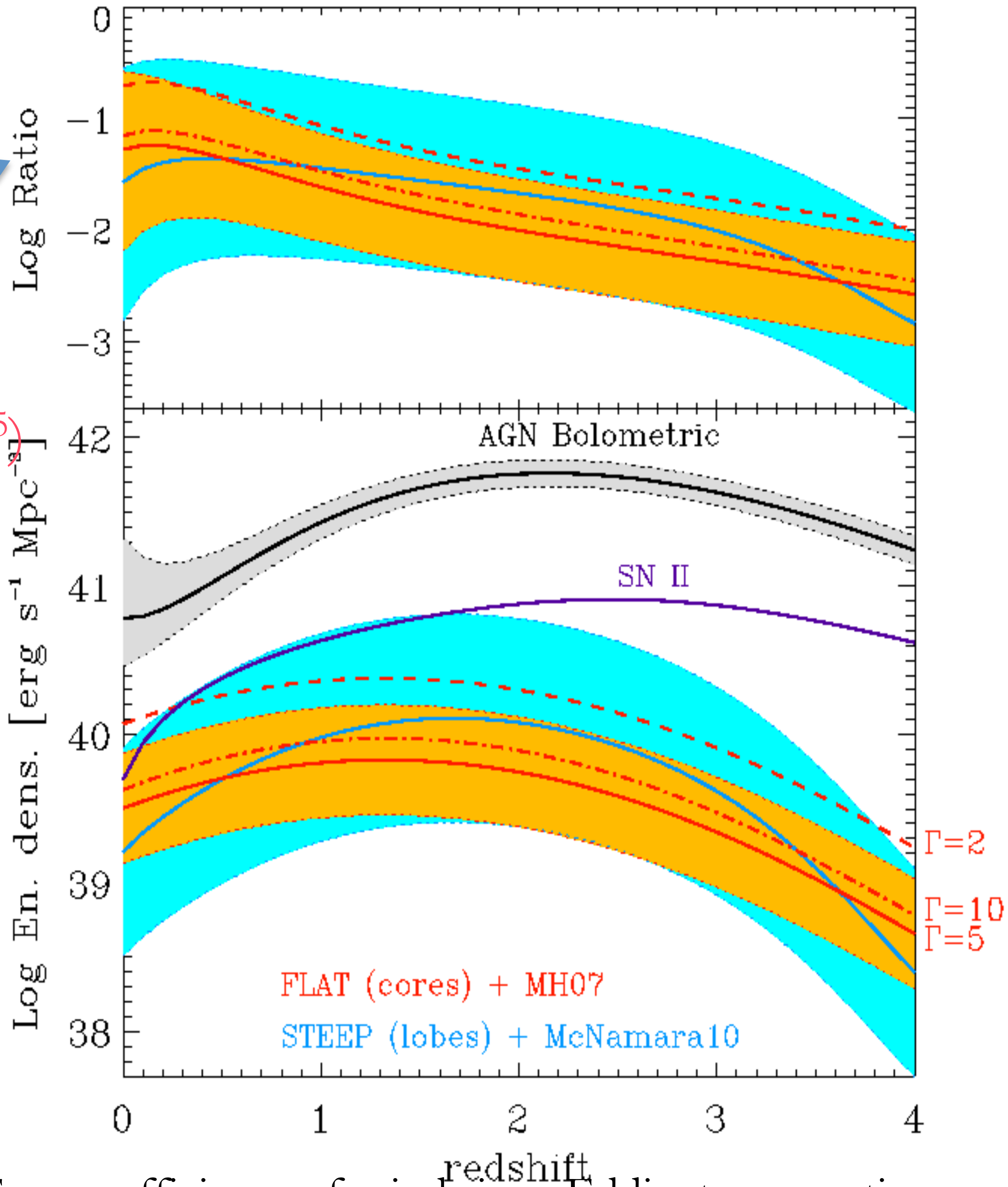
(Blandford & Begelman 1999, Körding et al. 2007, Merloni and Heinz 2008)

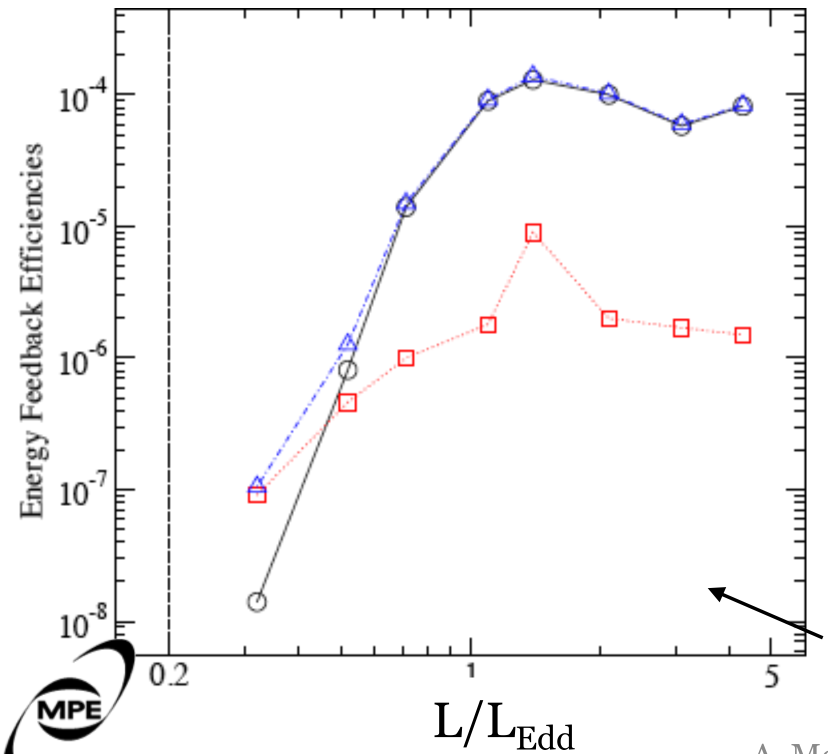
SMBH growth: weighting modes

Kinetic to radiative energy density ratio

$\log L_{kin} = 45.2 \times 0.8 \log (P_{1.4,core} / 10^{25})$

$\log L_{kin} = 44.6 \times 0.7 \log (P_{1.4} / 10^{25})$





Energy efficiency of winds in ~Eddington accretion
Kurosawa et al. 2009

Thank you