Coevolution of Supermassive Black Holes and their host galaxies: open questions and prospects for VLBI

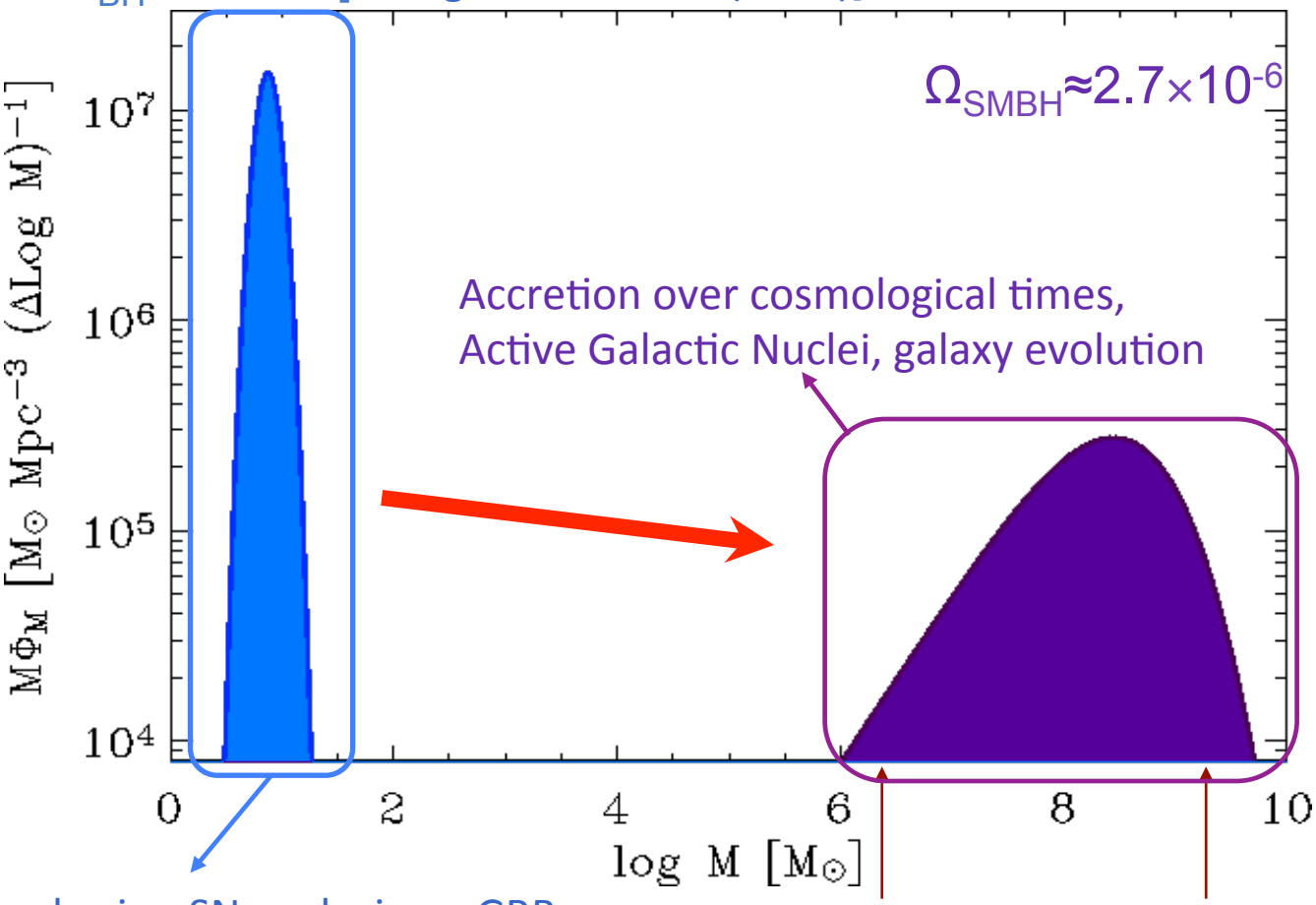
Andrea Merloni (MPE)

Outline

I. Introduction/motivation
II. Exploiting multi-wavelength surveys to unveil the history of accretion onto supermassive black holes
III. Radio surveys and the global history of AGN feedback
IV. The key role of VLBI

Unveiling Black Holes' growth

$\Omega_{*BH} \approx 7\times10^{-5}$ [Fukugita & Peebles (2007)]



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

AGN and cosmology: early developments

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LETTERS TO THE EDITOR

ASTRONOMY

Evidence on the Evolutionary Character of the Universe derived from Recent Red-shift Measurements

Hoyle and Burbidge[1] have recently examined the red-shifts of a number of quasi-stellar radio sources[2,3] and have plotted their radio flux densities (S) against red-shift (z); they conclude that the results are inconsistent with a cosmological interpretation of these red-shifts.

This communication shows that this conclusion is not valid and that indeed the observed relationship between S and z provides valuable new information on the evolutionary nature of the Universe.

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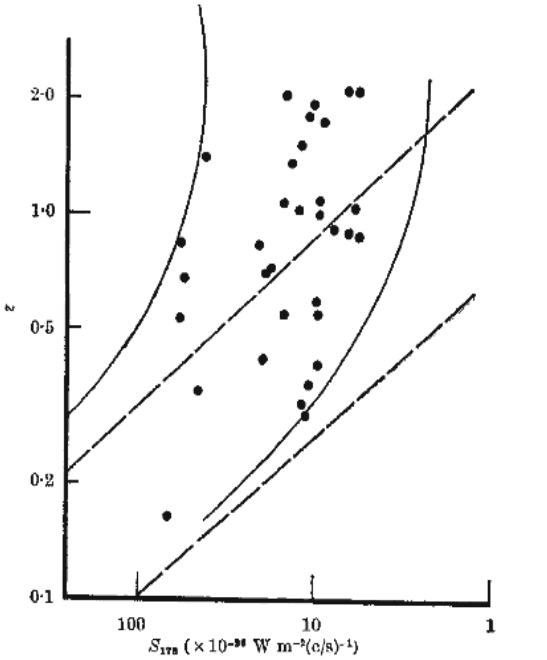


Fig. 1. The red-shift flux density plots expected in evolutionary cosmologies in which density evolution (dashed lines) and luminosity evolution (full lines) are included. The distribution of observational points is that presented by Hoyle and Burbidge restricted to $S_{178} \geqslant 8 \times 10^{-26}$ W m^{-2}(c/s)$^{-1}$.

Longair 1966

A shift of paradigm

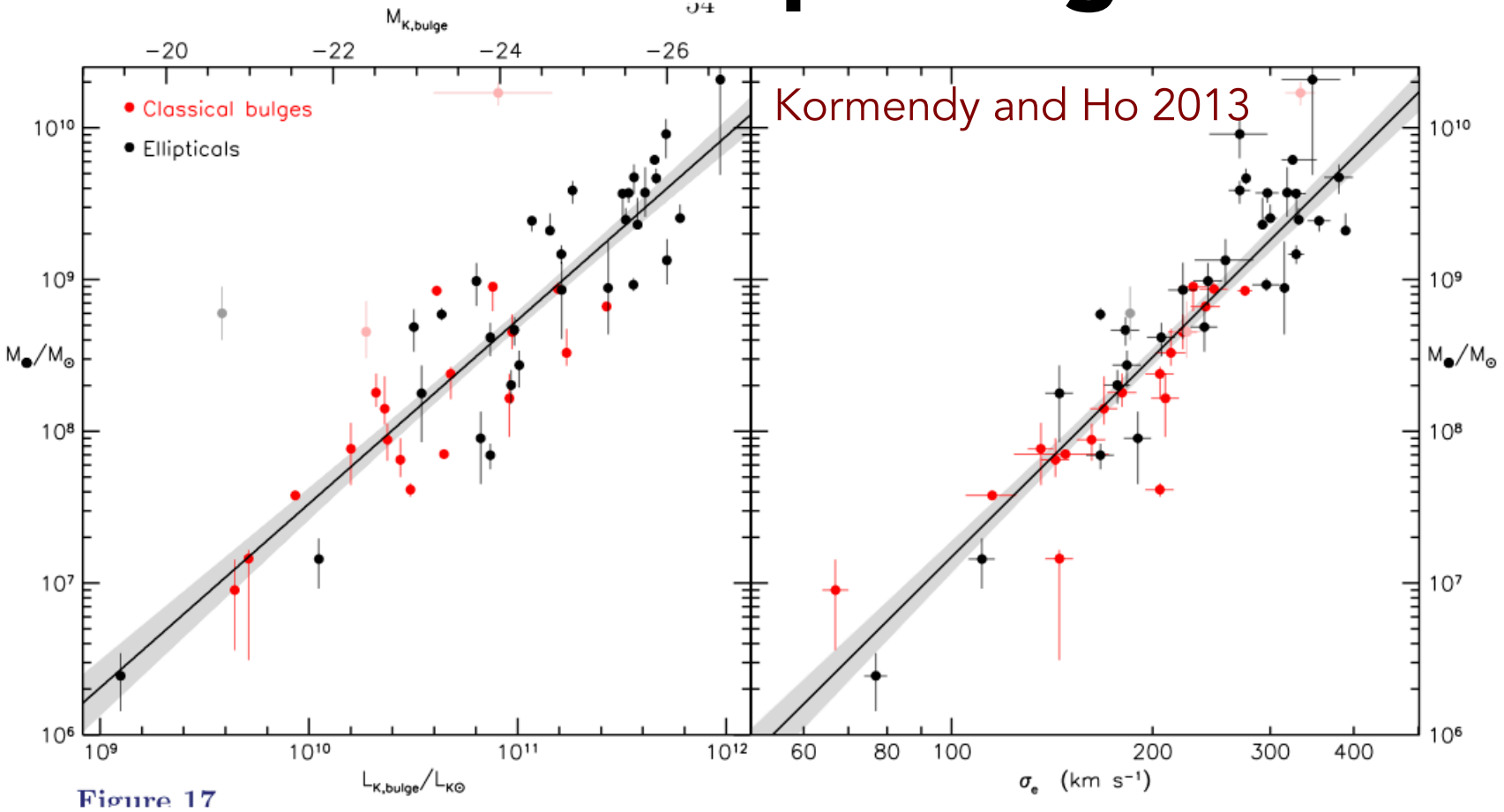


Figure 17

BH/Galaxy Scaling relations discovered in 2000 (HST)

No direct causal connection: hint of a past co-evolution

Gebhardt et al. 2000; Ferrarese et al. 2000; Greene et al. 2005

The theoretical necessity of AGN feedback: a history of failures

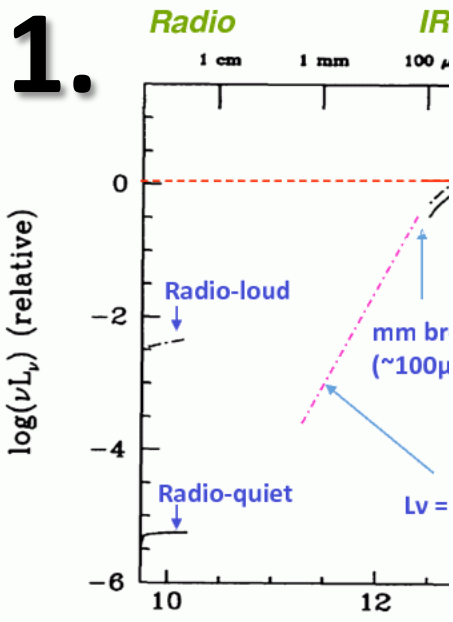
1. Maintain the observed close connection between the growth of SMBH and the growth of galaxies
2. Ensure a tight relation between black hole mass and galaxy mass/velocity dispersion
3. Help establishing the color-bimodality of galaxies
4. Prevent too massive galaxies from forming
5. Solve the cooling flow problem in clusters of galaxies

Part II

Exploiting multi-wavelength surveys to unveil the history of accretion onto supermassive black holes

SMBH census is a matter of contamination

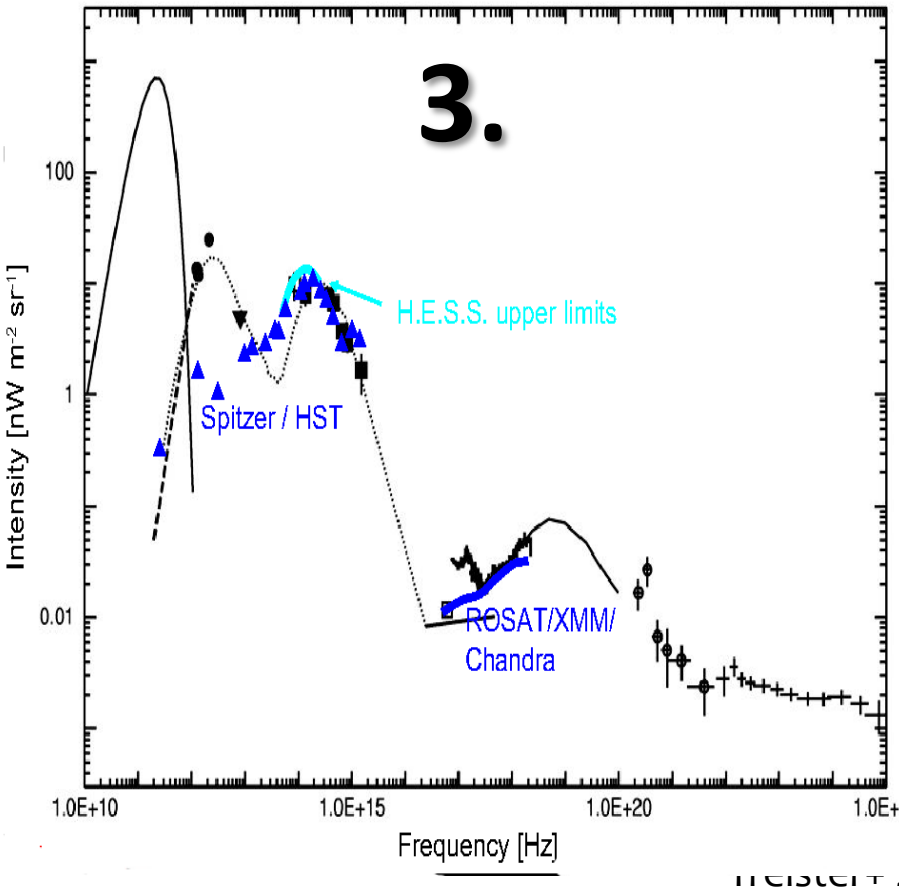
1.



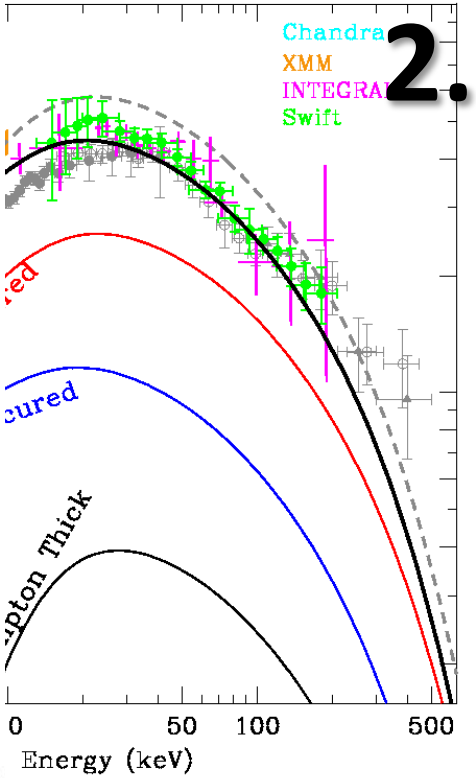
Elvis et al

Richards+

3.



2.



mastri+ 1995, Gilli+2007,

meister+ 2009, Moretti+ 2011

- AGN dominate XRB, but contribute only to ~10% of IRB
- XRB itself is dominated by obscured (and heavily obscured) AGN

AGN selection basics: contrasts

Assume: (1) $M_{BH}/M_* = A_0$; (2) $\log SFR = \alpha(z)(\log M_* - 10.5) + \beta(z)$

(BH-galaxy scaling relation) ("Main sequence" of star formation)

$$\frac{L_{\rm X,AGN}}{L_{\rm X,SF}} \approx 10^5 \lambda\, 10^{-\beta(z)} \left(\frac{f_X}{0.03}\right) \left(\frac{A_0}{0.002}\right) \left(\frac{M_*}{10^{10.5} M_\odot}\right)^{1-\alpha(z)}$$

$$\frac{L_{\rm 1.4GHz,AGN}}{L_{\rm 1.4GHz,SF}} \approx 10^{5.6} \left(\frac{\eta_j}{\epsilon}\lambda\right)^{1.16} 10^{-\beta(z)} \left(\frac{M_*}{10^{10.5} M_\odot}\right)^{1.16-\alpha(z)}$$

$$\frac{L_{\rm IR,AGN}}{L_{\rm IR,SF}} \approx 160 \lambda\, 10^{-\beta(z)} \left(\frac{f_{24}}{0.1}\right) \left(\frac{A_0}{0.002}\right) \left(\frac{M_*}{10^{10.5} M_\odot}\right)^{1-\alpha(z)}$$

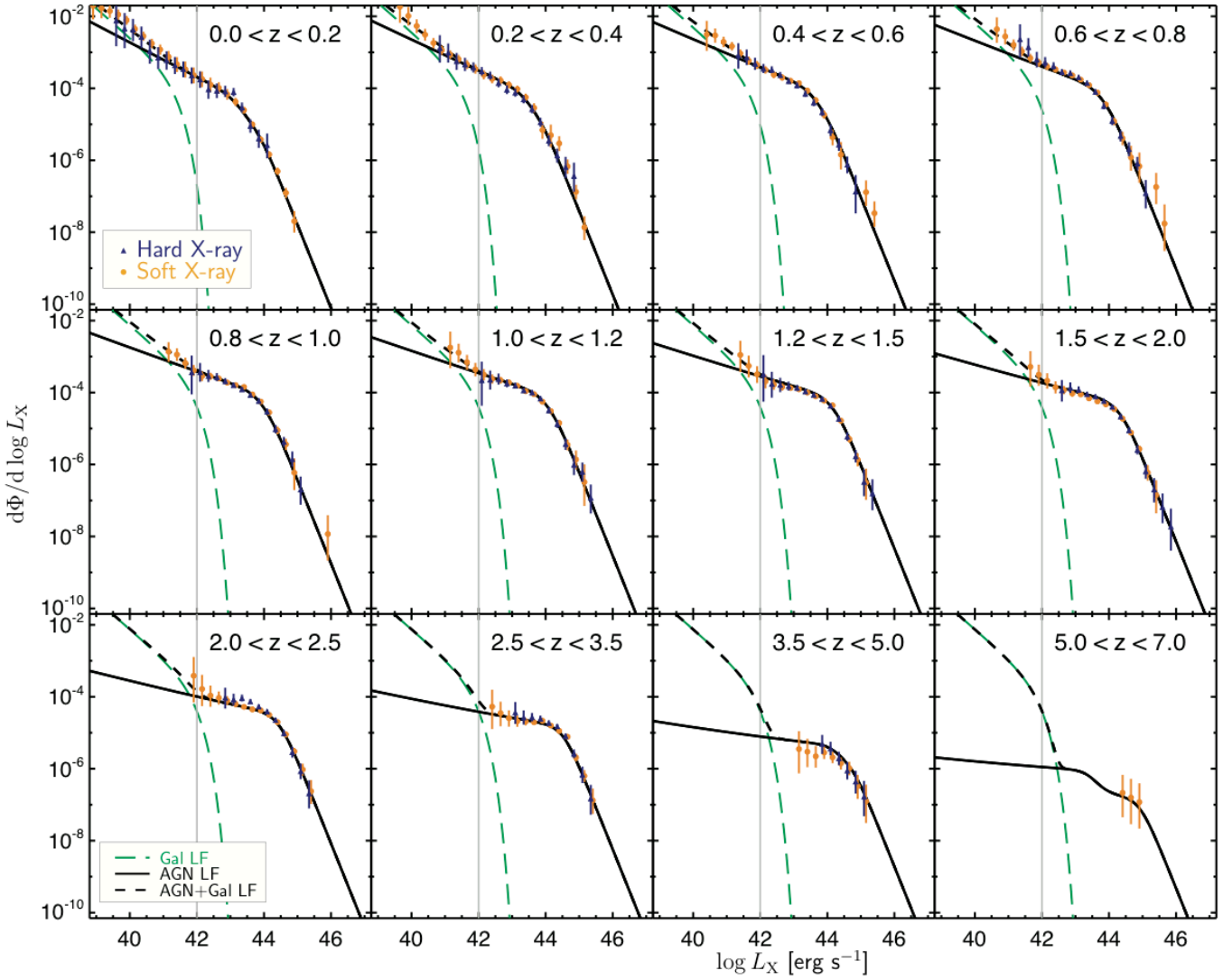
$$\frac{L_{\rm B,AGN}}{L_{\rm B,host}} = 39 \lambda \left(\frac{f_{\rm B}}{0.1}\right) \left(\frac{A_0}{0.002}\right) \frac{(M_*/L_{\rm B})_{\rm host}}{3(M_\odot/L_\odot)}$$

Merloni (2016)

AGN selection basics: contrasts

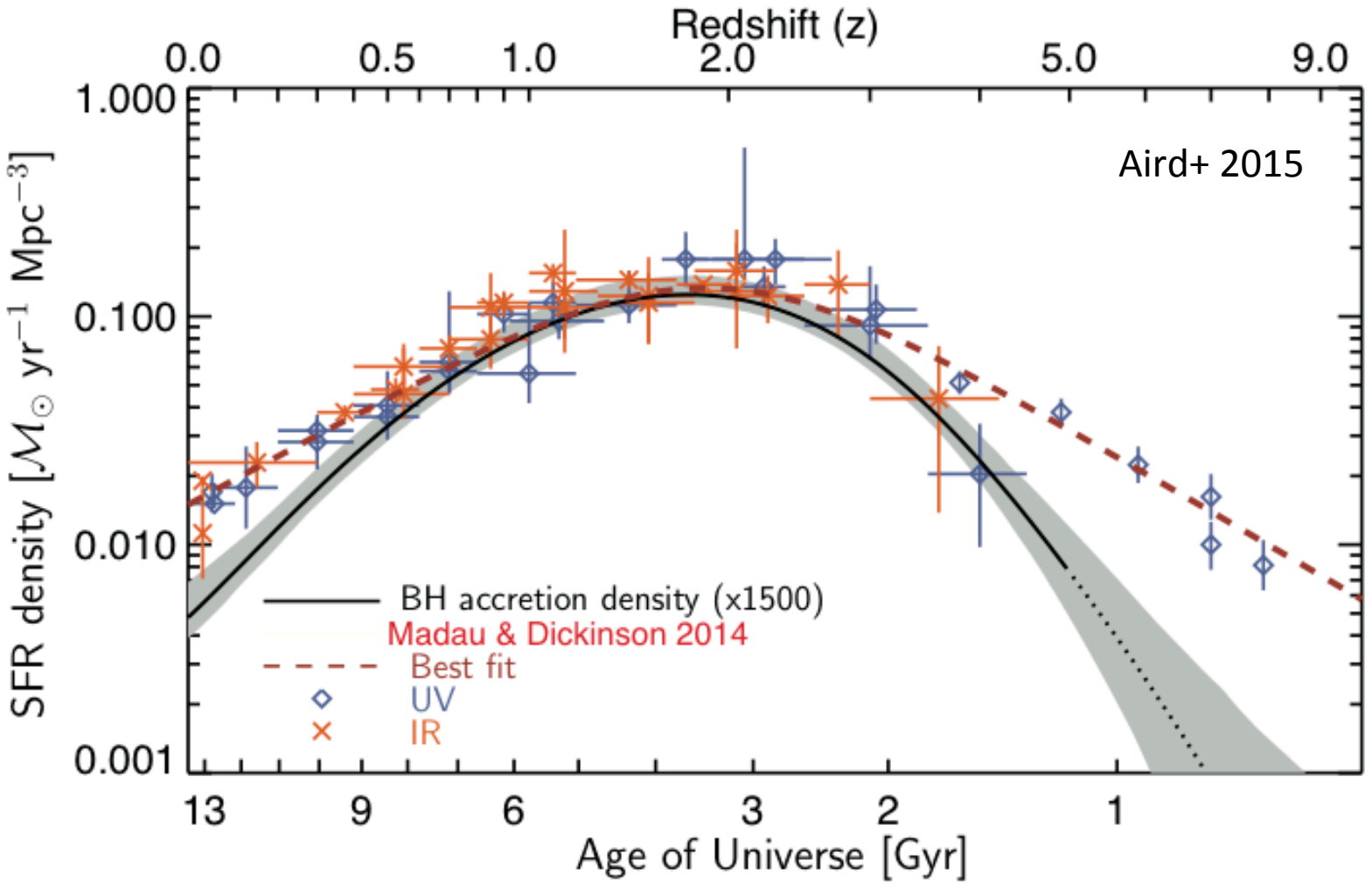
	Critical Eddington rate [$M^* = 10^5\ M_{sun}$]		"visible fraction
	z=0	**z=1**	
X-ray	$\approx 2*10^{-5}$	$\approx 2*10^{-4}$	~ 80%
Radio ($\eta_j=\varepsilon$)	$\approx 3*10^{-5}$	$\approx 2*10^{-4}$	ALL? 10%?
MIR	≈ 0.015	≈ 0.13	ALL
Opt/UV	≈ 0.025	≈ 0.2	<50%

X-ray luminosity function



Aird et al 2015; Buchner et al. 2015; Ueda et al. 2014; Miyaji et al. 2015

BH accretion vs. Star Formation

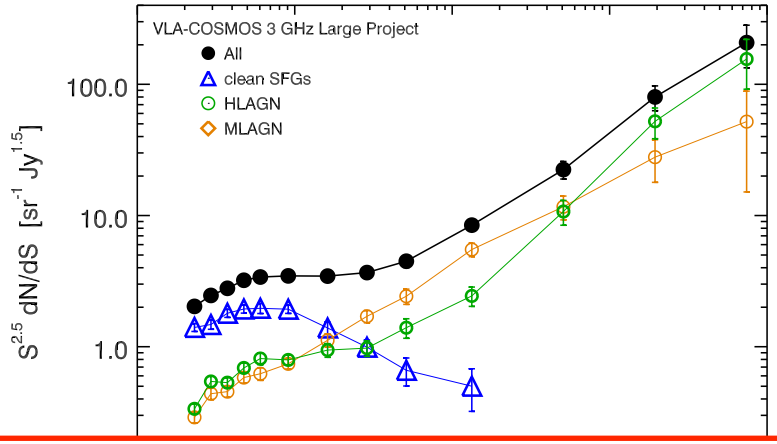


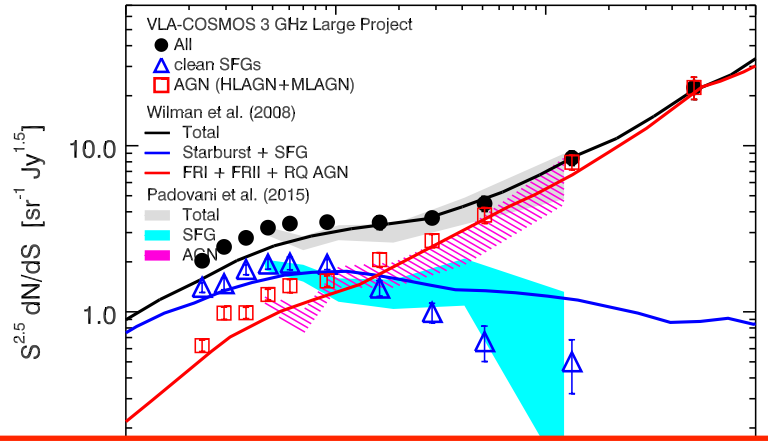
Ueda+ 2003; Marconi+ 2004; Merloni & Heinz 2008; Ueda+ 2014; Delvecchio+ 2014; Buchner+ 2015; Myiaji+ 2015

Part III

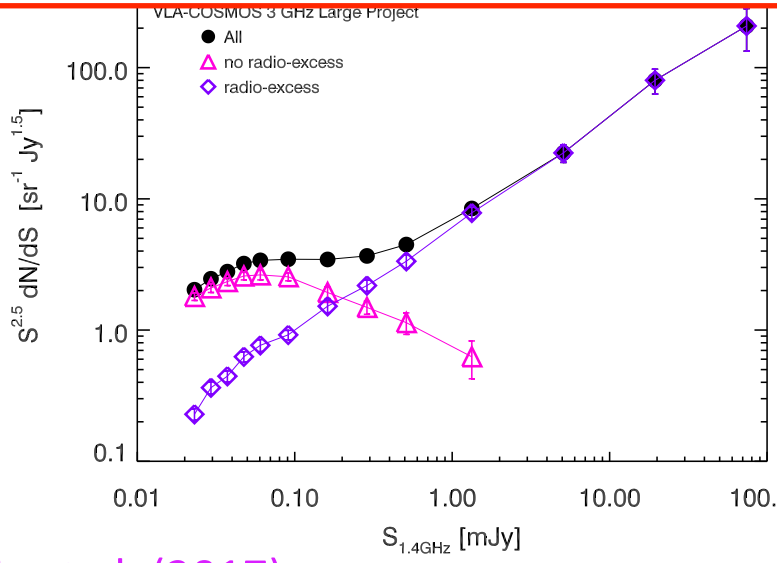
Radio surveys and the global history of AGN (kinetic) feedback

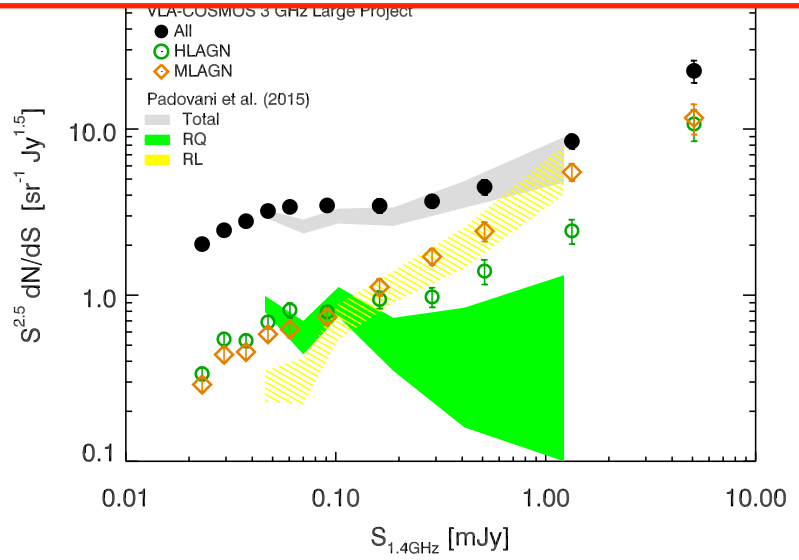
The sub-mJy population





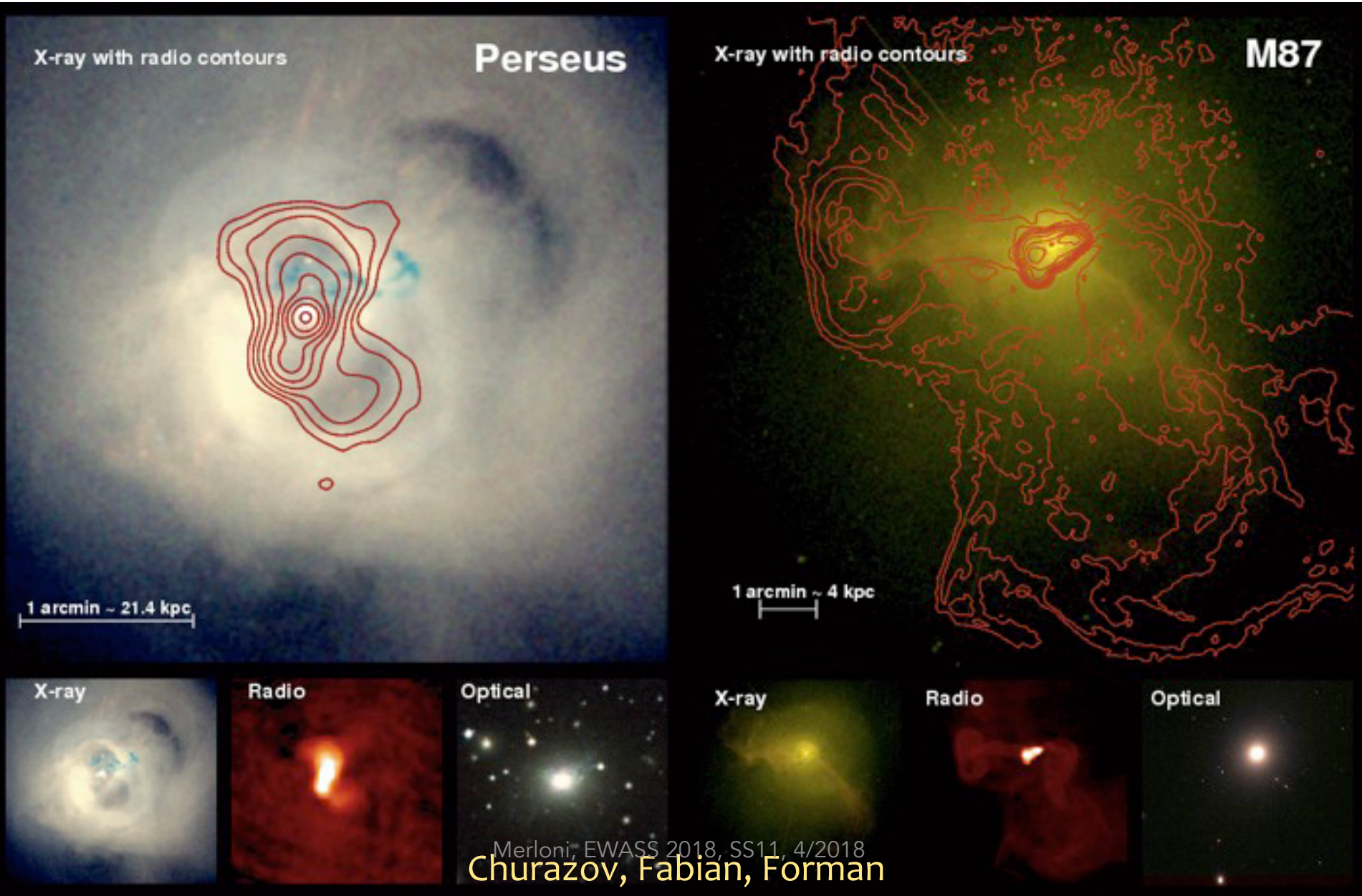
Disentangling the contribution of weak "jetted" AGN vs. Star-formation in RQ AGN is critical!





Smolcic et al. (2017)

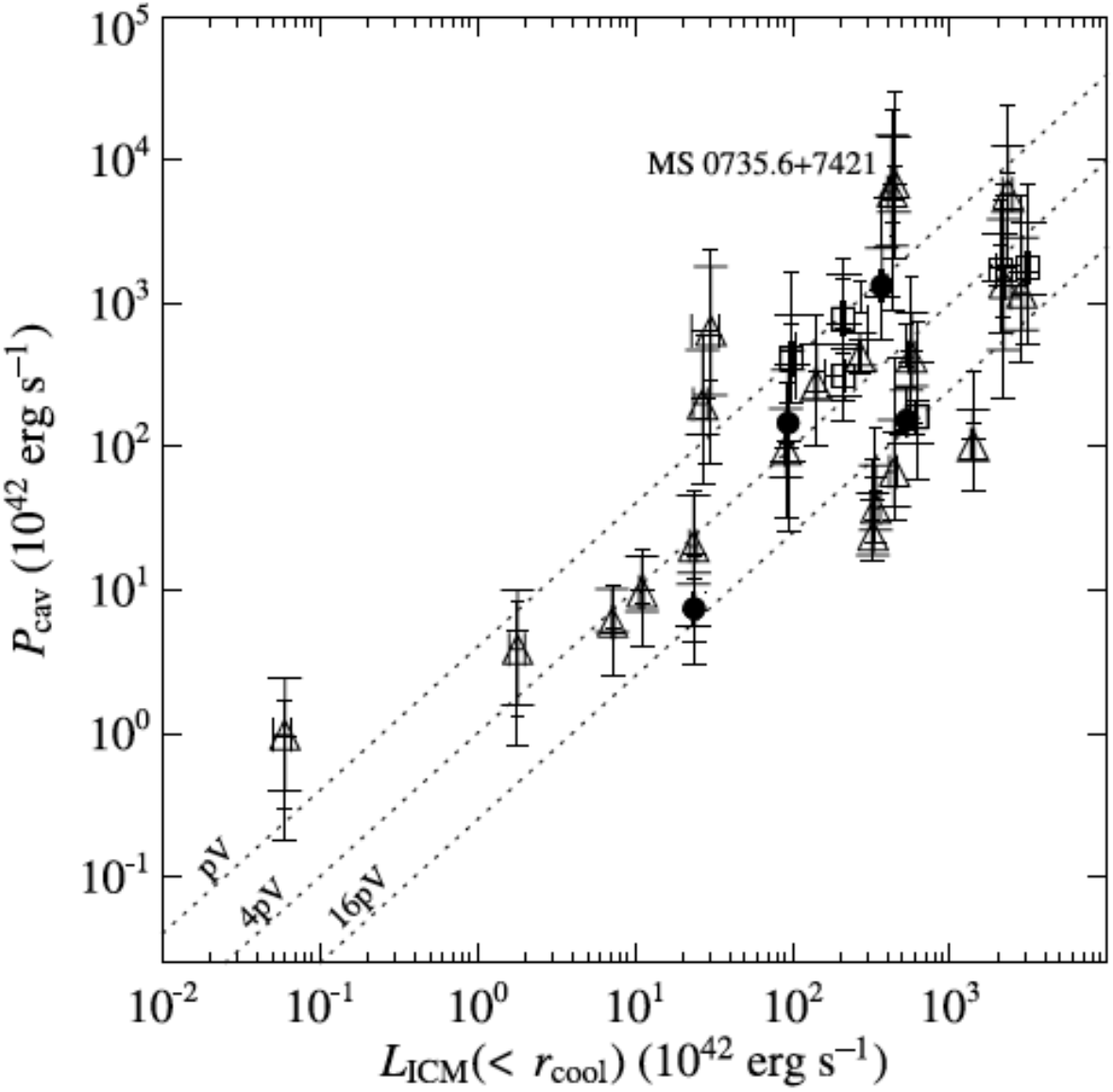
Low-power AGN: jet-disc connection



Merloni, EWASS 2018, SS11, 4/2018

Churazov, Fabian, Forman

PdV work vs. cooling luminosity



Rafferty+06

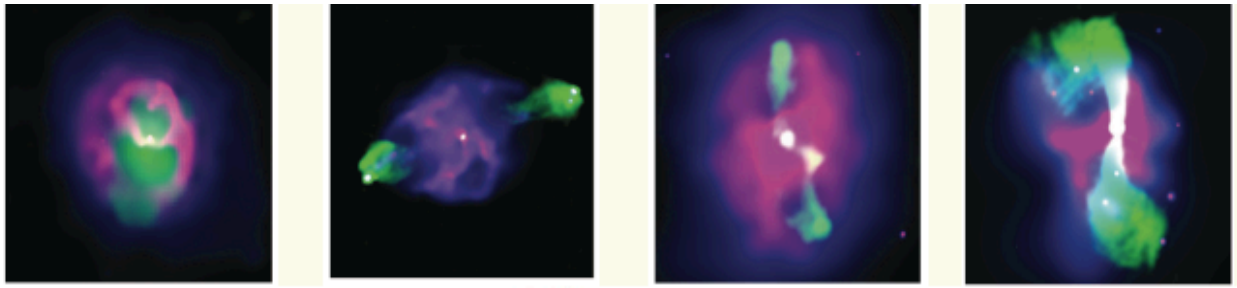
- Relatively tight balance between heating and cooling
- High "efficiency" of AGN heating might require (for extreme objects) spin powering of Jets (McNamara et al. 2011)

What is the right proxy for Jet power?

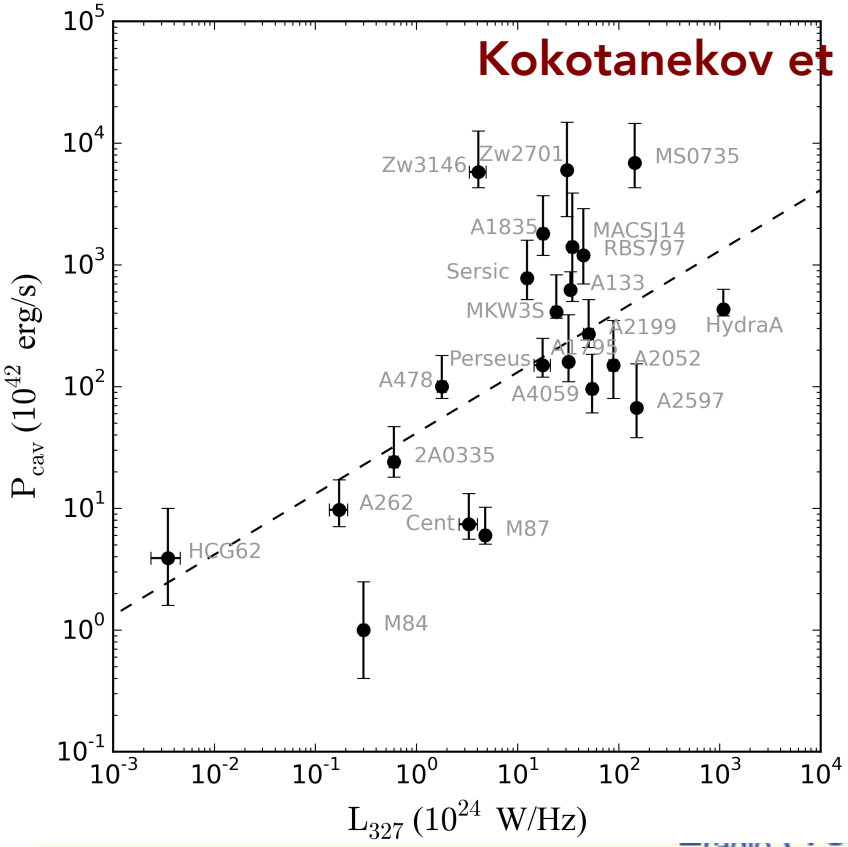
- Measuring PdV work done by the jets in carving the bubbles in the Intra-Cluster Medium is very hard (need lots of X-ray photons)
- It would be nice to have a cheaper way to estimate kinetic jet powers: can radio luminosity help?

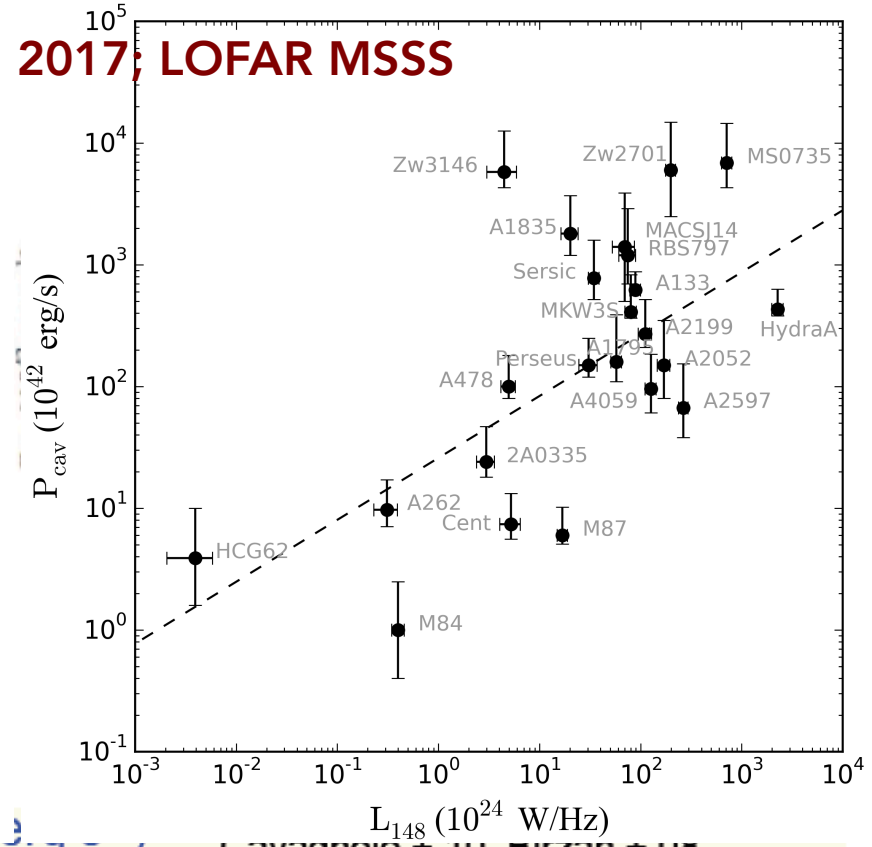
Extended Radio/L_{Kin} relation

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



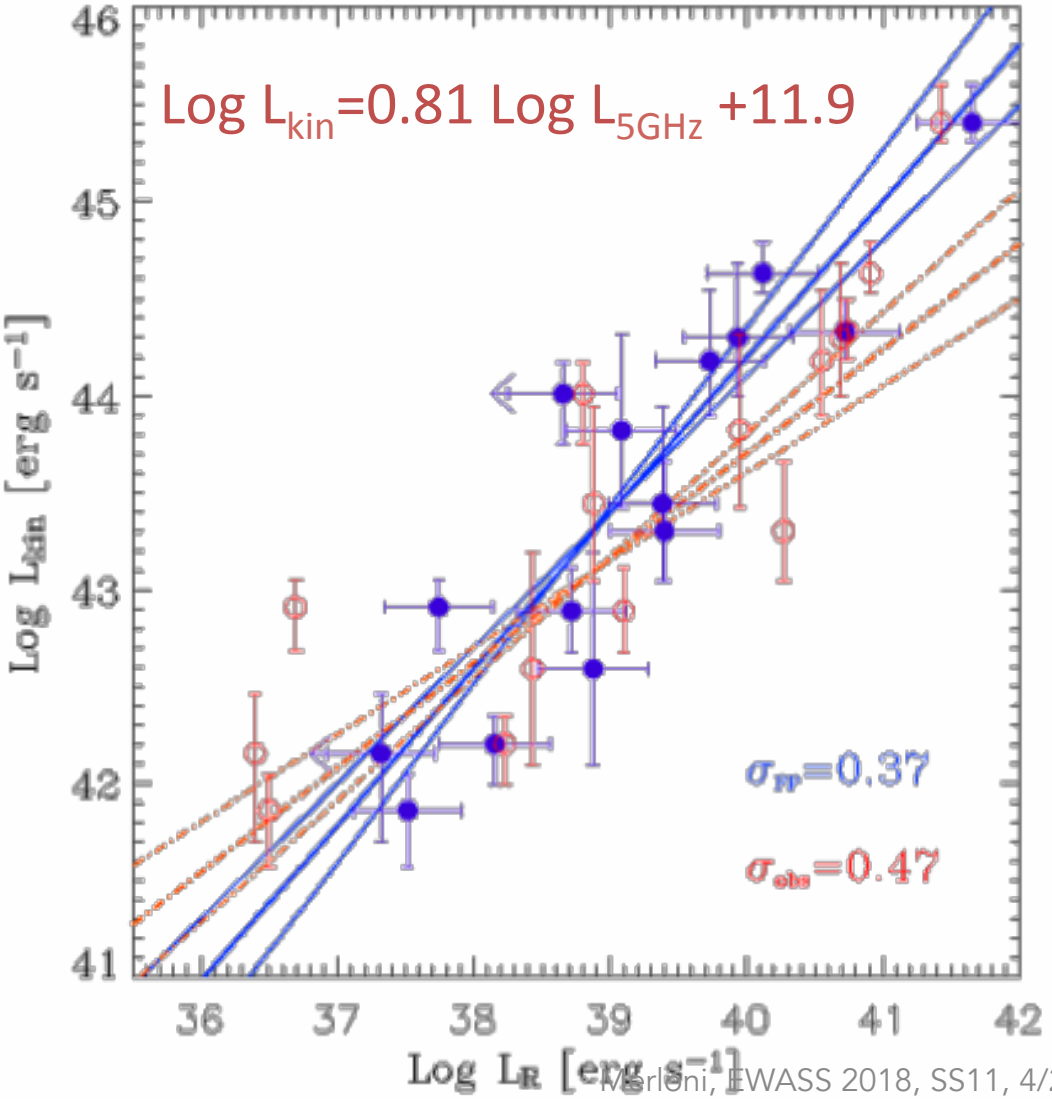
Kokotanekov et al. 2017; LOFAR MSSS





Cavagnolo + 10, Birzan + 08

Core Radio/L_{Kin} relation

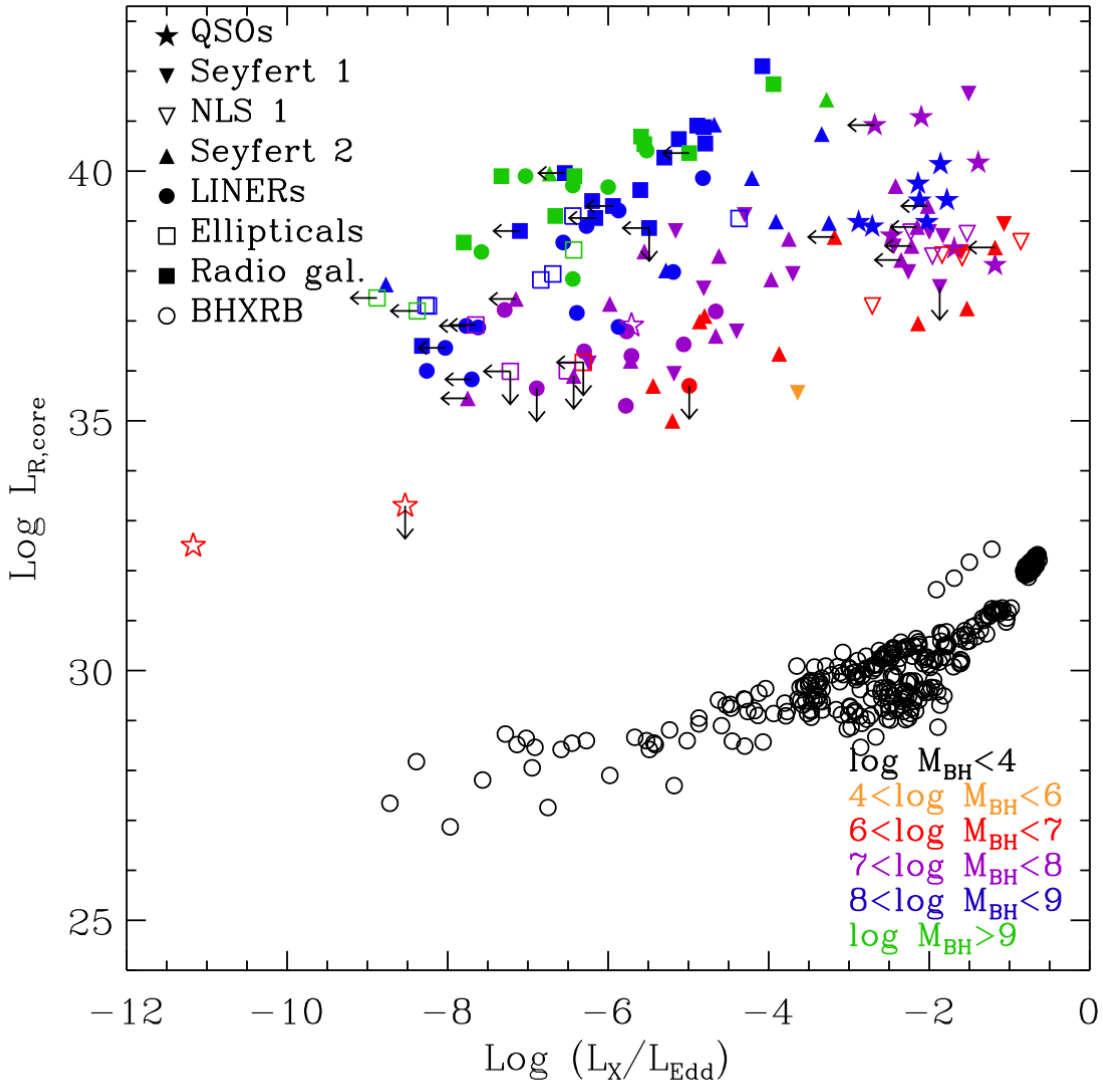


Observed L_R (beaming)
Derived from FP relation

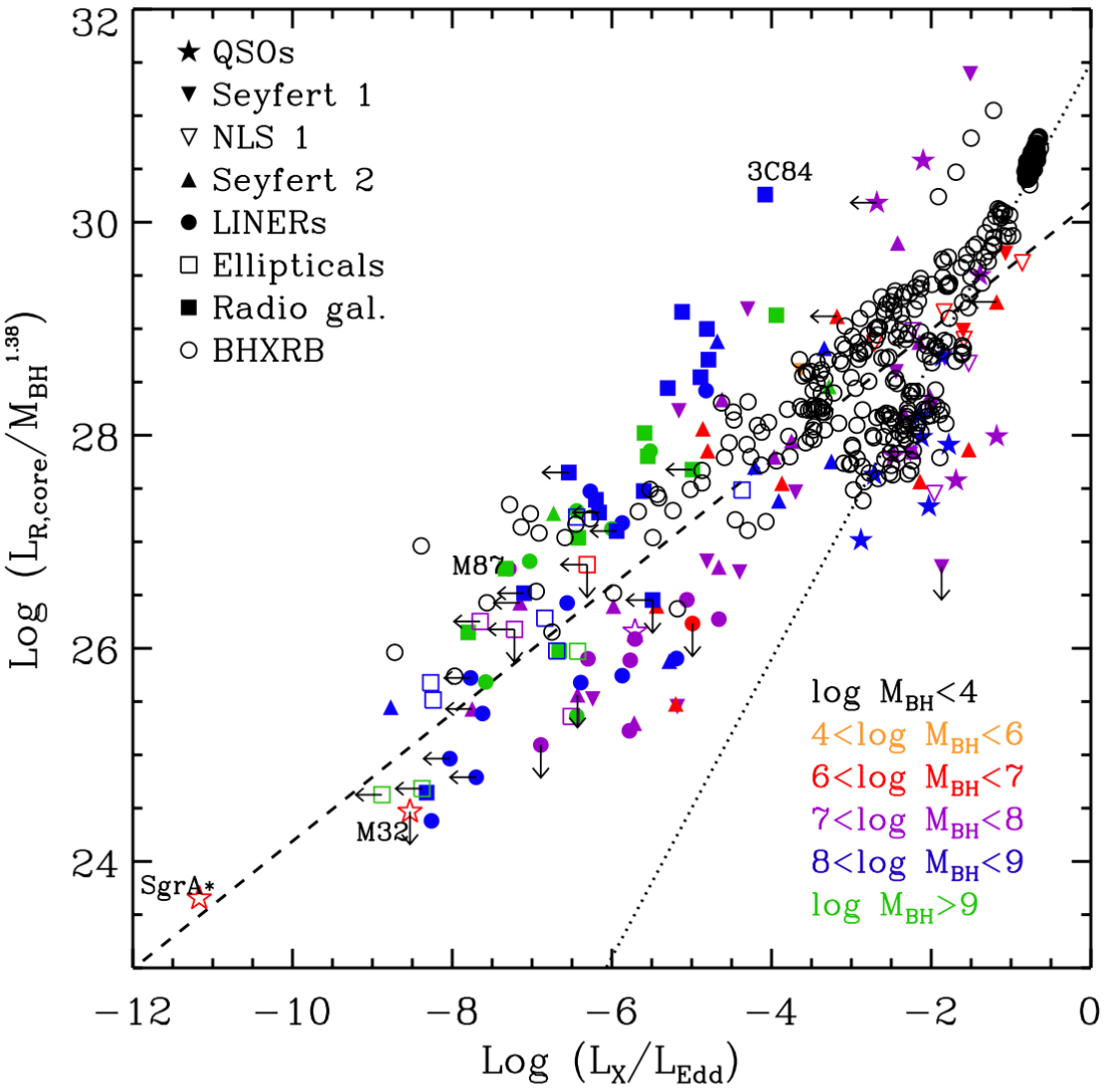
Monte Carlo simulation:
Statistical estimates of
mean Lorentz Factor Γ~7

Merloni and Heinz (2007)

Jet-disc connection

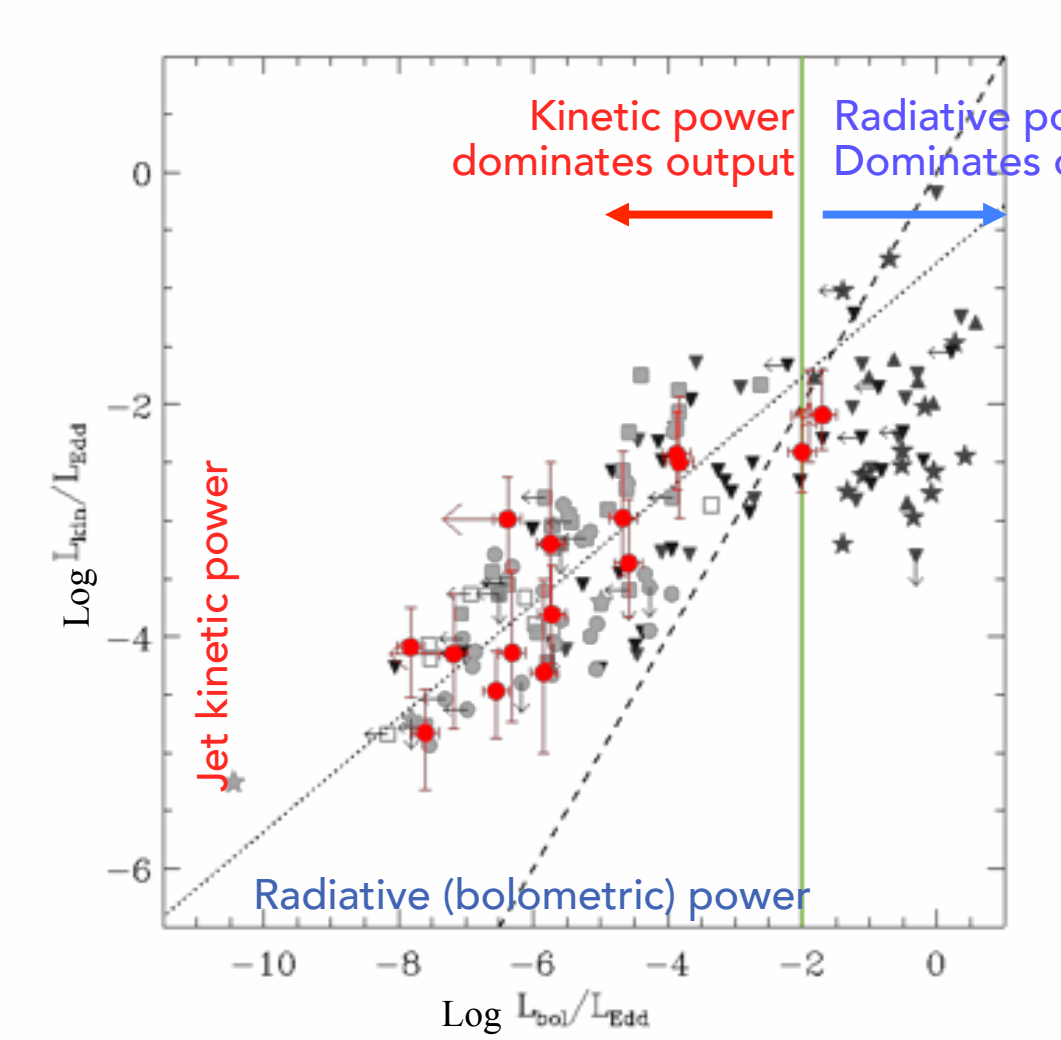


Jet-disc connection



A "fundamental plane" of active BHs [Merloni+ 2003; Falcke+ 2004]

Low-Power AGN are jet dominated



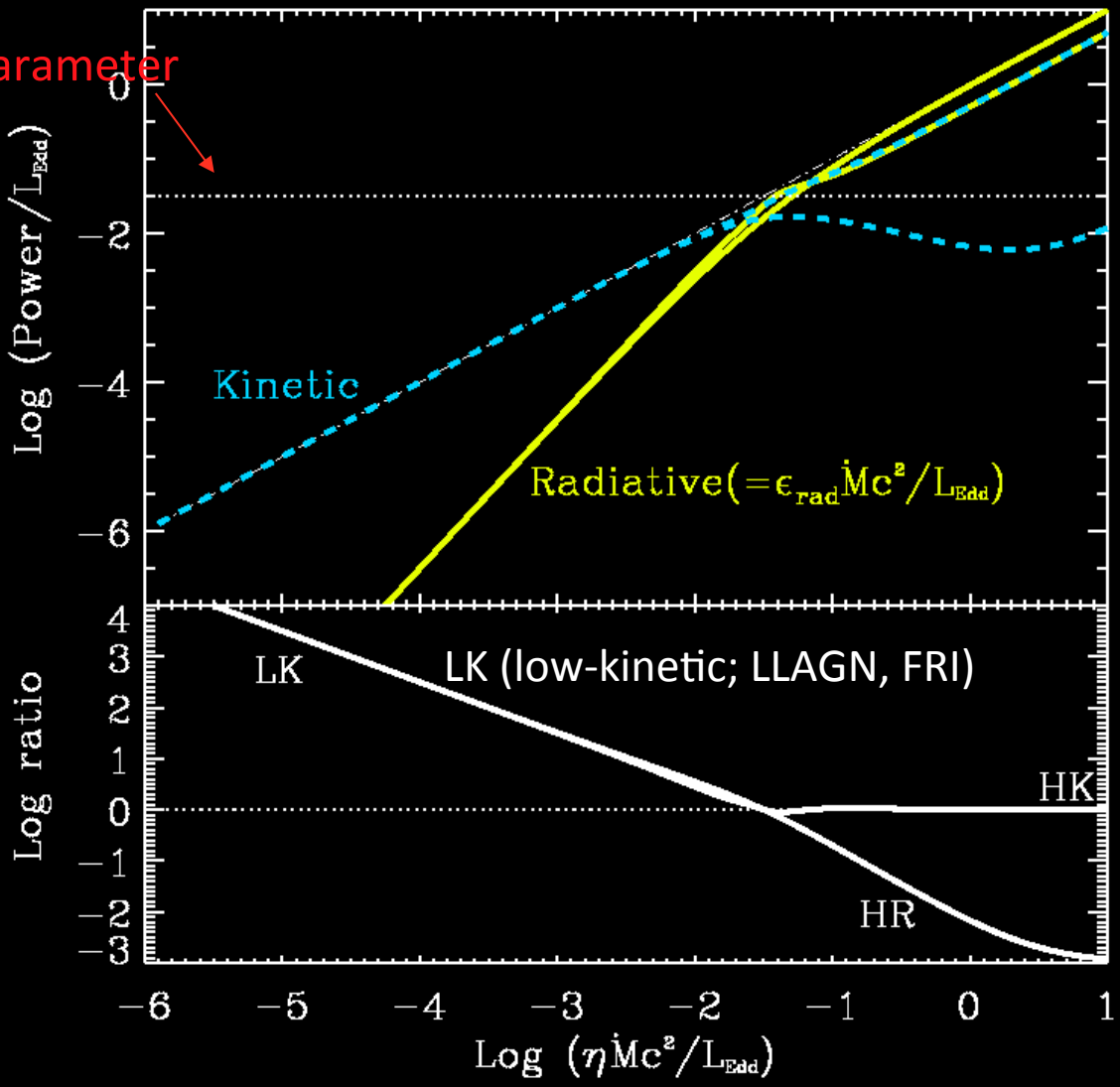
$L_{kin}/L_{edd}=0.16*(L_{bol}/L_{edd})^{0.49}$

From observations to a theoretical accretion diagram:

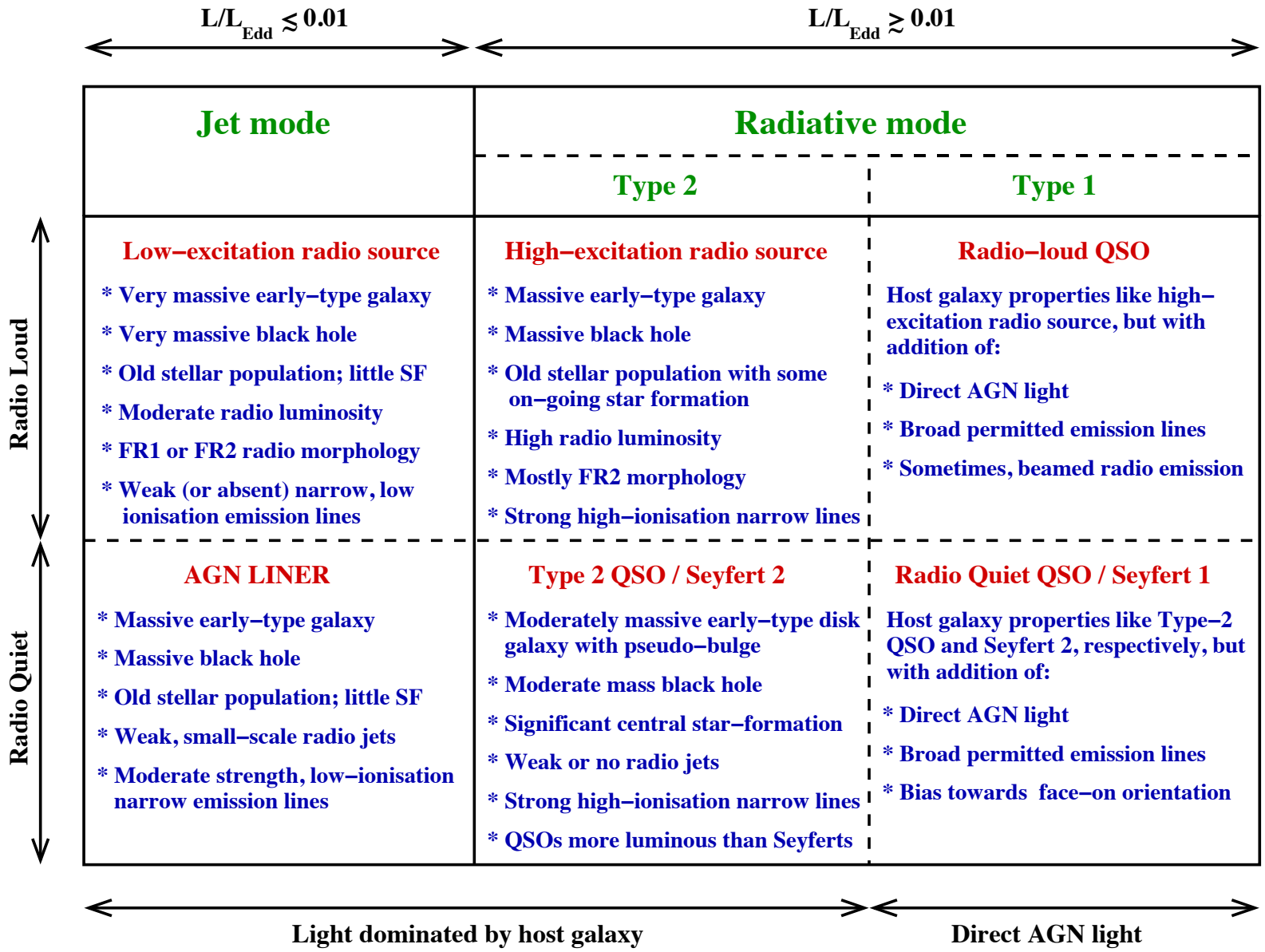
Clues on the physics of "adiabatic", radiative inefficient accretion modes

Merloni et al. 2003
Merloni & Heinz 2007

Accretion diagram for LMXB & AGN



(Körding et al. 2007; Churazov et al. 2005; Merloni and Heinz 2008)

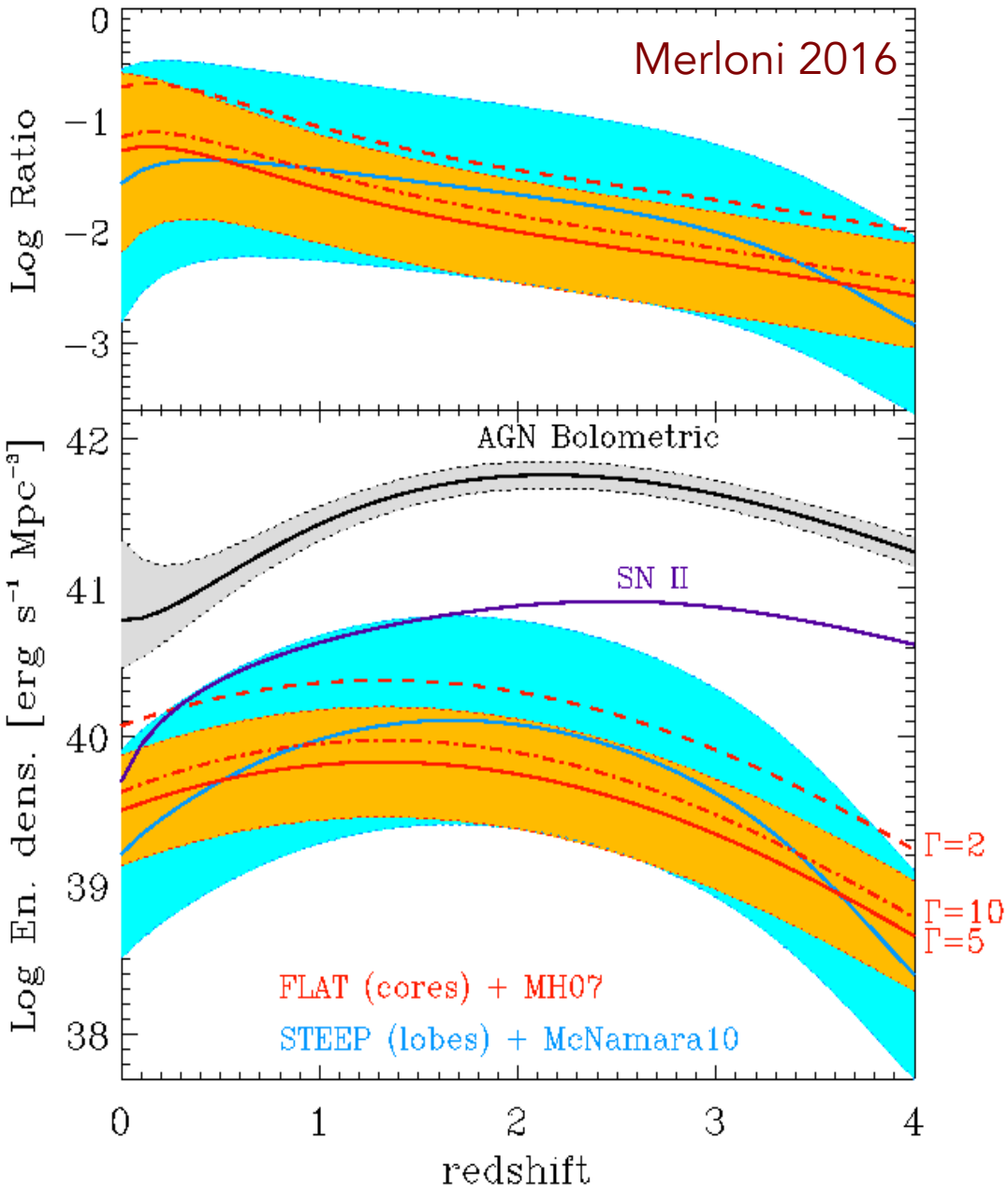


Heckman & Best 2014

SMBH growth: weighting modes

Log L_{kin}= 45.2 x 0.8 Log(P_{core} /10^{25})
(Merloni & Heinz 2007)

Log L_{kin}= 44.6 x 0.7 Log ($P_{1.4}$ /10^{25})
(Cavagnolo 2010, "cavity power")

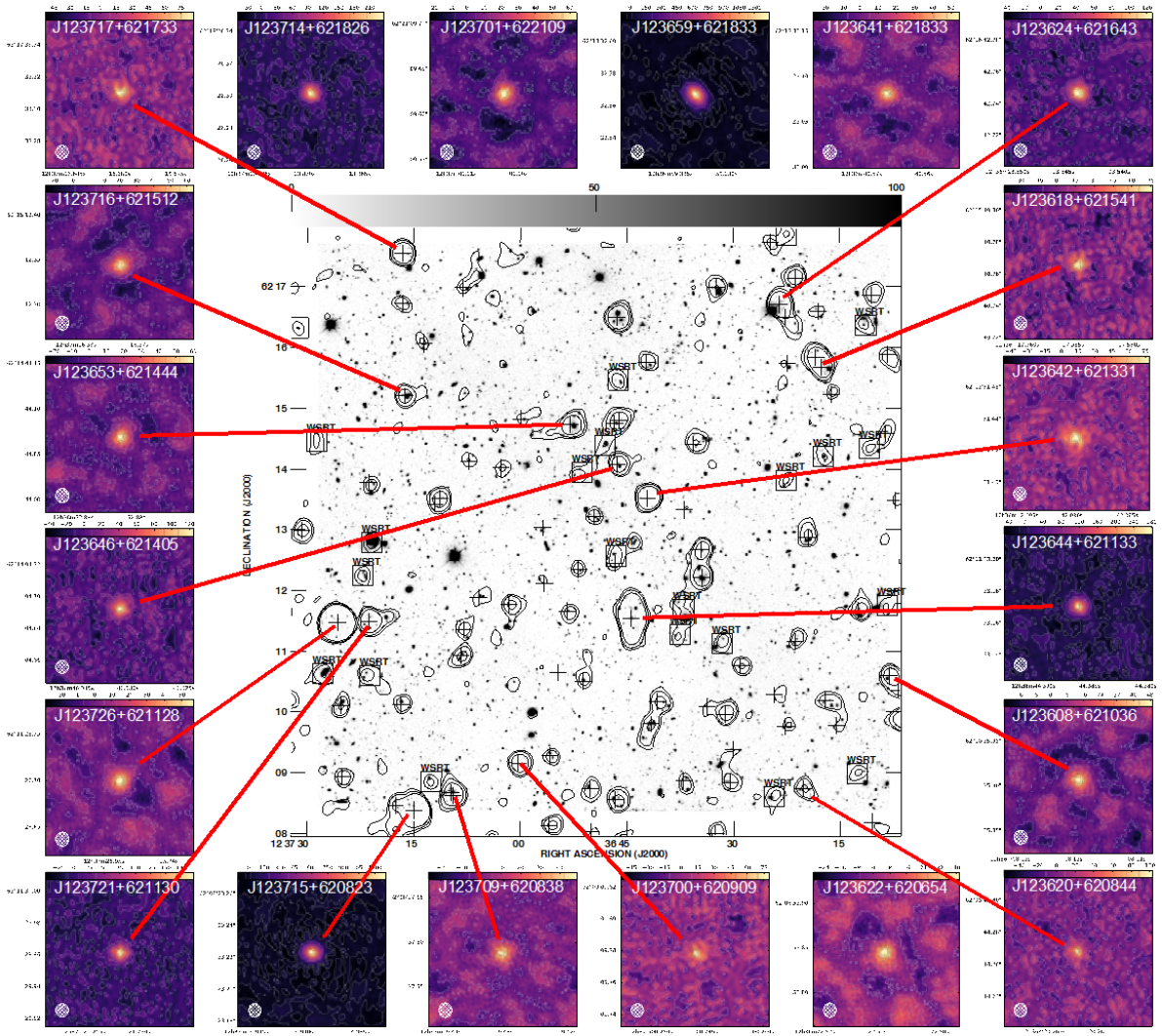


Heinz, Merloni and Schwaab (2007);
Körding, Jester and Fender (2007);
Merloni & Heinz (2008); Cattaneo and Best (2009); Smolcic et al. 2017

IV: The key role of VLBI

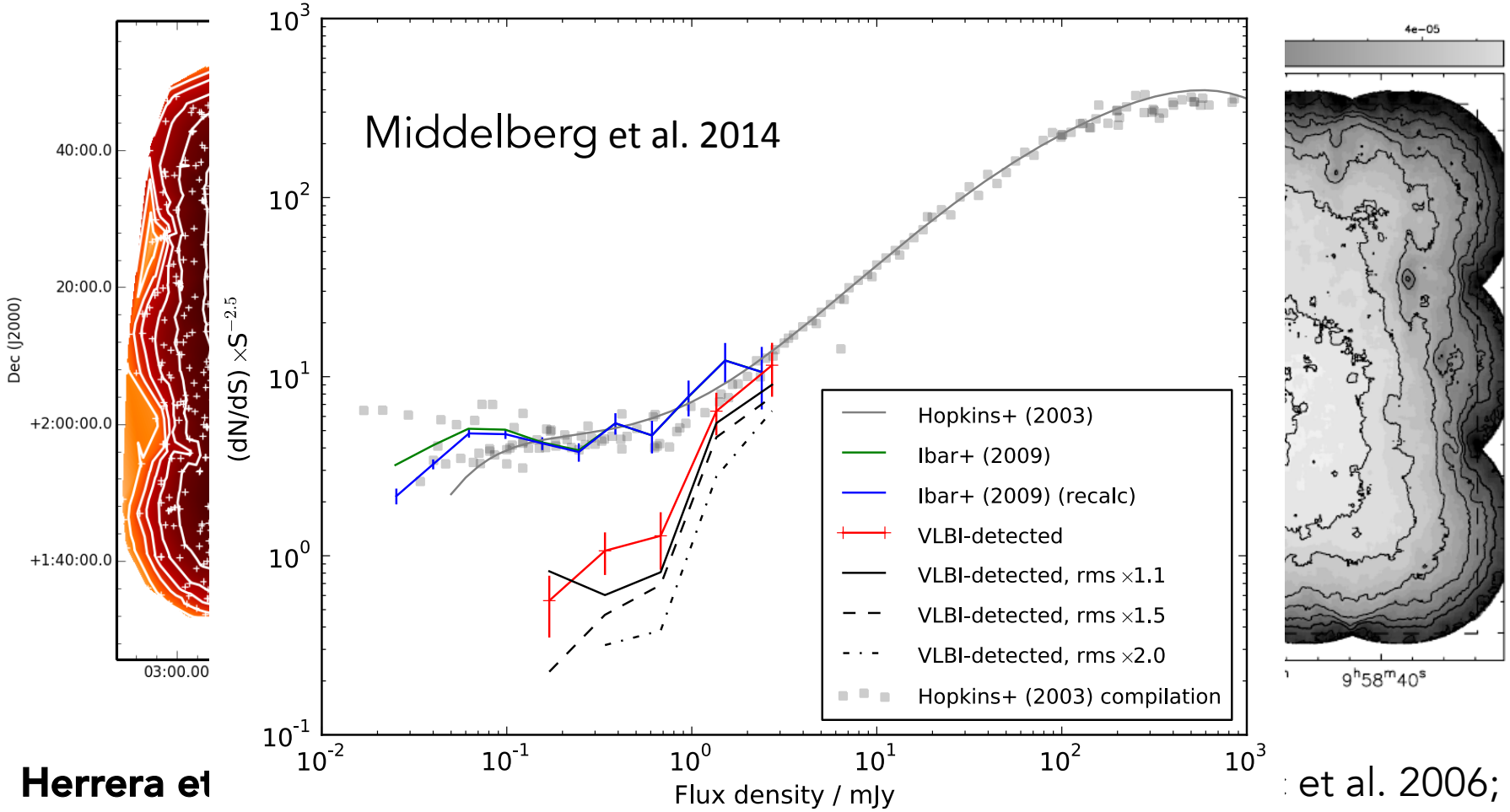
- Deep VLBI -> Jet physics (acceleration, collimation, energetics, Lorentz factors distribution)
- Wide VLBI-> unambiguous identification of jetted AGN in sub-mJy population

Wide Field VLBI



Radcliffe et al. 2016

Wide Field VLBI



Herrera et et al. 2006; Middleberg et al. 2011 [CDFS]; Middelberg et al. 2013 [Lockman Hole]; Cao et al. 2014 [Stripe 82]; Deller & Middleberg 2014 [mJIVE-20]; Radcliffe et al. 2016 [HDFN, HFF]

Conclusions

I. Deep radio surveys provide a key complement to X-ray (and optical/IR) surveys to probe the history of SMBH growth
II. High resolution (~mas) radio images are probably the least confused AGN tracer, down to extremely small Eddington rates
III. Too many uncertainties in jet physics/ acceleration prevent a robust assessment of overall energetics
IV. High-sensitivity, wide field VLBI shall become a key component of AGN surveys, as we probe deep into the high redshift populations and we seek clues to understand AGN-galaxy coevolution