The physical state of radio-mode, low-luminosity AGN

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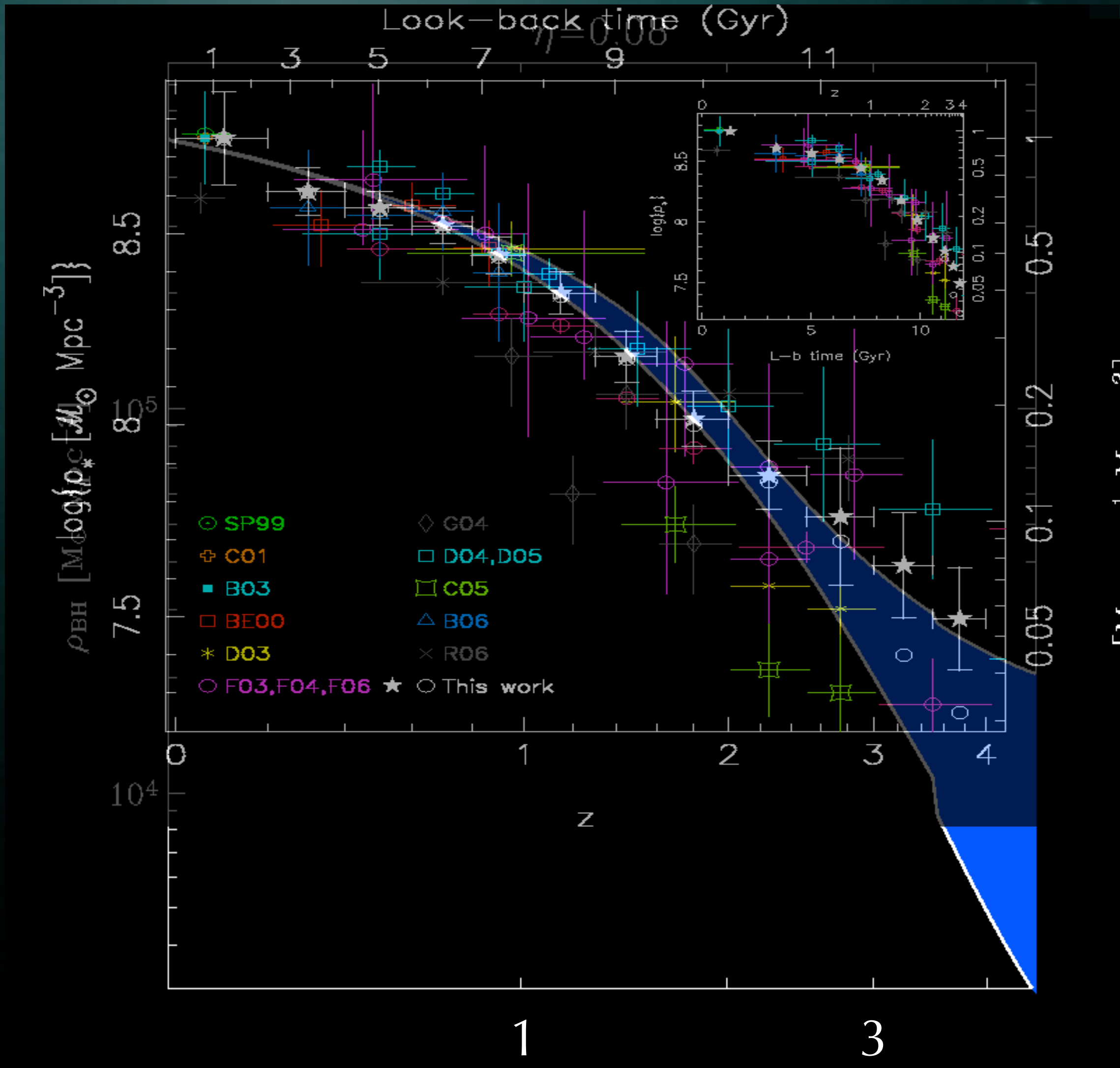
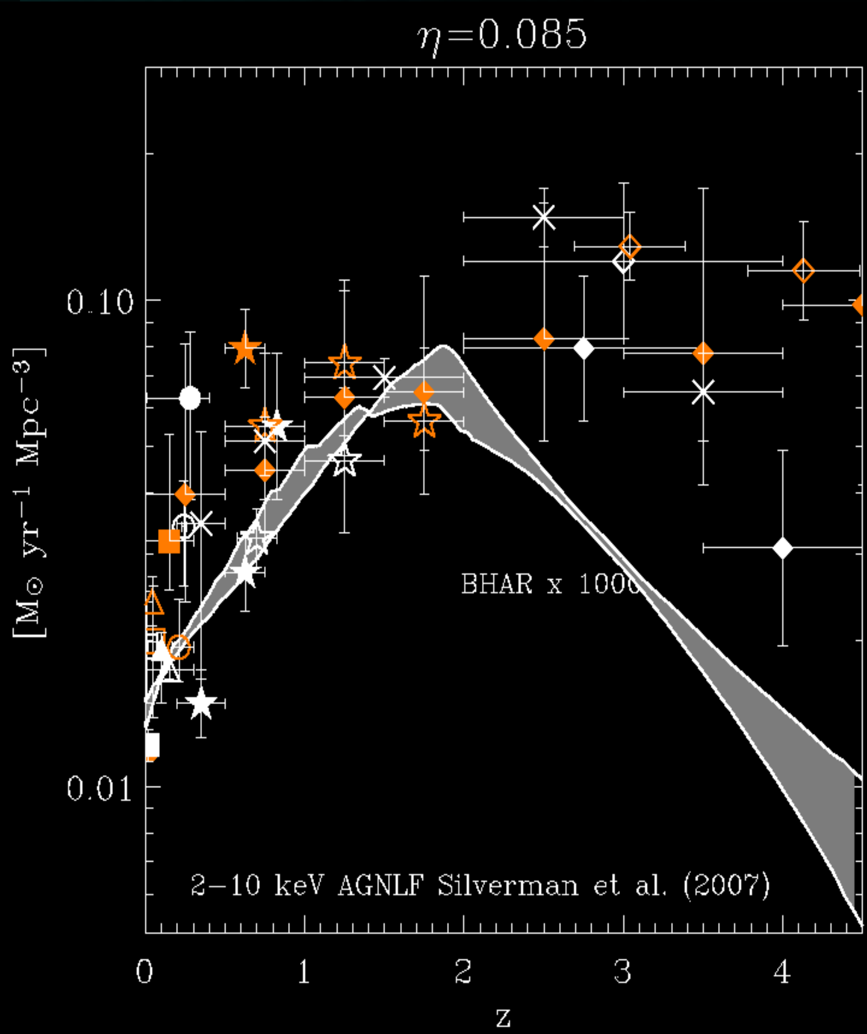
5GHz, VLA image of Cyg A by R. Perley

PhiGN start-up workshop, 14/12/2007

Parallel lives

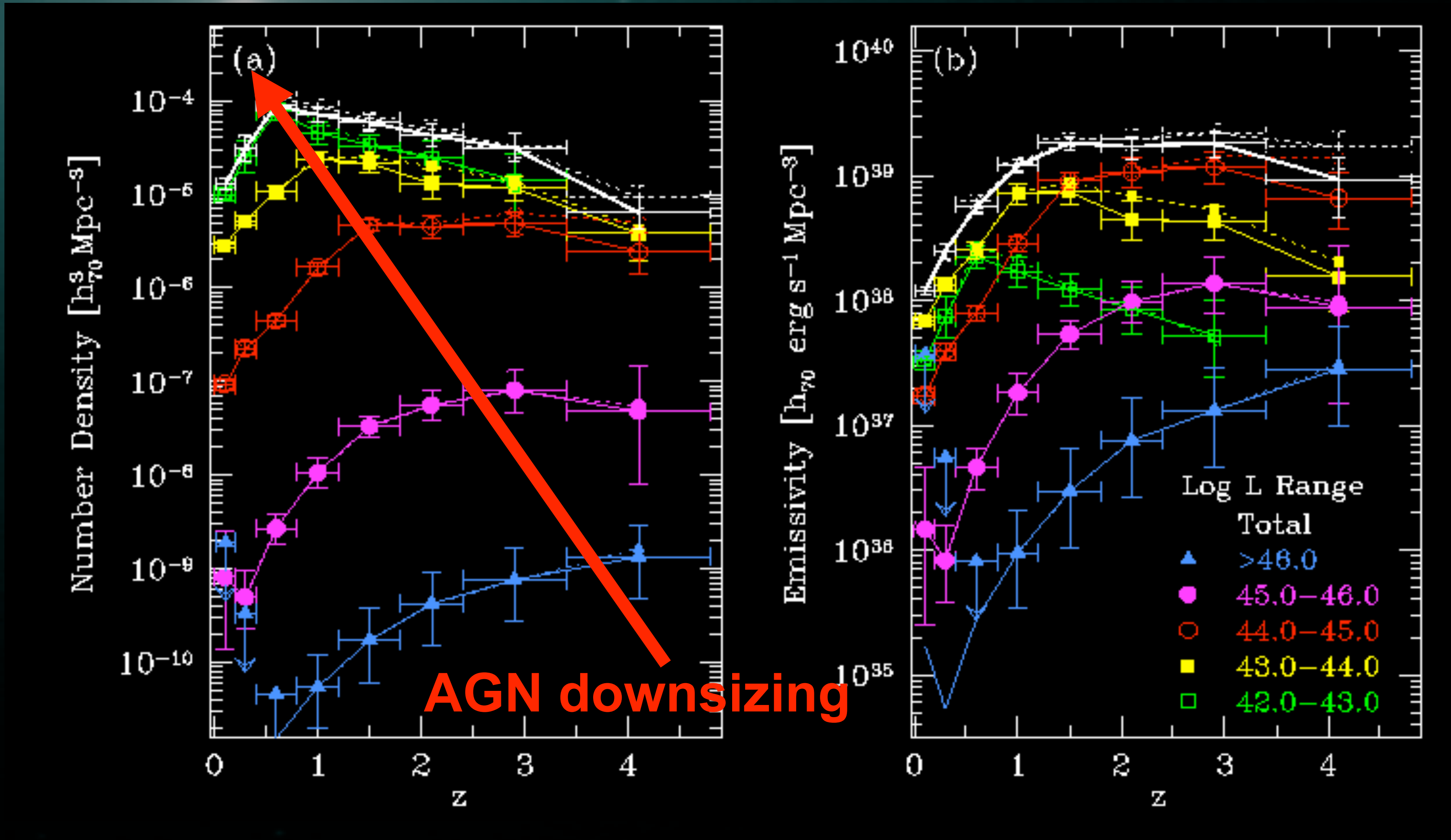


Stellar mass density:
Perez-Gonzalez et al. (2006)



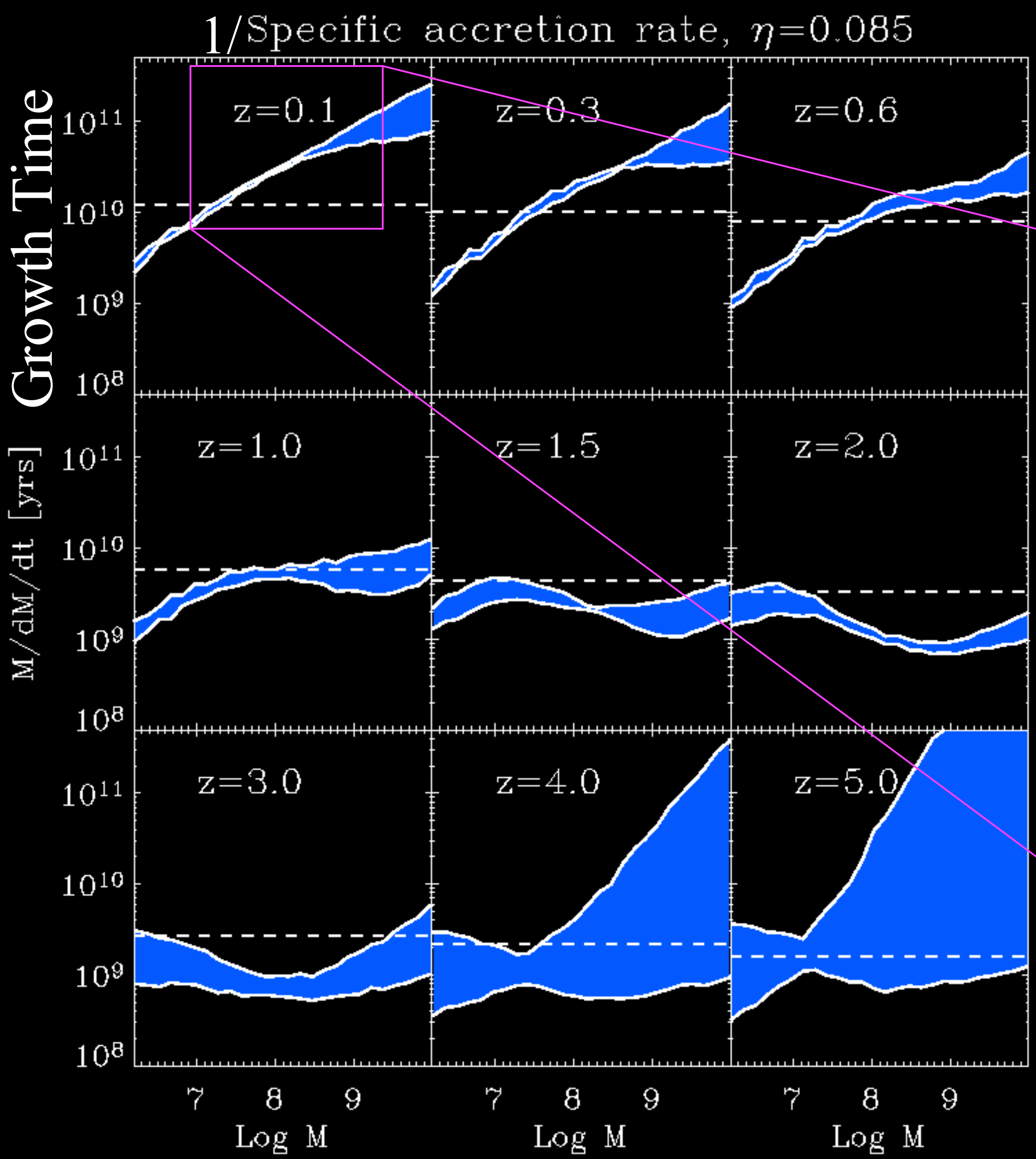
Marconi et al. 2004; Merloni et al. 2004

AGN downsizing: clues from X-rays



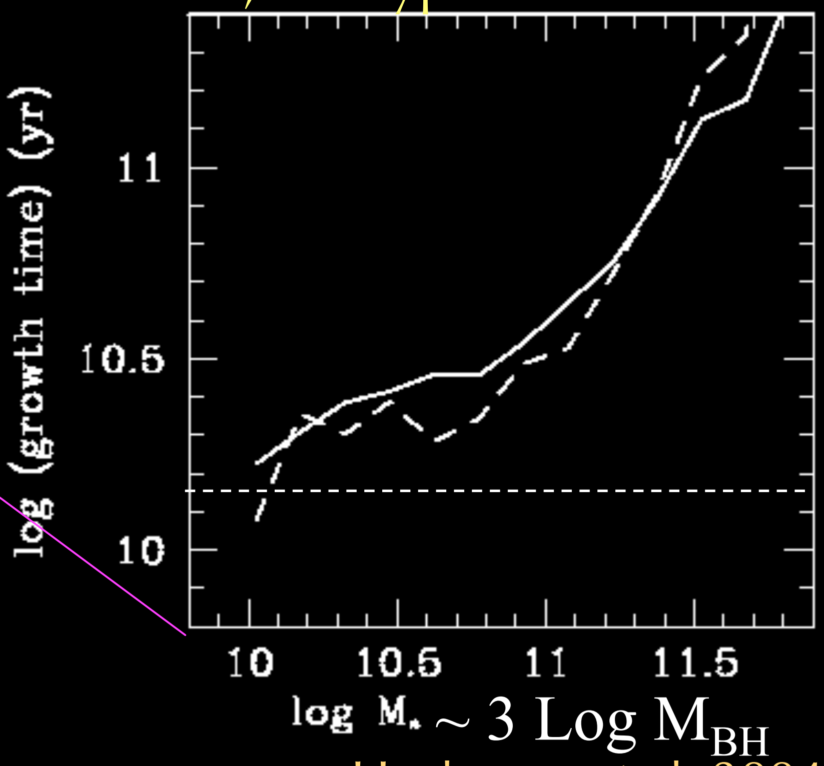
Ueda et al. 2003; Fiore et al. 2003; Barger et al. 2005; Hasinger et al. 2005

AGN downsizing



The anti-hierarchical evolution at low z seems reversed at high z

23,000 type 2 AGN at z<0.1



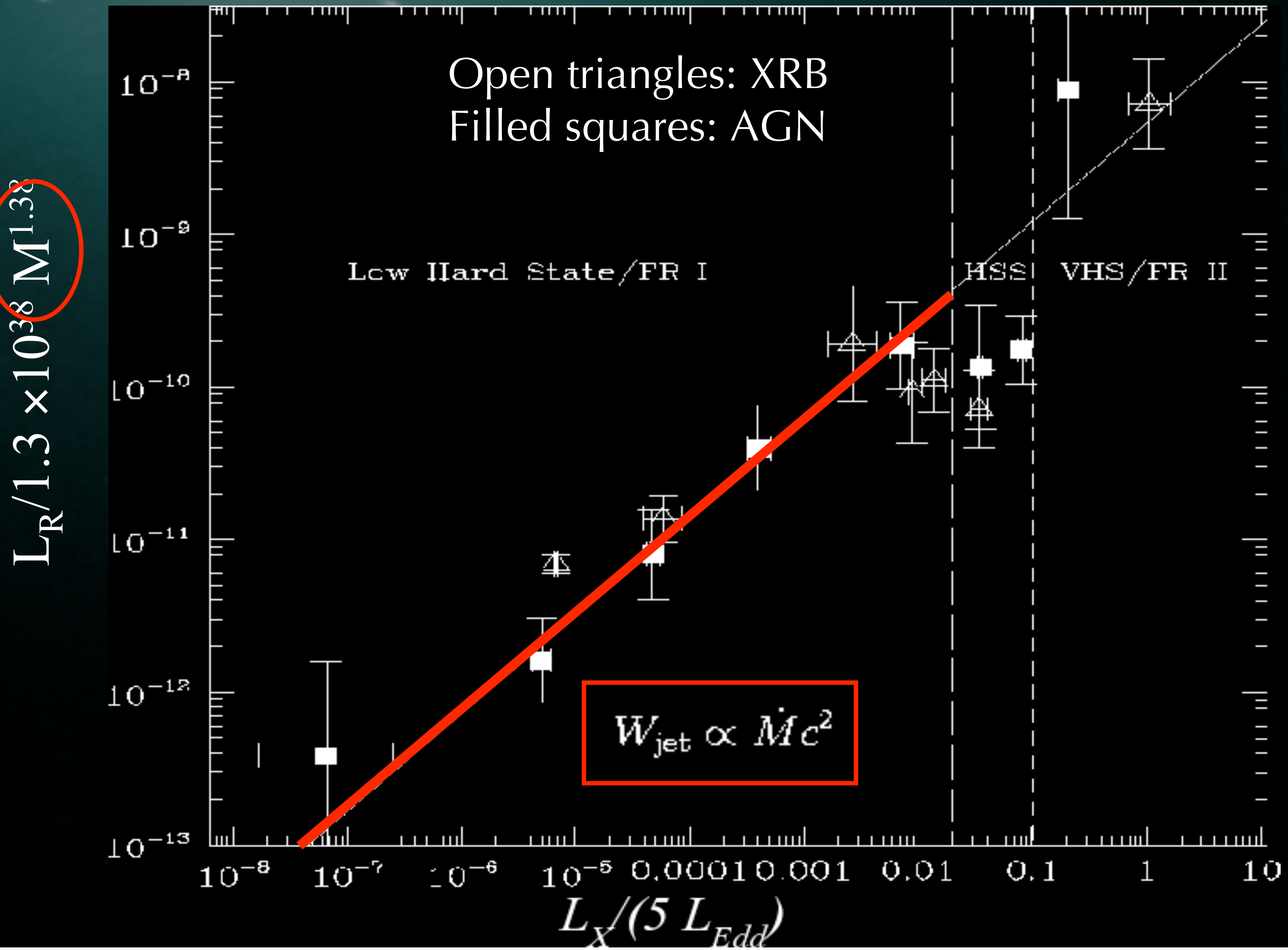
Heckman et al. 2004

AGN downsizing: changing accretion modes

- SMBH must accrete at lower (average) rates at later times
- Accretion theory (and observations of X-ray Binaries) indicate that
  - The energy output of an accreting BH depends crucially on its accretion rate
  - Low-accretion rate systems tend to be "jet dominated"
- Quasar mode vs. Radio mode (explosive vs. gentle)

Radio cores scaling with M and mdot

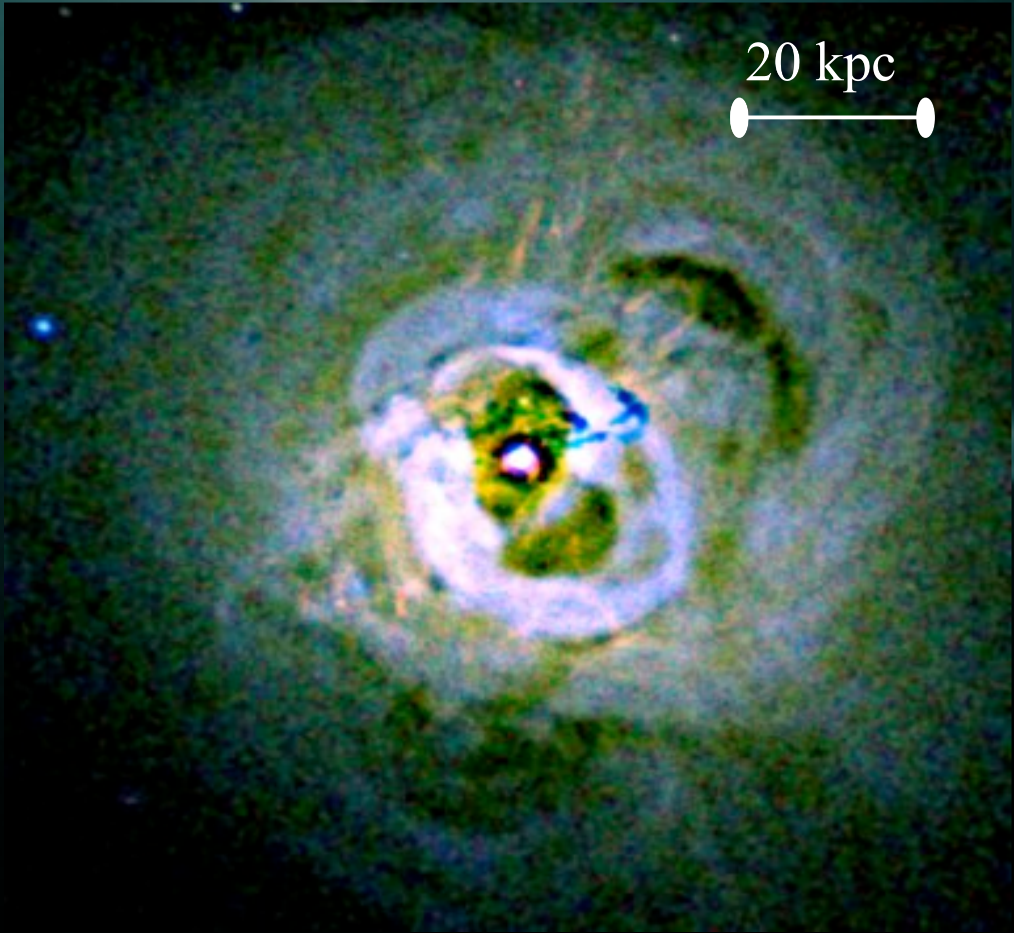
A "fundamental plane" of active BHs [Merloni et al. 2003; Falcke et al. 2004]



Very little scatter if only flat-spectrum low-hard state sources are considered (Körding et al. 2006)

Maccarone et al. 2003

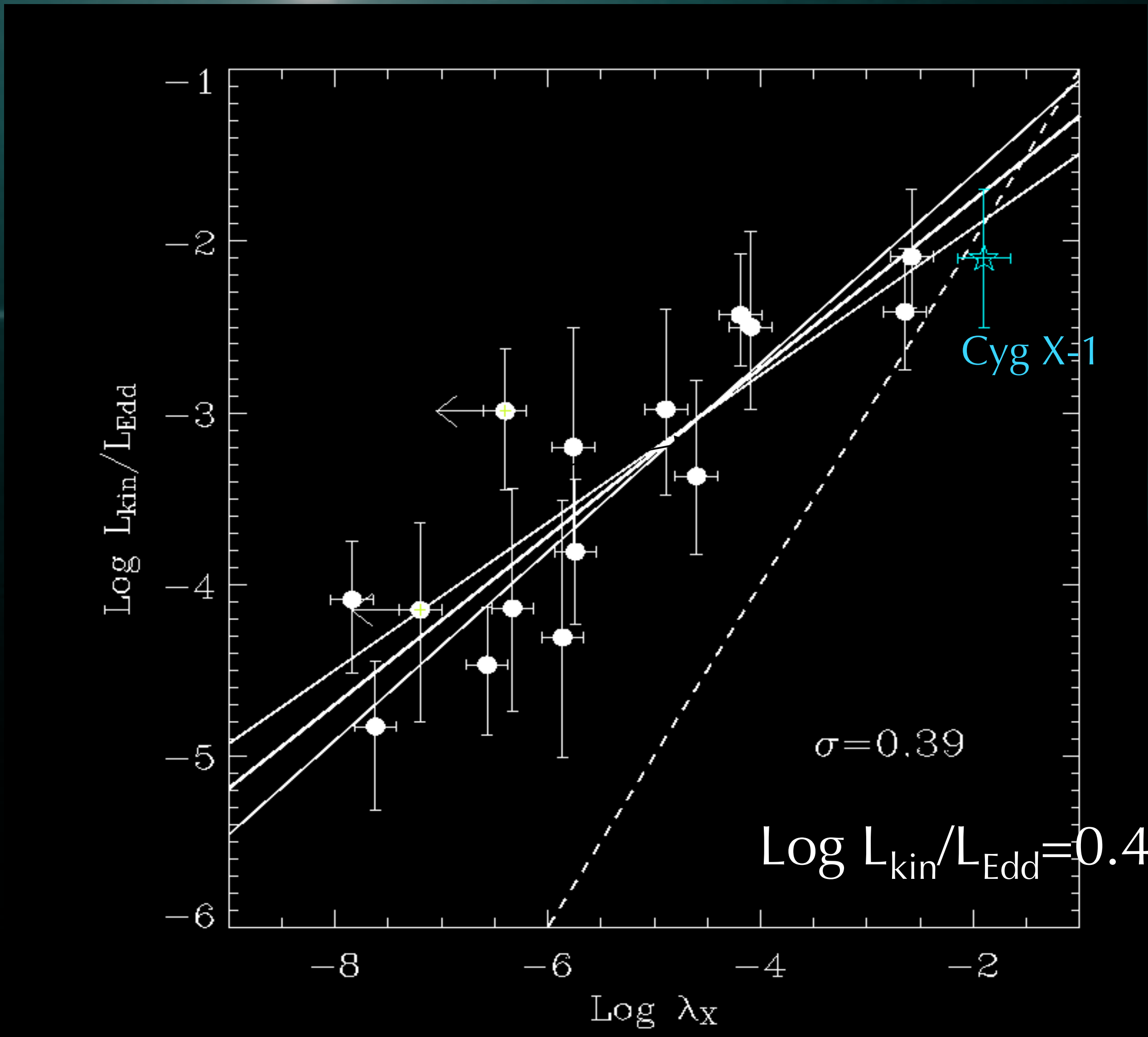
AGN feedback: evidence on cluster scale



- 1 Msec observation of the core of the Perseus Cluster with the *Chandra* X-ray Observatory
- True color image made from 0.3-1.2 (red), 1.2-2 (green), 2-7 (blue) keV photons
- First direct evidence of ripples, sound waves and shocks in the hot, X-ray emitting intracluster gas
- Radio maps reveal close spatial coincidence between X-ray morphology and AGN-driven radio jets

Fabian et al. 2006

Low Power AGN are jet dominated!

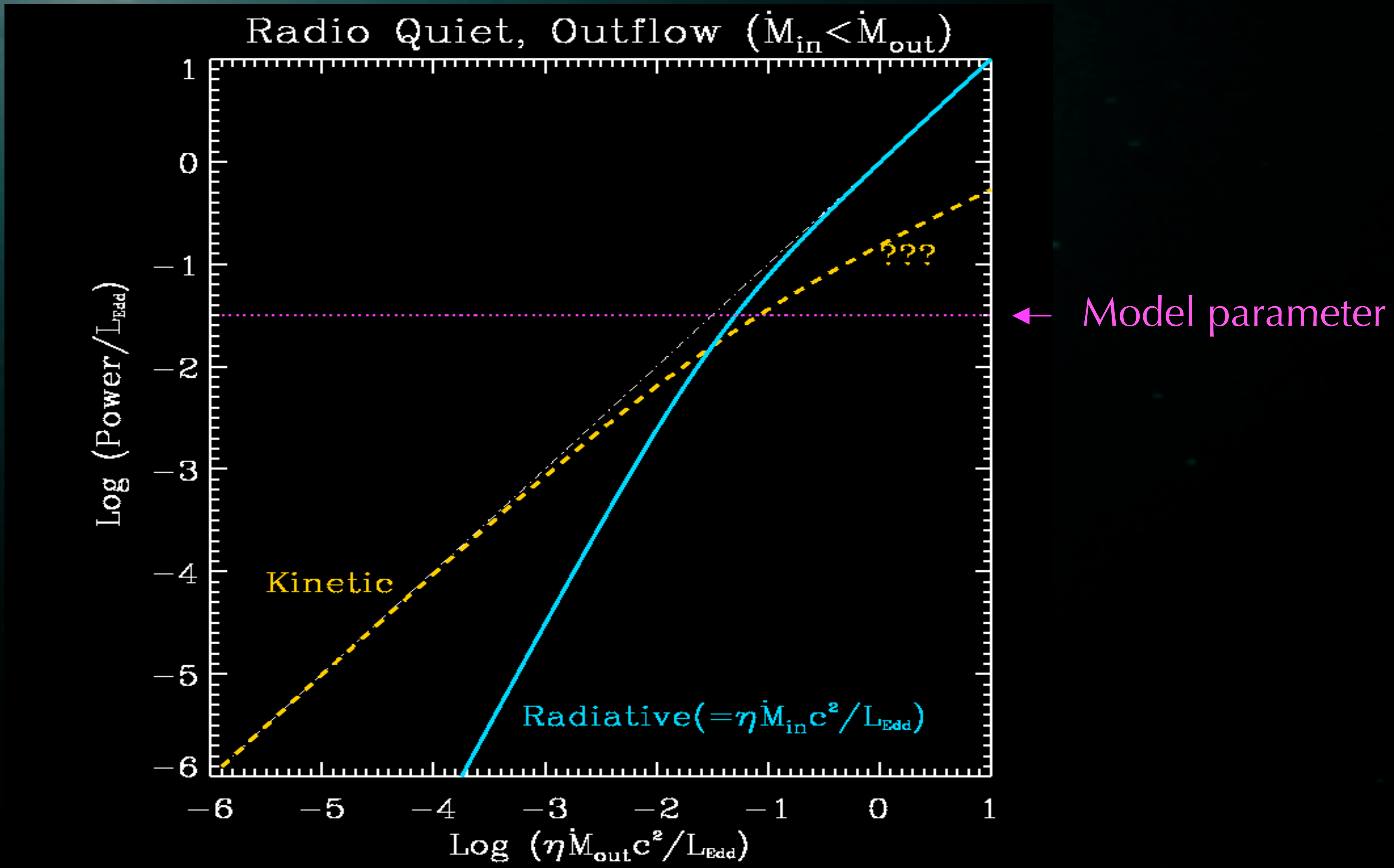


- By studying the nuclear properties of the AGN we can establish a link between jet power and accretion power
- The observed slope (0.50±0.045) is perfectly consistent with radiatively inefficient "jet dominated" models

$$\text{Log } L_{kin}/L_{Edd} = 0.49 \text{ Log } L_{bol}/L_{edd} - 0.78$$

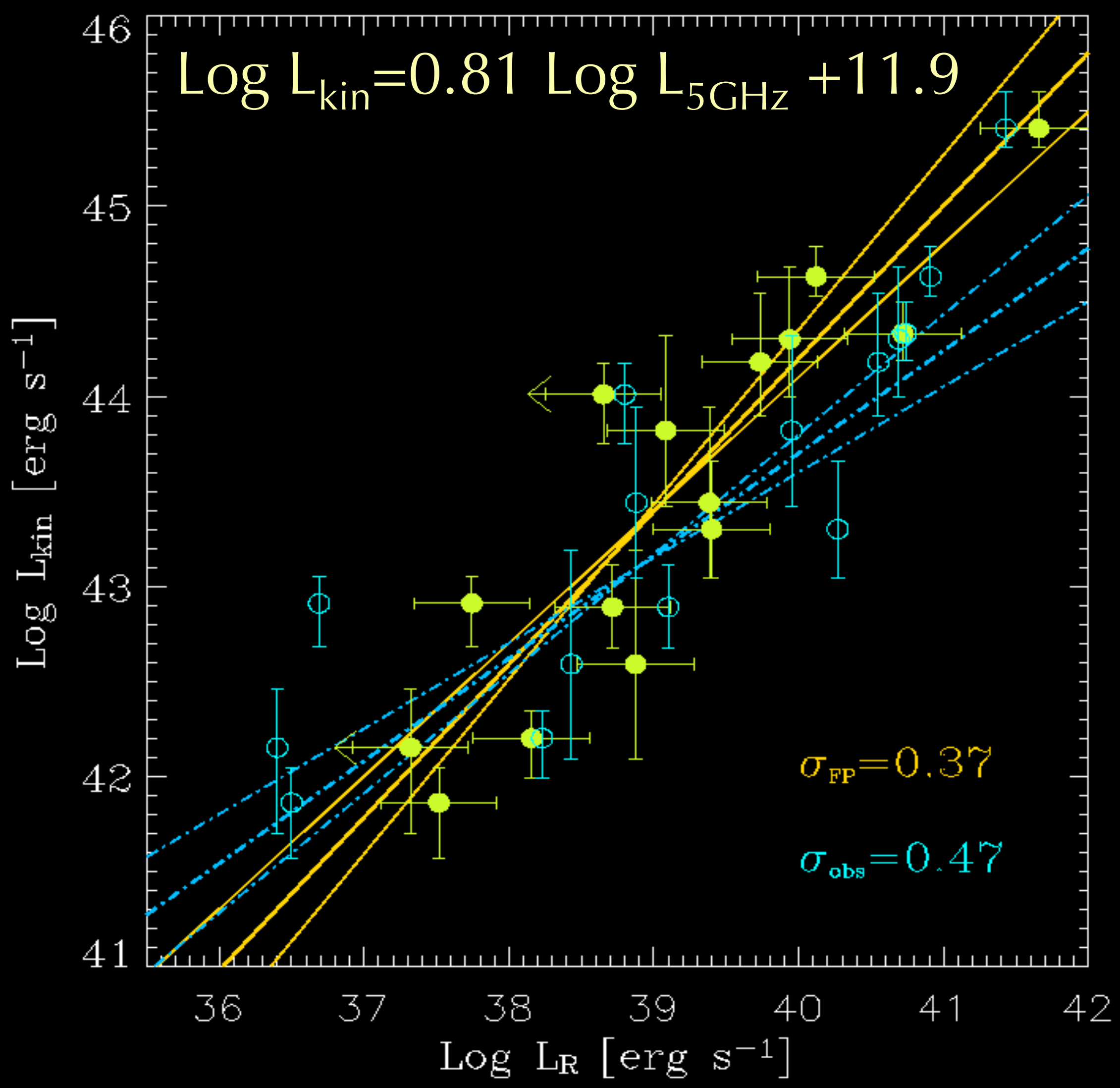
Merloni and Heinz (2007)

Accretion diagram for LMXB & AGN



(Blandford & Begelman 1999)

Core Radio/L_{Kin} relation: effects of beaming



Slope=0.81

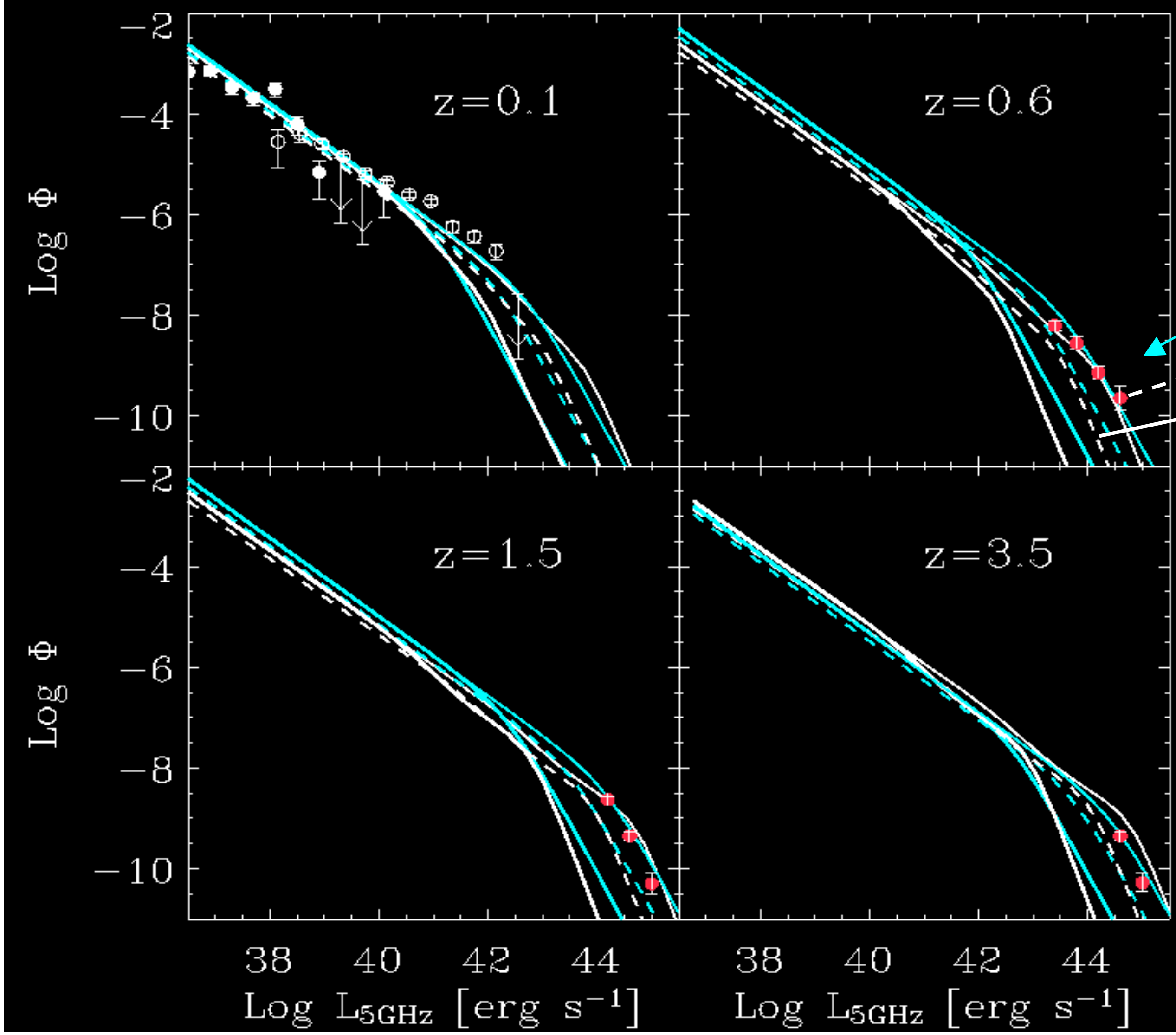
Observed L_R (beaming)

Derived from FP relation

Monte Carlo simulation:
Statistical estimates of
mean Lorentz Factor Γ~8

Merloni and Heinz (2007)

Flat Spectrum radio LF: de-beaming



$L^* \cong L^*_{,obs}/\delta_{max}^{\ 2}$

$\Phi^* \cong \Phi^*_{,obs}/\Delta$

$\Delta \cong 2^{(2a-3)}\Gamma^{(2a-4)}/(2a-3)$

"Observed" FSRLFs

<Γ>=2

<Γ>=8

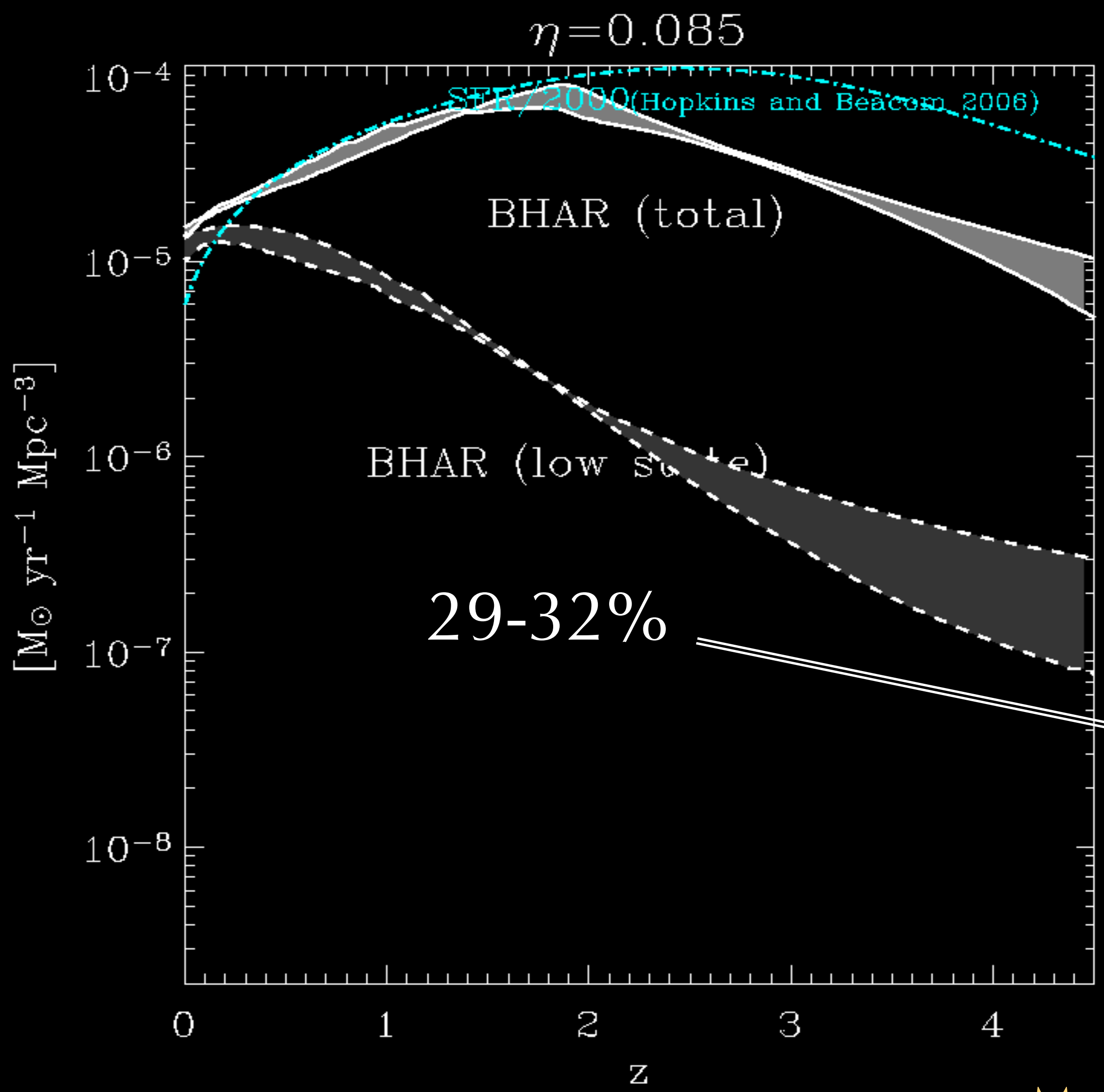
Local data points from
Filho, Barthel & Ho (2006)
High-z data
Wall et al. (2005)
RLF models from
De Zotti et al. (2005)
Dunlop & Peacock (1990)
Beaming model from
Urry & Schaefer (1984)
Urry & Padovani(1991)

SMBH population synthesis model: accretion and jets

- Derive the intrinsic, un-beamed core radio luminosity function of AGN from the observed flat spectrum radio sources LF (Dunlop & Peacock 1990; De Zotti et al. 2005).
    - Assumes radio jets have all the same Gamma factor (or a distribution peaked around a single value)
- Use the L_R/L_{Kin} relation to estimate kinetic power (CAVEAT: extension to high power sources uncalibrated)
- Use the fundamental plane of active black holes to "couple" the evolving X-ray (accretion) and radio (kinetic power output) AGNLF (Merloni 2004)

(Merloni 2007; Heinz, Merloni & Schwab 2007)

SMBH growth



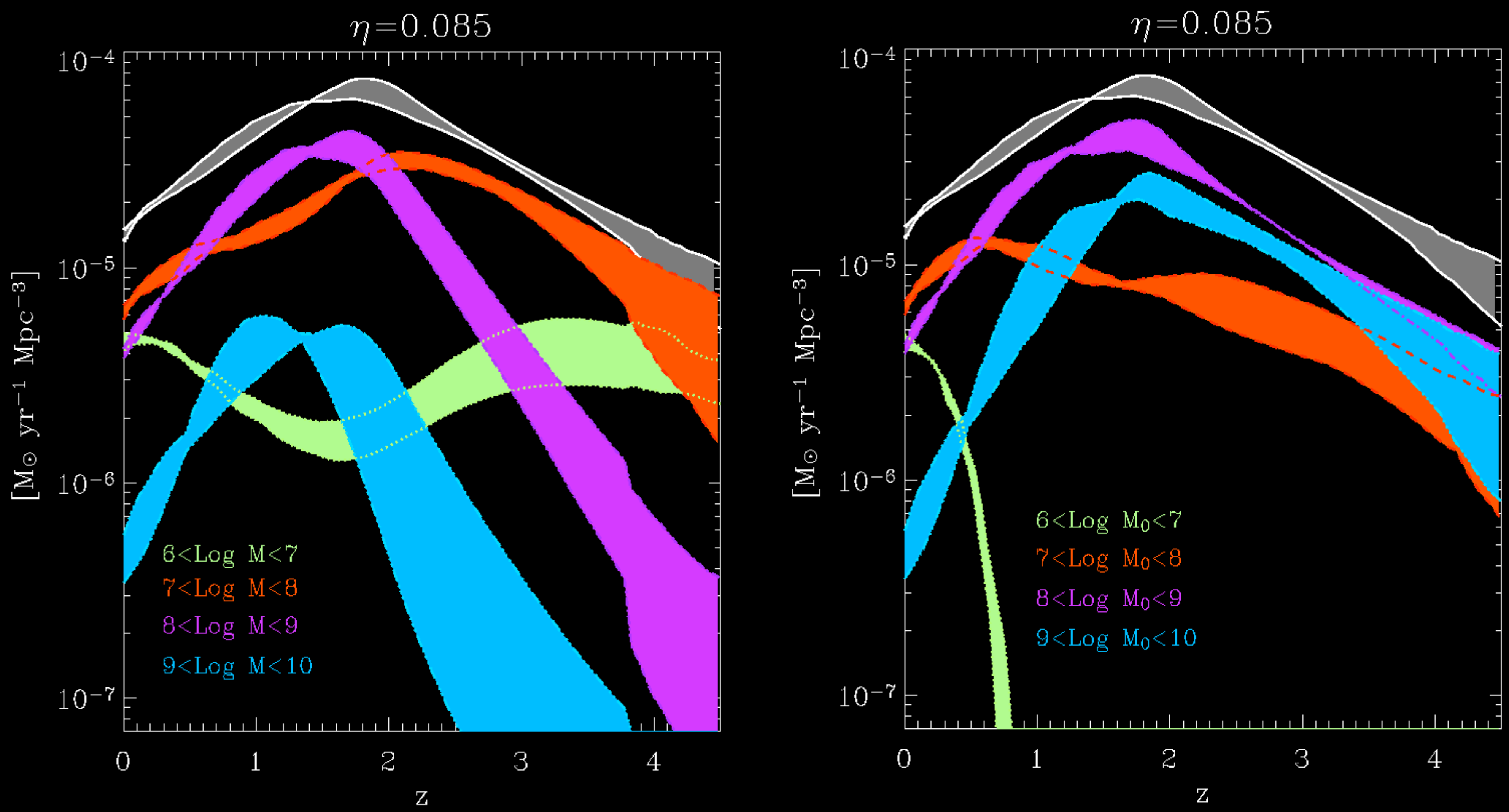
1) Most of SMBH growth in radiatively efficient mode

ε ≈ 0.04-0.05

Marconi et al. (2004)

Merloni 2004; Merloni, in prep.

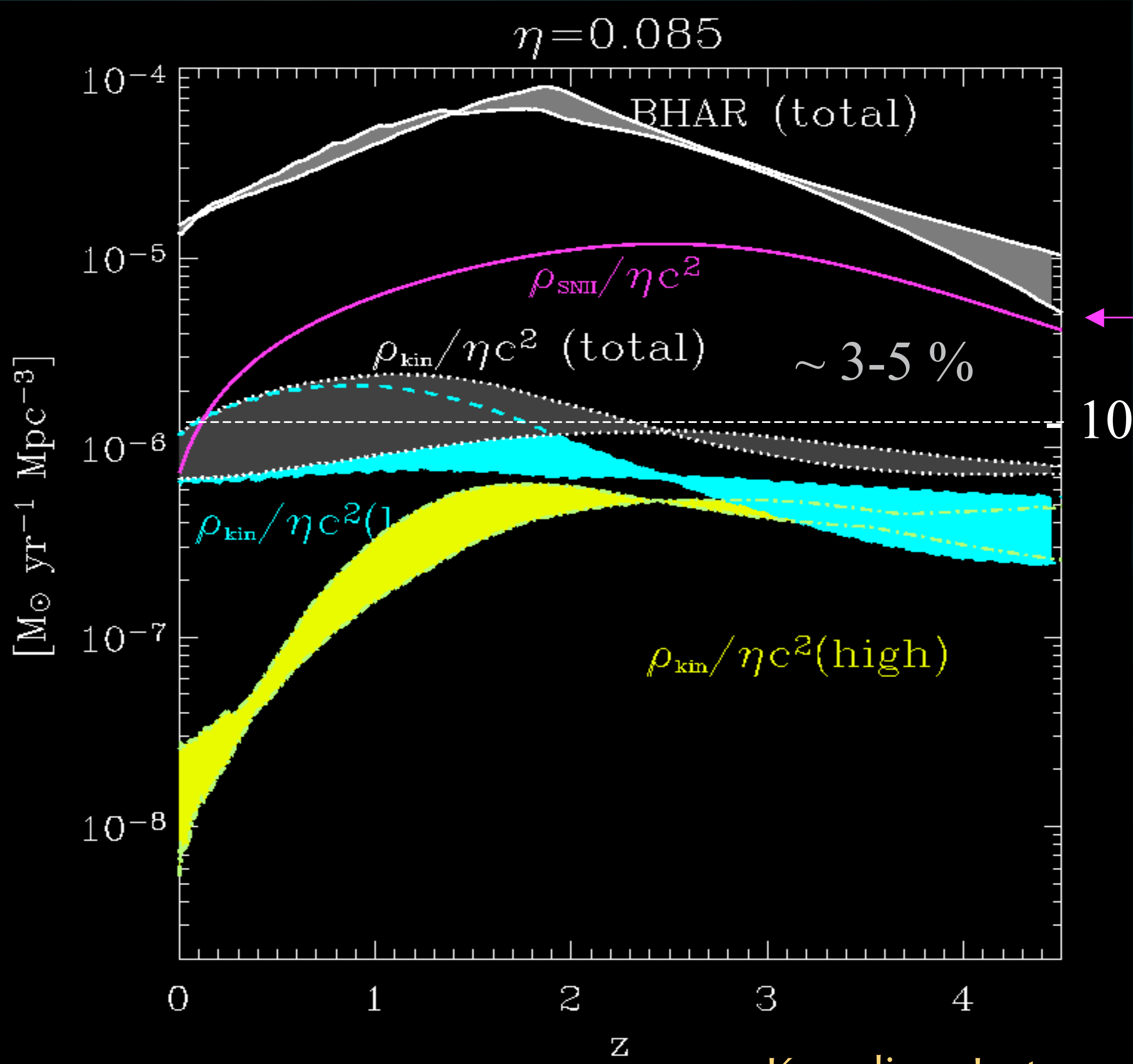
Accretion rate density by BH mass



Merloni (2008)

We can follow the history of progenitors of local black holes

Kinetic Energy output and SMBH growth



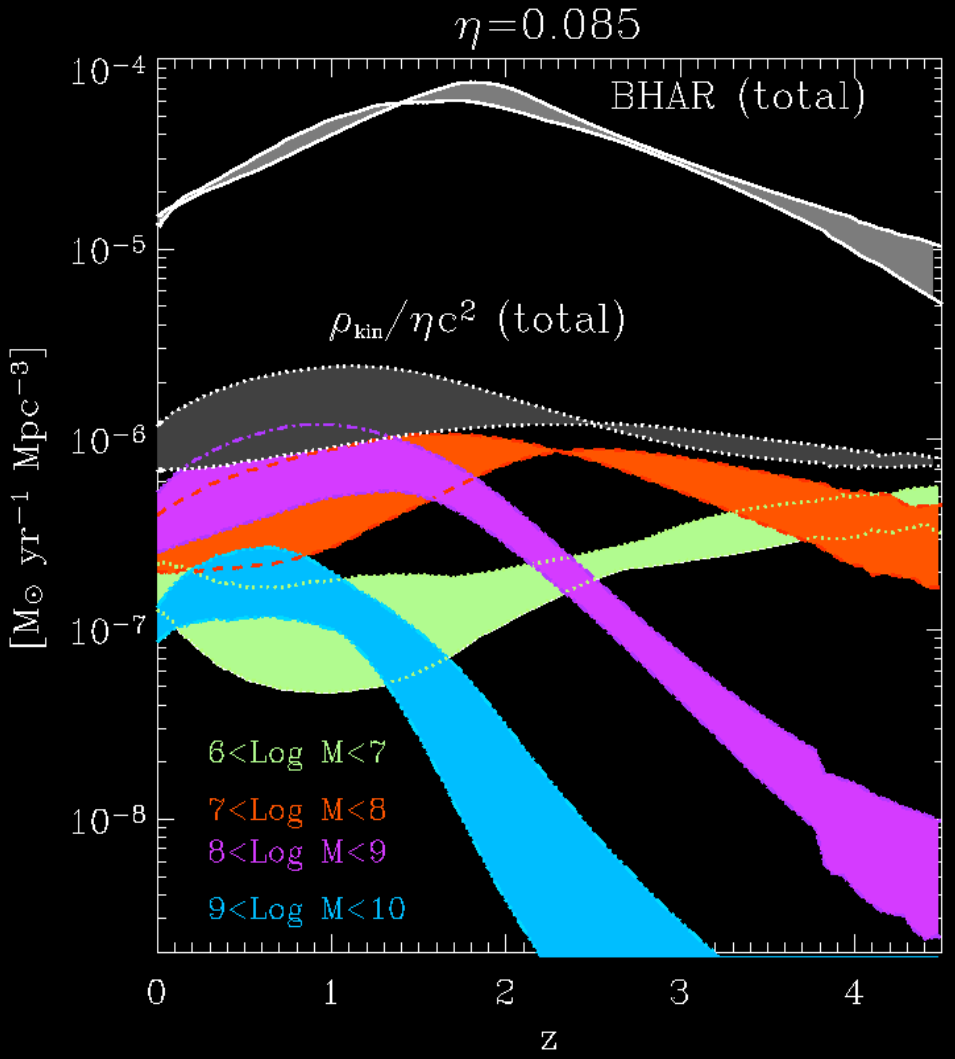
SN II K.E. output rate from SFR (Hopkins & Beacom 2006)

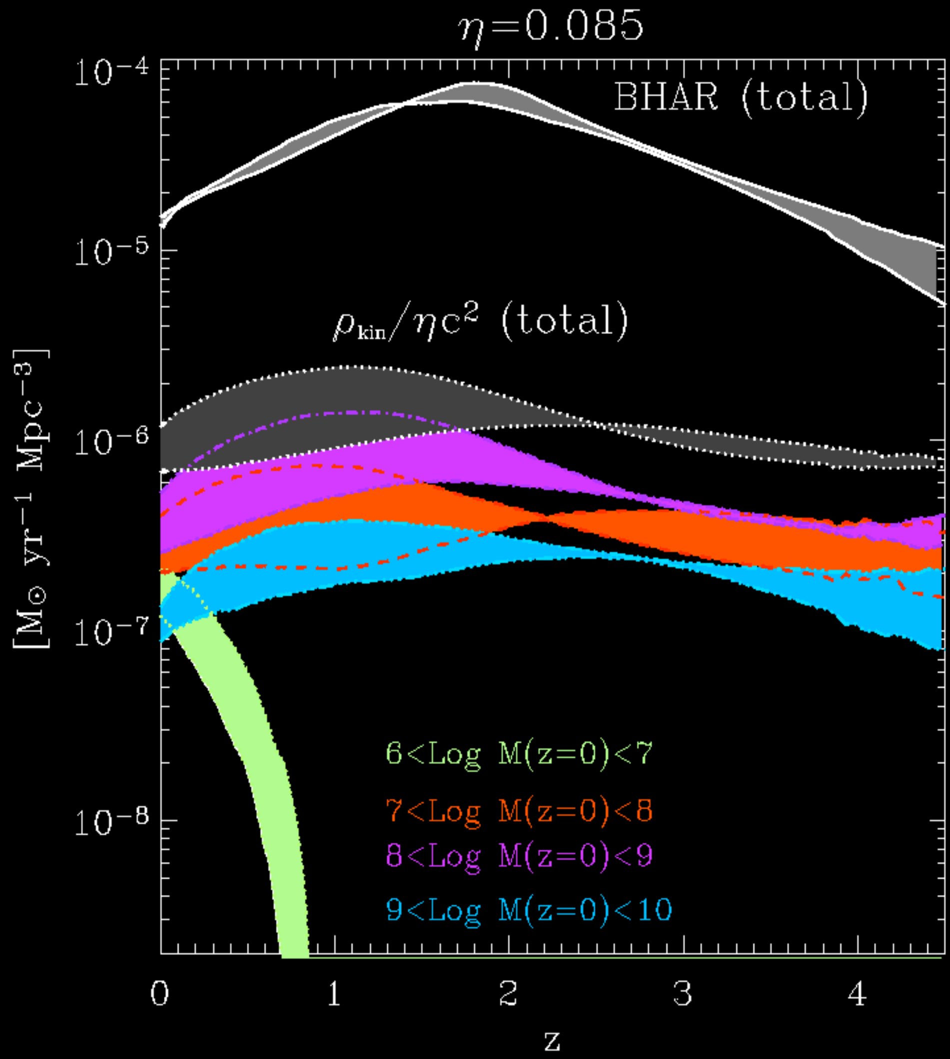
10^{40} erg/s Mpc^{-3}

In the local universe, kinetic feedback is dominated by low luminosity objects ("radio mode" AGN)

Koerding, Jester and Fender 2007, Merloni, in prep.

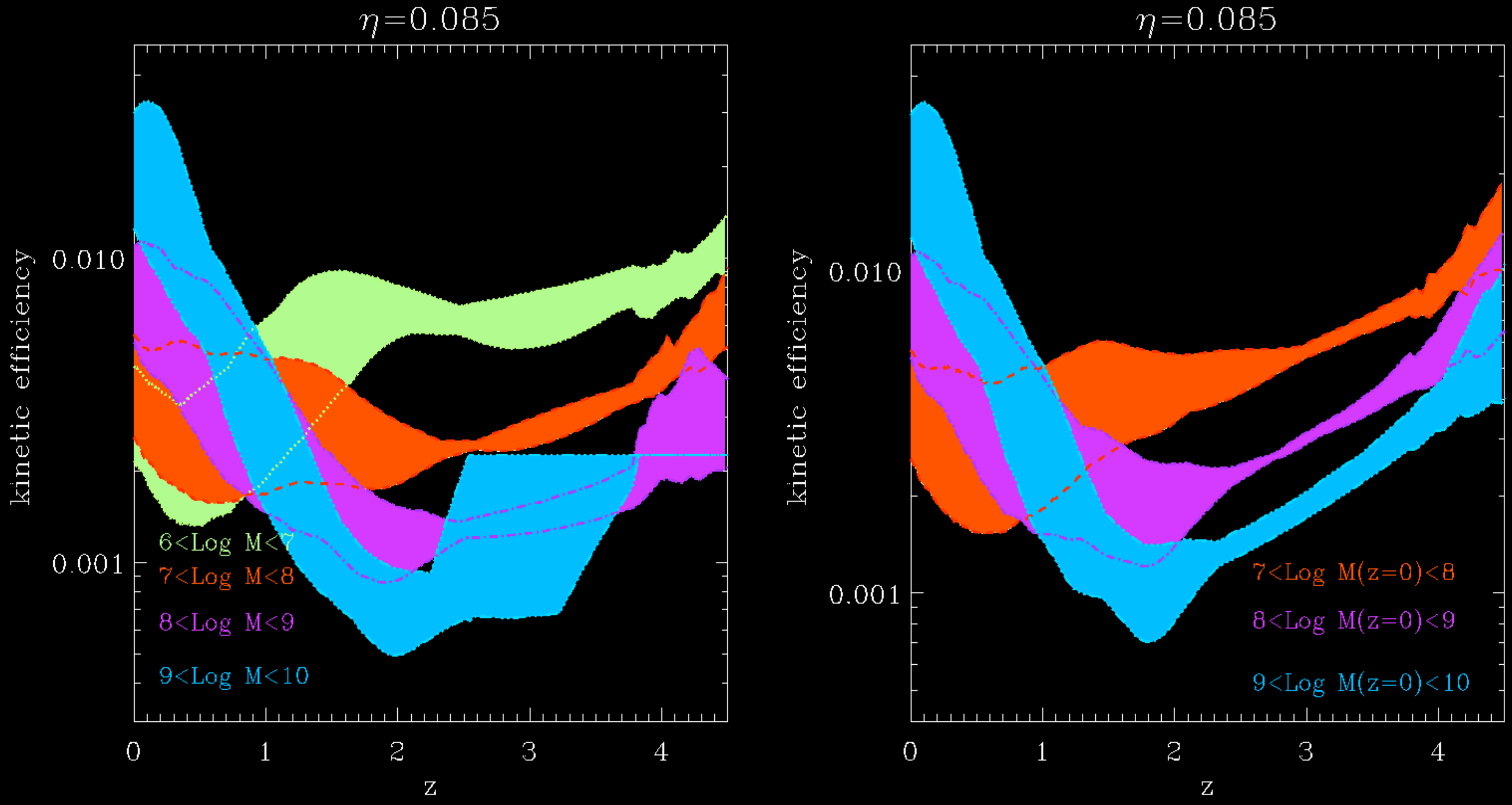
Kinetic Energy output by SMBH mass





Merloni (2008)

Kinetic efficiency of growing black holes



Merloni (2008)

Conclusions

- Most of SMBH growth occurred in radiatively efficient episodes of accretion.
- The anti-hierarchical trend is clearly seen in the low-z evolution of SMBH mass function. Reversal at higher z?
- Constraints on the physics of accretion/jet production are crucial for our understanding of AGN feedback
- Feedback from "Low-luminosity AGN" are most likely dominated by kinetic energy
- The efficiency with which growing black holes convert mass into mechanical energy is 0.1-3%, depending on mass and redshift

Open questions

- Contribution of heavily absorbed sources (Compton Thick): What redshift distribution? What typical luminosity?
  - Understand relationship between fuelling and absorption
- High redshift (z>5) evolution unknown (XEUS, SKA)
  - Need firm theoretical prediction of early mass function and seed bh
- Relative contribution to kinetic feedback of (high Mdot) radio loud QSOs and (low Mdot) `radio mode' AGN
- Physics of radio mode feedback: increase statistics of radio cavities and relics
- What trigger? Mergers, secular evolution, both, others?


The M87 jet
Hubble Heritage Project
http://heritage.stsci.edu/2000/20/index.html