

The cosmic growth of the active black hole population out to $z=2$

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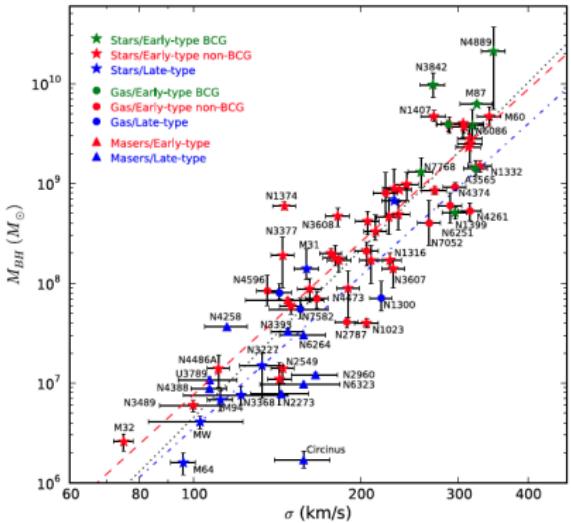
APEC Seminar, Kavli IPMU
26.02.2015



Outline

- 1 Introduction: BH-galaxy co-evolution & AGN demographics
- 2 Local active black hole mass function
- 3 Active black hole mass function at $1 < z < 2$
- 4 AGN host galaxy mass function

Black hole - galaxy coevolution



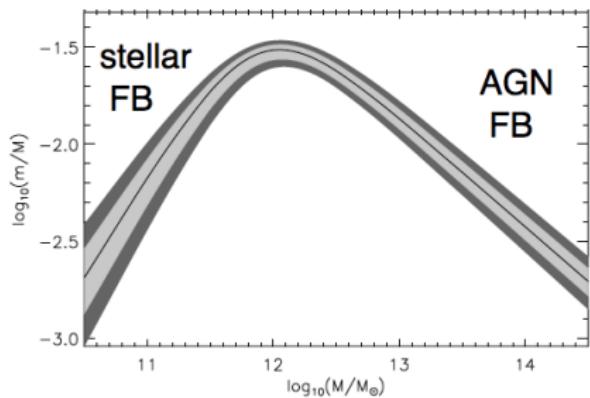
$M_{\bullet} - \sigma_*$ relation:

- ⇒ AGN feedback driven co-evolution?
 - ⇒ hierarchical assembly through galaxy mergers?
 - ⇒ Both?
 - ⇒ what effect has the black hole on its host galaxy?

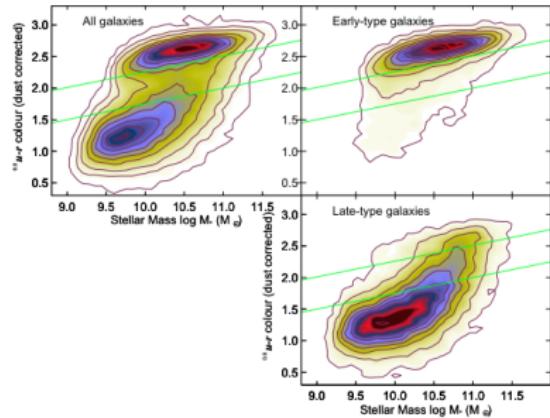
McConnell & Ma (2013)

AGN feedback

$M_\star - M_{\text{DM}}$ -relation



Moster et al. (2010)

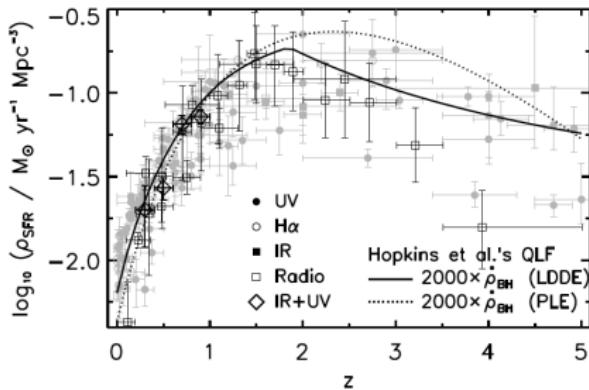


Schawinski et. al (2014)

- ⇒ AGN Feedback required to shut off SF in massive galaxies
- ⇒ transition of galaxies from blue cloud to red sequence via quenching of SF

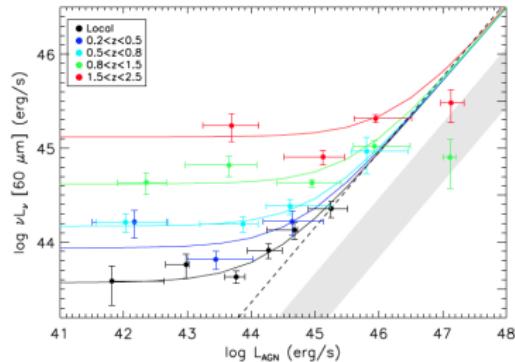
AGN vs. star formation

integrated cosmic BH accretion history parallel to SF history

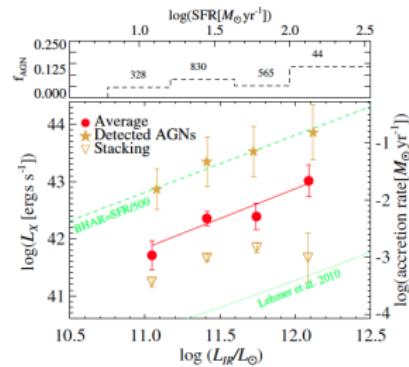


Zheng et al. (2009)

- ⇒ link between black hole growth and galaxy evolution
- ⇒ how are black holes growing?



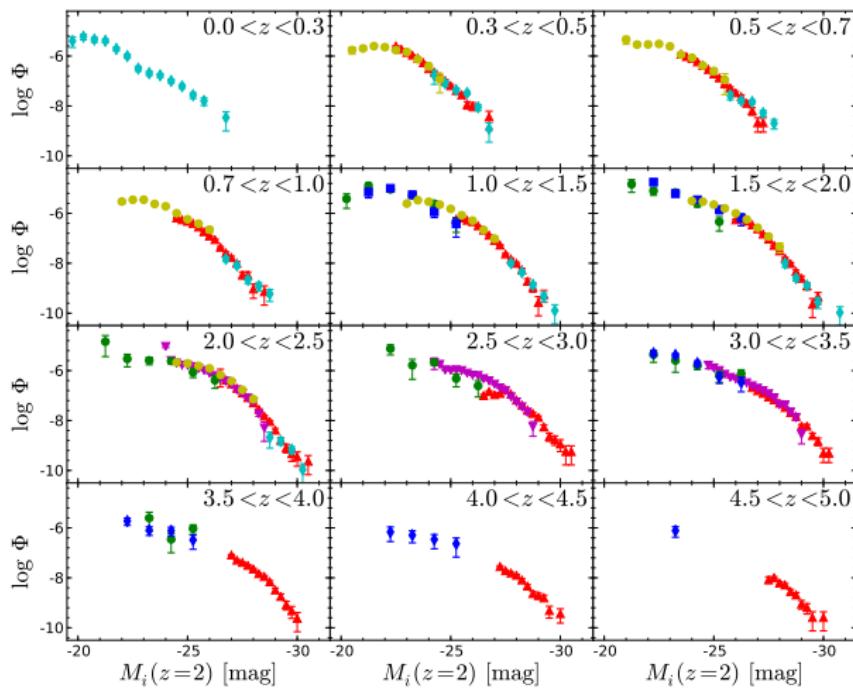
Rosario et al. (2012)



Chen et al. (2013)

AGN demographics: The AGN LF

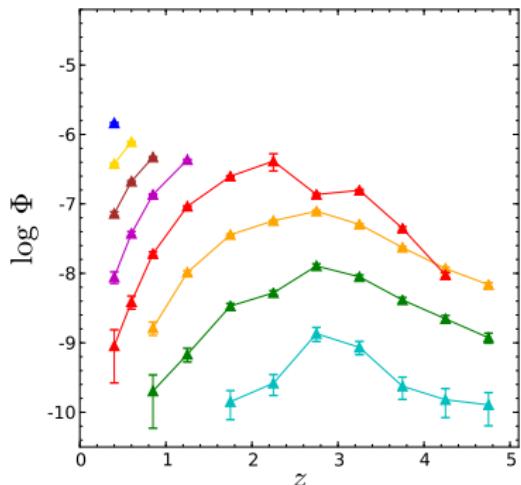
AGN Luminosity function is main demographic quantity



AGN demographics: AGN LF evolution

AGN Luminosity function is main demographic quantity

- space density of bright QSOs peaks at $z \approx 2 - 3$

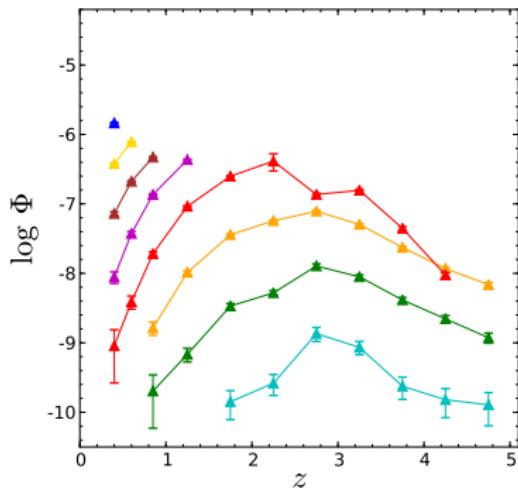


optical: SDSS (Richards et al. 2006)

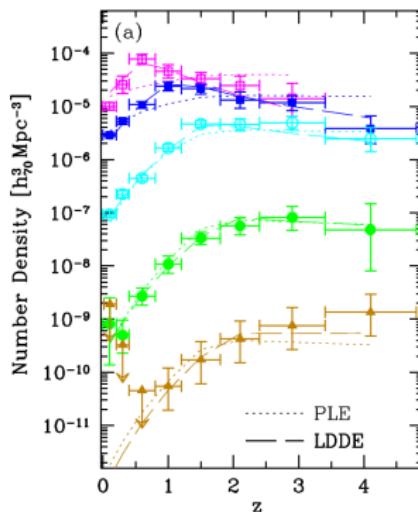
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- space density of bright QSOs peaks at $z \approx 2 - 3$
 - peak is shifted towards lower z for fainter AGN
- ⇒ AGN cosmic downsizing



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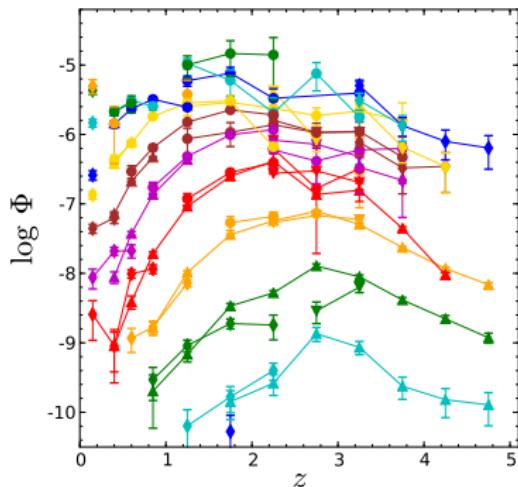


X-rays: Hasinger et. al (2005)

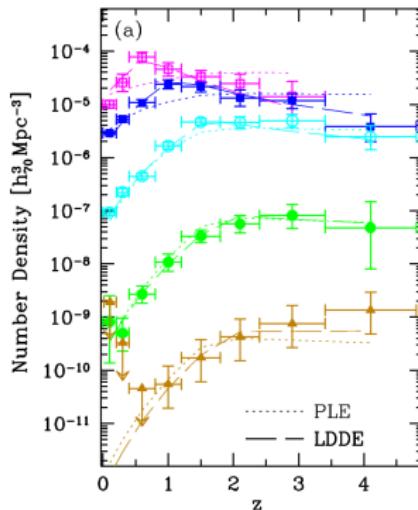
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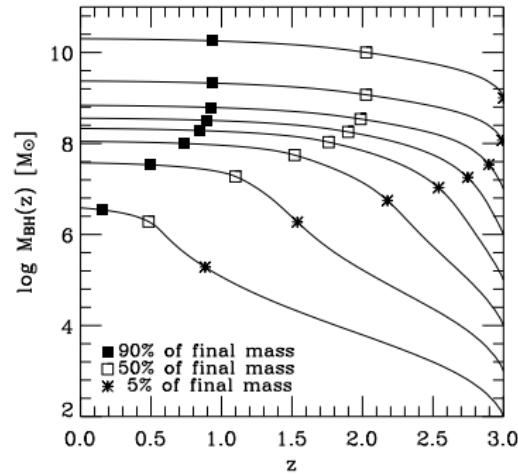
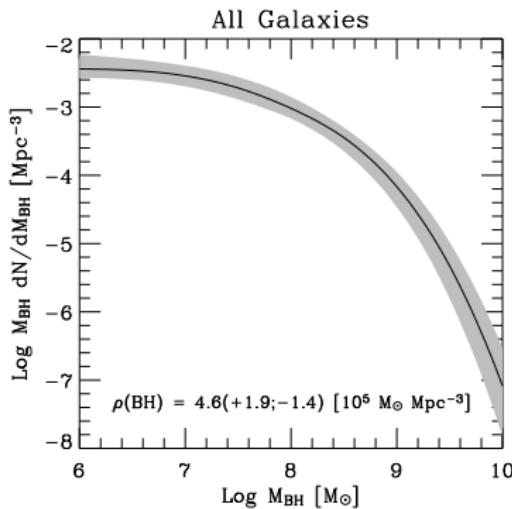
optical: various surveys



X-rays: Hasinger et. al (2005)

Implications for BH growth

- BH mass density accreted during QSO phases = local BH mass density (Soltan argument)
 - most BH growth takes place in luminous AGN phase
- ⇒ AGN downsizing implies anti-hierarchical BH growth

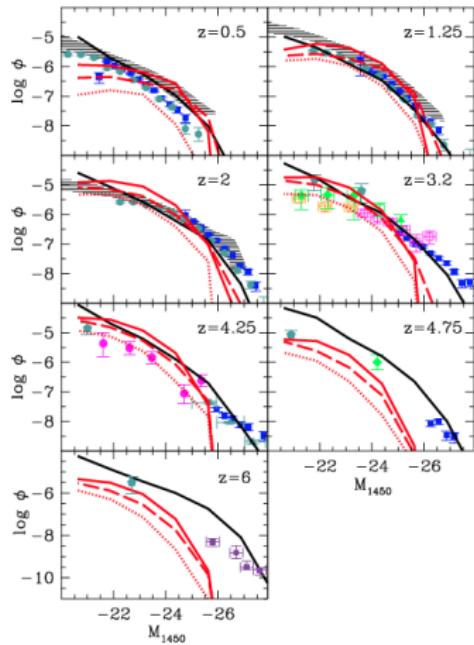


Marconi et. al (2004)

Constraints on theoretical models

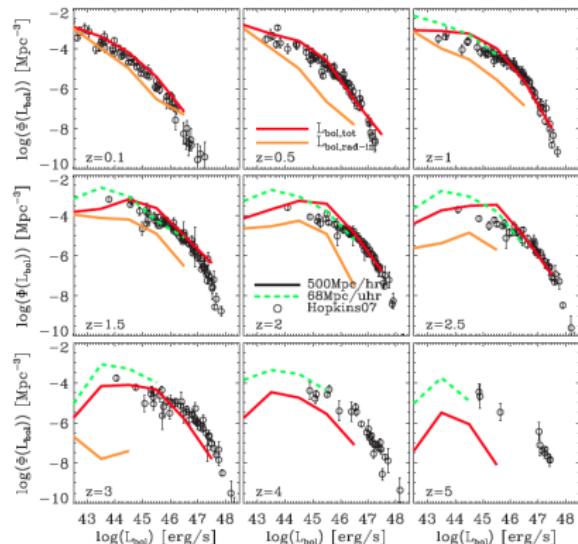
- SAMs & numerical simulations able to reproduce AGN LF and downsizing

SAMs



Menci et. al (2014)

Numerical simulations



Hirschmann et al. (2014)

How can we trace black hole growth?

Limitation of AGN LF:

Physical quantities of black holes:

- black hole mass M_{\bullet}
- accretion rate / Eddington ratio $\lambda = L_{\text{bol}}/L_{\text{Edd}}$

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Active black hole mass function - $\Phi_{\bullet}(M_{\bullet})$

Eddington ratio distribution function - $\Phi_{\lambda}(\lambda)$

- well-defined AGN sample
- black hole mass estimates

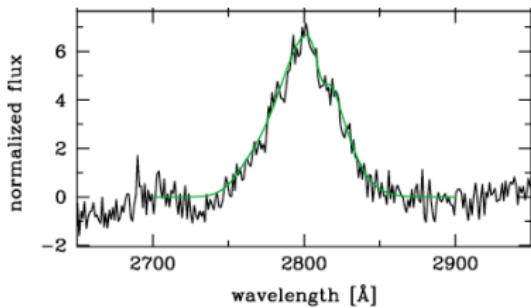
Black hole masses for broad line AGN

- for virial motion in BLR:

$$M_{\bullet} = f \frac{R_{\text{BLR}} \Delta V^2}{G}$$

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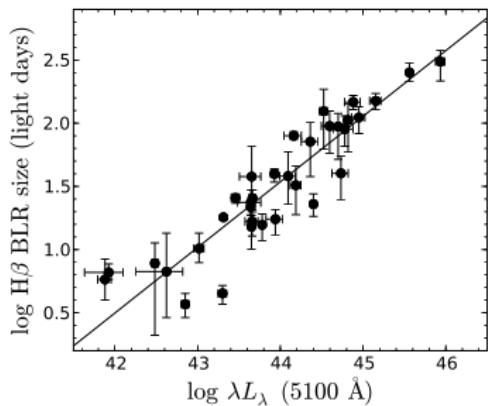
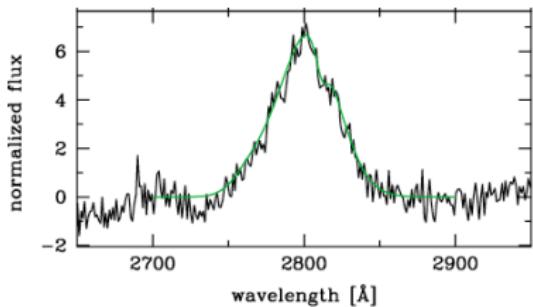
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- ΔV from broad line width
- scaling relation between BLR size and continuum luminosity (via reverberation mapping)

$$R_{\text{BLR}} \propto L_{5100}^{0.5}$$



Bentz et al. (2009)

Black hole masses for broad line AGN

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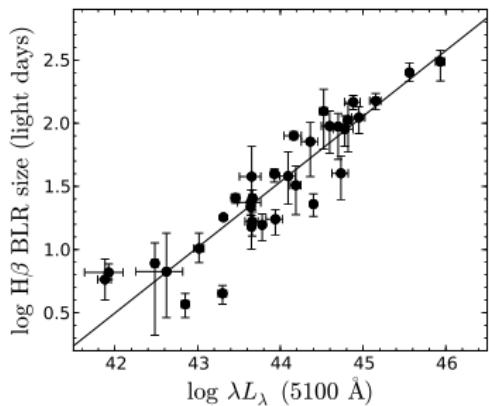
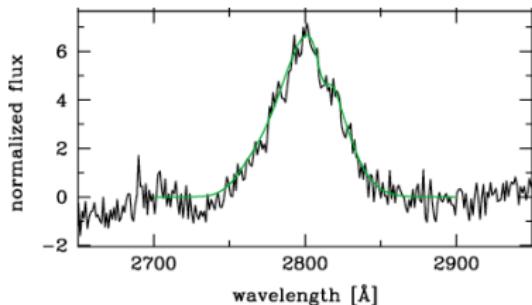
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$$R_{\text{BLR}} \propto L_{5100}^{0.5}$$

- estimate M_{\bullet} from spectrum

$$M_{\bullet} \propto L_{5100}^{0.5} \Delta V^2$$

→ feasible to estimate M_{\bullet} for large samples of broad line AGN out to high z

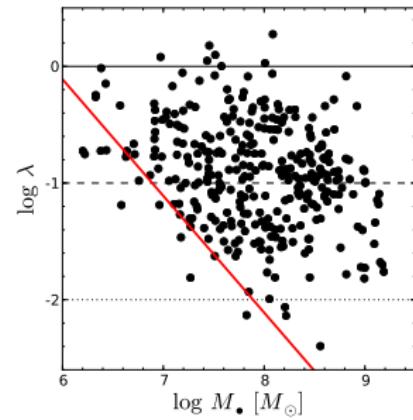
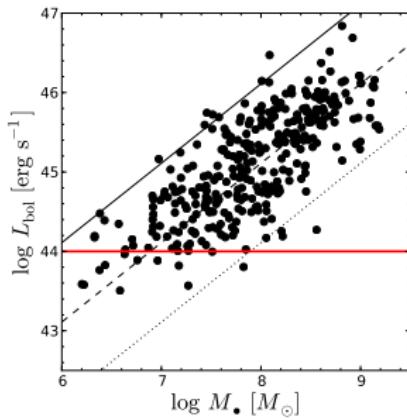


Bentz et al. (2009)

What is an *active* black hole?

define *active* BH:

- ⇒ active BHs limited to broad line AGN
- ⇒ luminosity limit poor criteria for BHMF (incompleteness at low mass by definition)
- ⇒ define *active* black hole by Eddington ratio limit
- ⇒ **active BH:** type-1 AGN with $\log \lambda > -2$

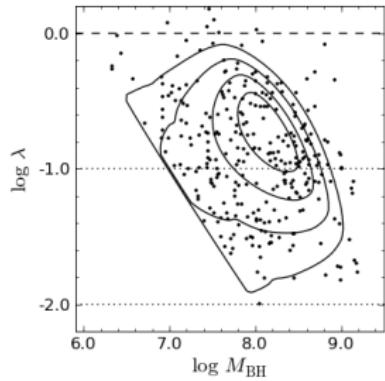


The bivariate distribution function of BH mass and Eddington ratio

- model DF via fitting of bivariate distribution function of M_{\bullet} and λ
 - ⇒ Black hole mass function (BHMF) and Eddington ratio distribution function (ERDF) determined jointly by fitting probability distribution in $M_{\bullet} - \lambda$ -plane
 - ⇒ via Maximum likelihood method (Schulze & Wisotzki 2010) or via Bayesian framework (Kelly et al. 2009)

ML approach

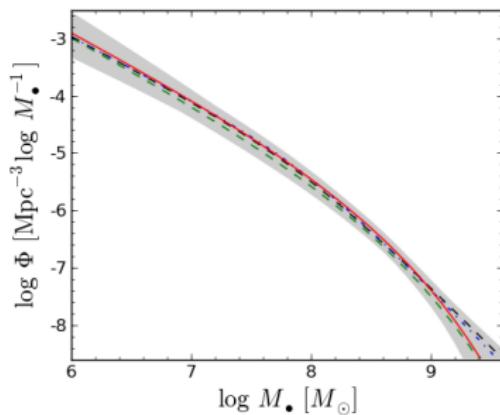
BHMF
+ ERDF
+ survey selection function
= probability distribution



The local active black hole mass function and Eddington ratio distribution function

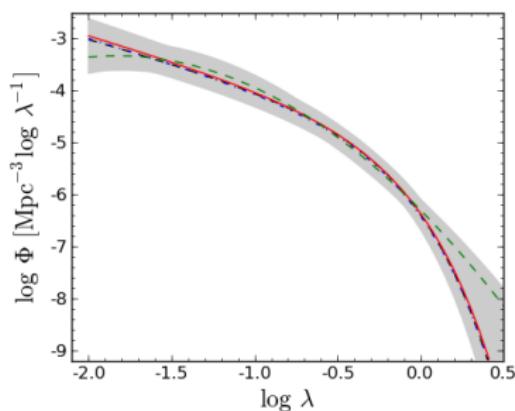
Local ($z < 0.3$) BHMF and ERDF from the Hamburg/ESO Survey

Active black hole
mass function



Schulze & Wisotzki (2010)

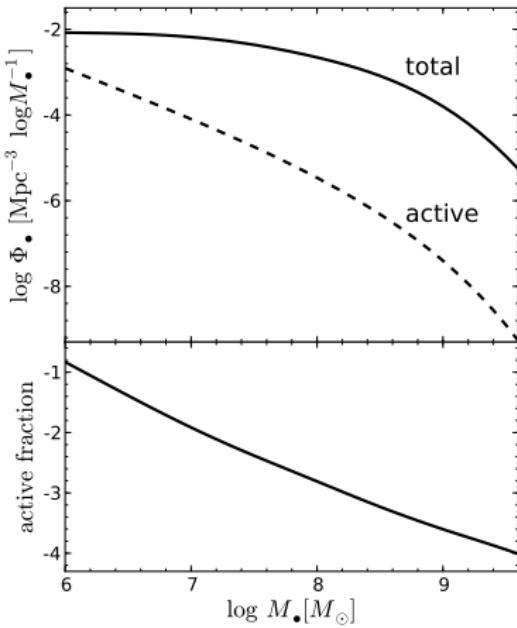
Eddington ratio
distribution function



⇒ No evidence for downturn at low black hole mass or at low Eddington ratio

Active fraction of local black holes

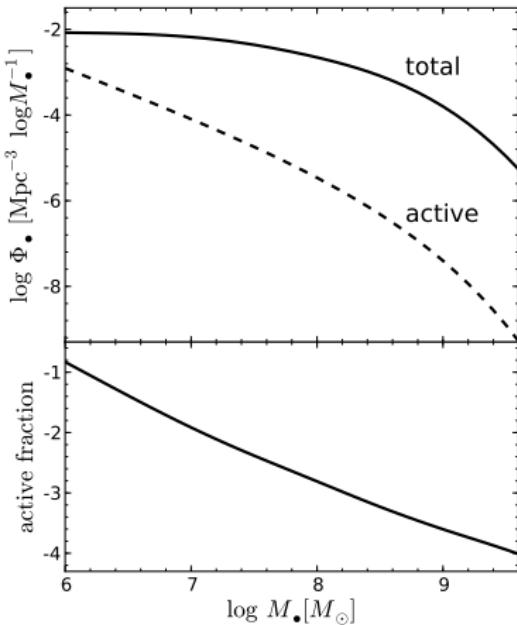
compare to quiescent BHMF of
Marconi et al. 2004



Active fraction of local black holes

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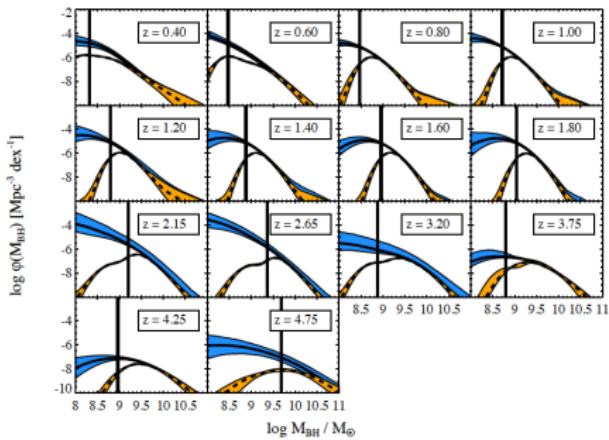
- significant decrease of active fraction toward higher M_{\bullet}
- indication for cosmic downsizing in black hole mass



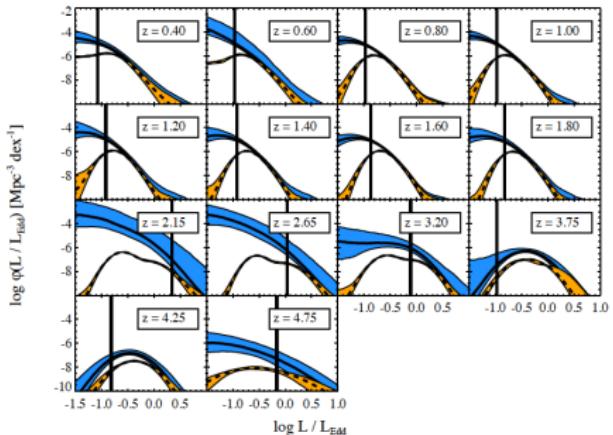
Active BHMF and ERDF at higher redshifts

at $z > 0.4$ BHMF and ERDF determined from SDSS QSO sample

- ⇒ evidence for black hole mass downsizing
- ⇒ only high mass end of BHMF, high λ end of ERDF



Kelly & Shen (2013)



BH demographics from VVDS, zCOSMOS and SDSS

combine bright, large area surveys (**SDSS**) with deep, small area AGN surveys (**VVDS, zCOSMOS**)

SDSS: $i < 19.1$ $\Omega_{\text{eff}} = 6248 \text{ deg}^2$
color selection

VVDS: wide: $I_{\text{AB}} < 22.5$ $\Omega_{\text{eff}} = 4.5 \text{ deg}^2$
deep: $I_{\text{AB}} < 24.0$ $\Omega_{\text{eff}} = 0.6 \text{ deg}^2$
random selection

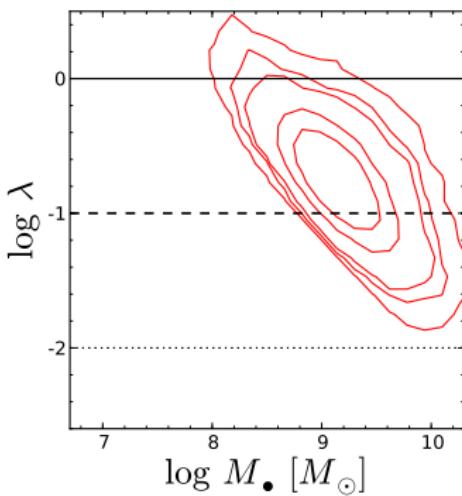
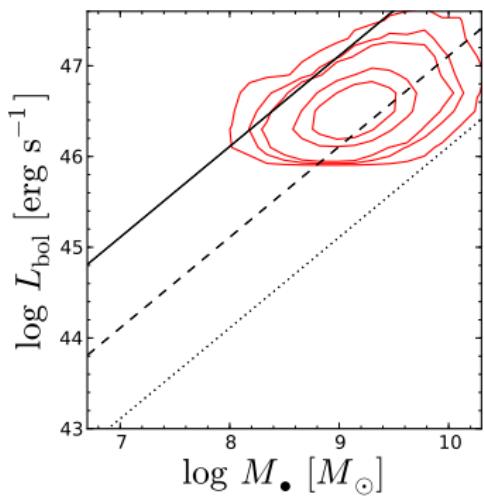
zCOSMOS: $I_{\text{AB}} < 22.5$ $\Omega_{\text{eff}} = 1.6 \text{ deg}^2$
random + X-ray selection

BH demographics from VVDS, zCOSMOS and SDSS

⇒ $1.1 < z < 2.1$

⇒ use MgII BH masses

⇒ SDSS: ~ 28000 AGN



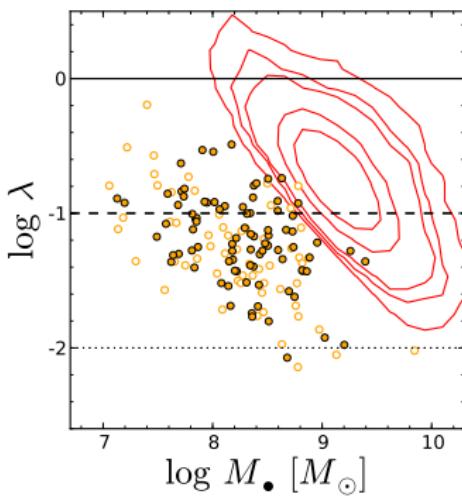
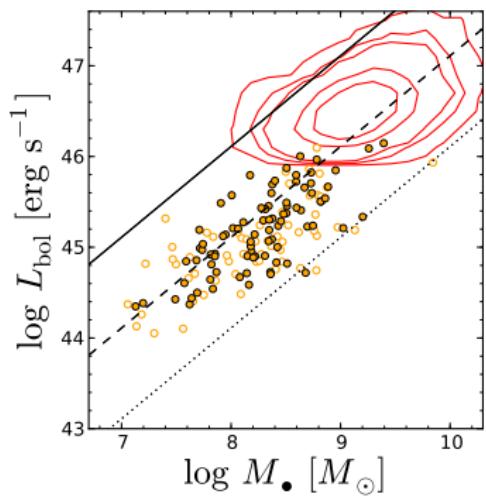
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⇒ VVDS: $86 + 61$ AGN

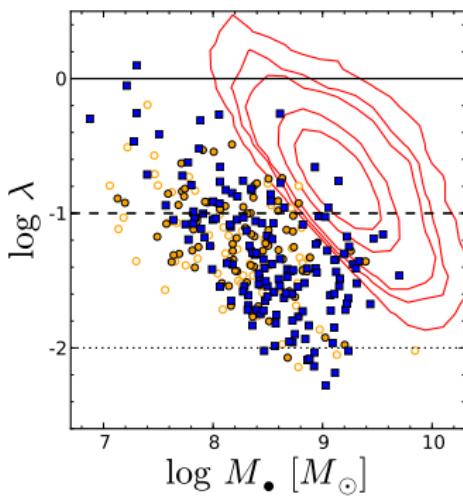
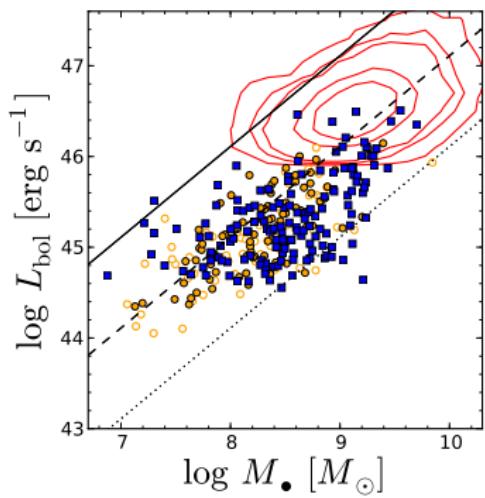


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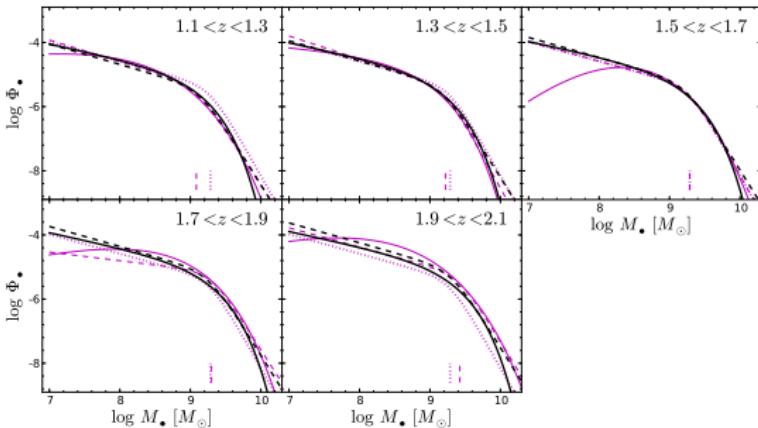
⇒ use MgII BH masses

- ⇒ SDSS: ~ 28000 AGN
- ⇒ VVDS: $86 + 61$ AGN
- ⇒ zCOSMOS: 145 AGN

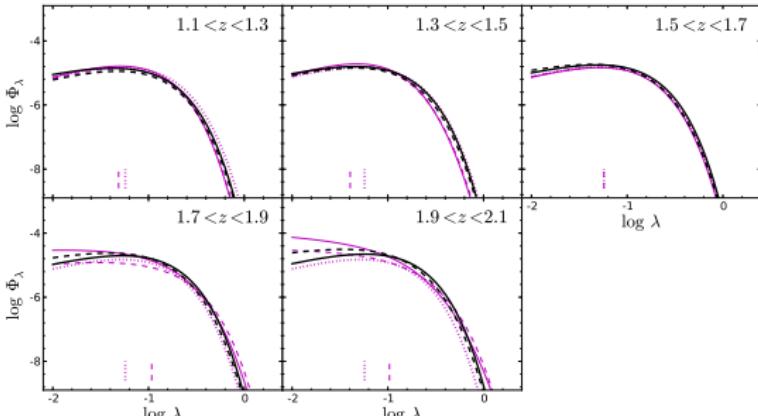


Active black hole demographics at $1 < z < 2$

active black hole
mass function

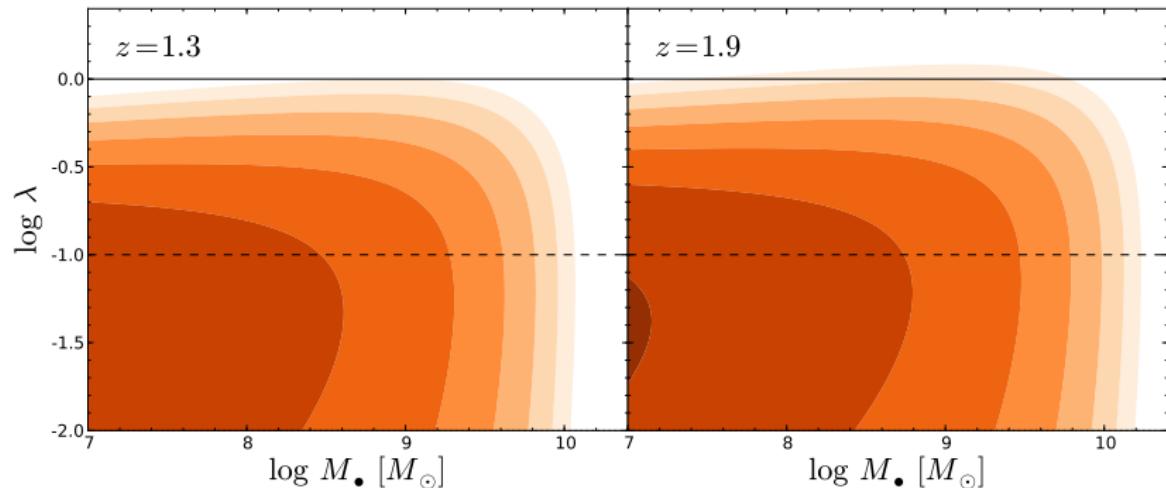


Eddington ratio
distribution function

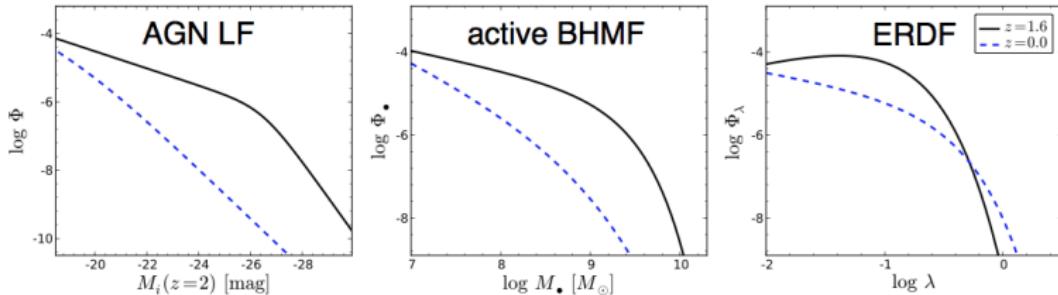


Schulze et al. (2015)

Bivariate distribution function of M_\bullet and λ at $1 < z < 2$

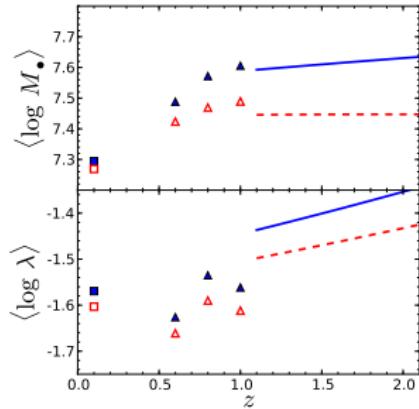


Evolution of the active black hole mass function and Eddington ratio distribution function

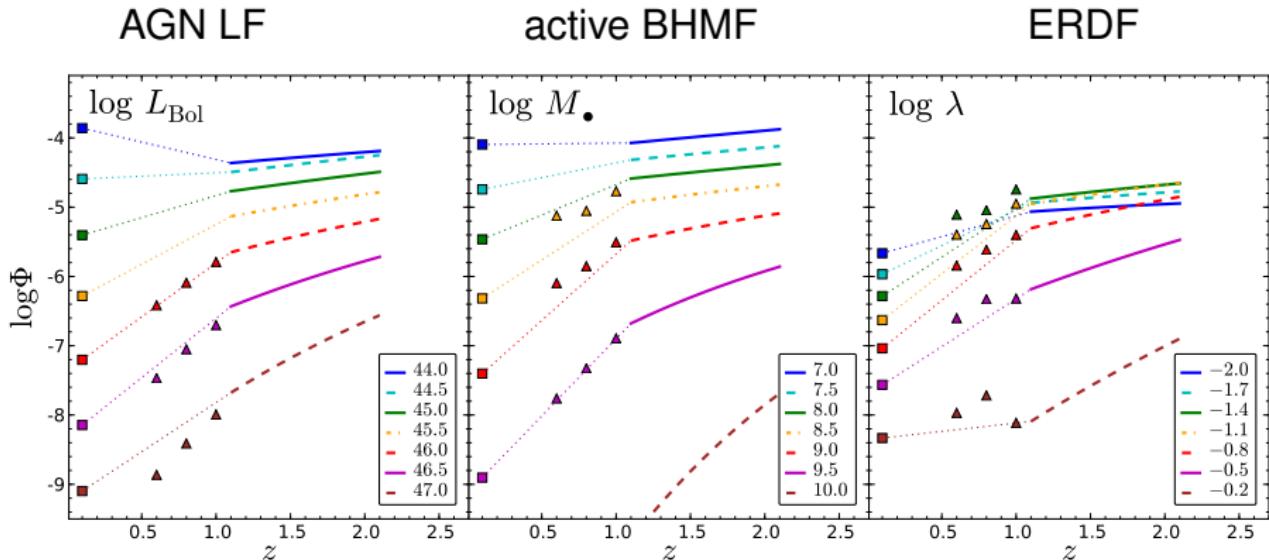


comparison with local distribution functions

- ⇒ strong downsizing in the active BHMF
- ⇒ decrease of average Eddington ratio towards $z = 0$



Evolution of the AGN space density

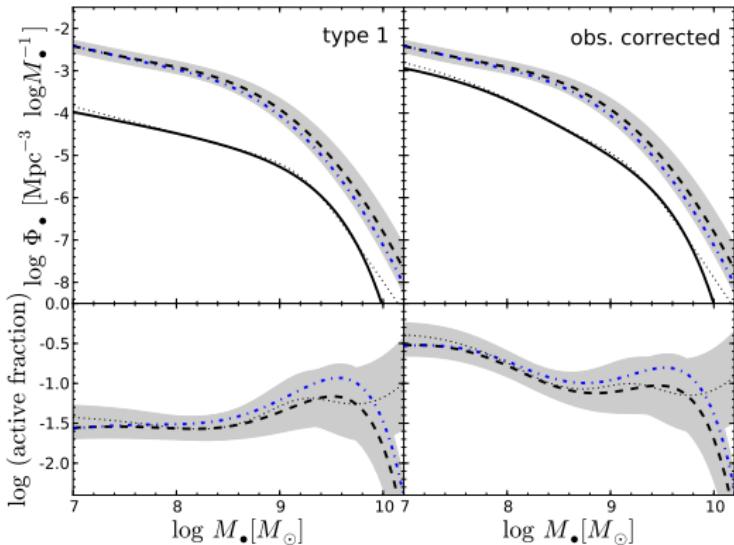


- ⇒ strong downsizing in the active BHMF
- ⇒ moderate evolution in ERDF

Active black hole fraction at $z \sim 1.5$

compare to quiescent BHMF derived from stellar mass function

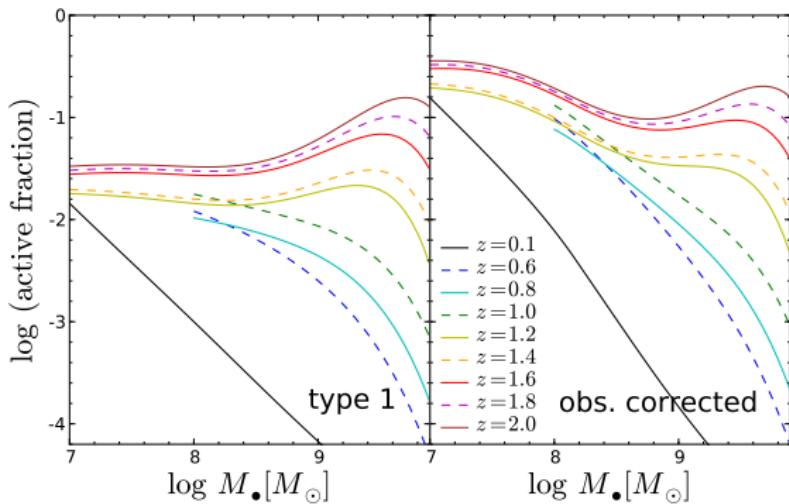
at $z \approx 1.5$ broad line AGN active fraction almost independent of M_\bullet



The evolution of the active black hole fraction

weak evolution at
 $\sim 10^7 M_\bullet$

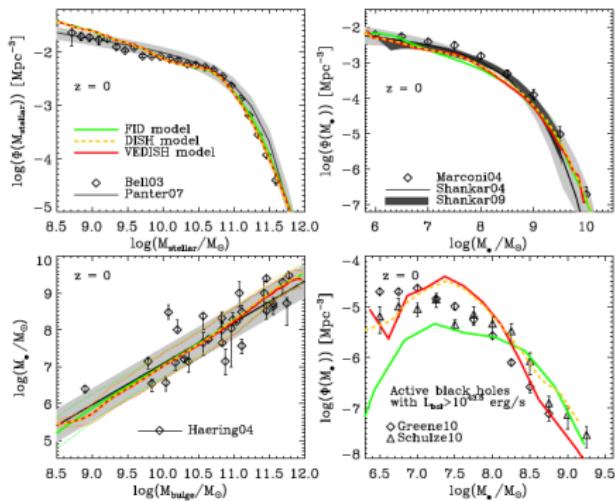
strong evolution
at $> 10^9 M_\bullet$



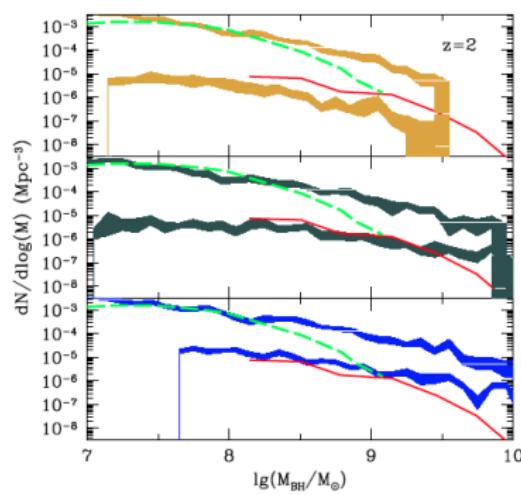
⇒ witness shutoff of black hole growth at the high mass end between
 $z = 2$ and $z = 0$

Constraints on theoretical models

- ⇒ comparison with galaxy evolution models
- ⇒ discriminate between different models of galaxy evolution, AGN feedback, SMBH seeds



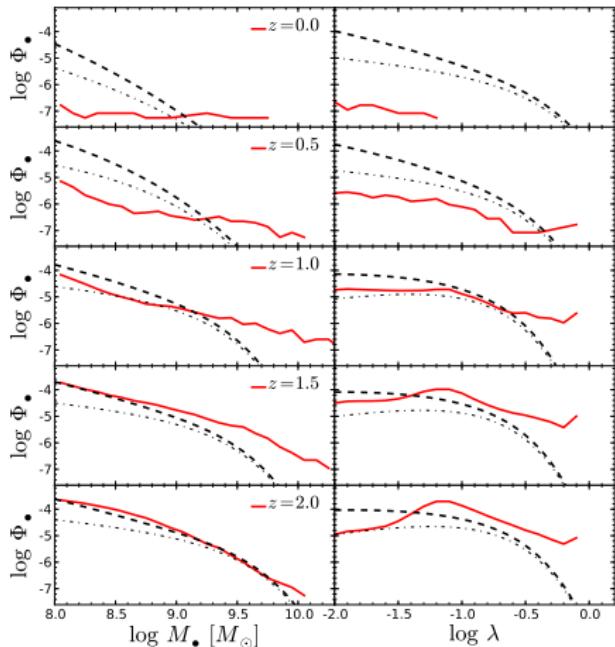
Hirschmann et al. (2012)



Natarajan & Volonteri (2012)

Comparison with numerical simulations

- comparison with simulation from Hirschmann et al. (2014)
 - ⇒ good match at $z > 1$ and $M_\bullet < 10^{9.5}$
 - ⇒ disagreement at low- z and high $M_\bullet \Rightarrow$ caused by radio-mode AGN feedback implementation



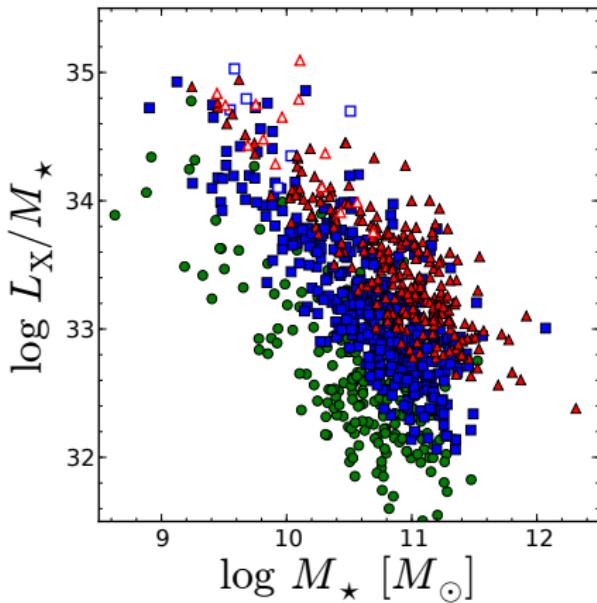
Schulze et al. (2015)

AGN host galaxy mass function in COSMOS

determine the AGN host galaxy mass function

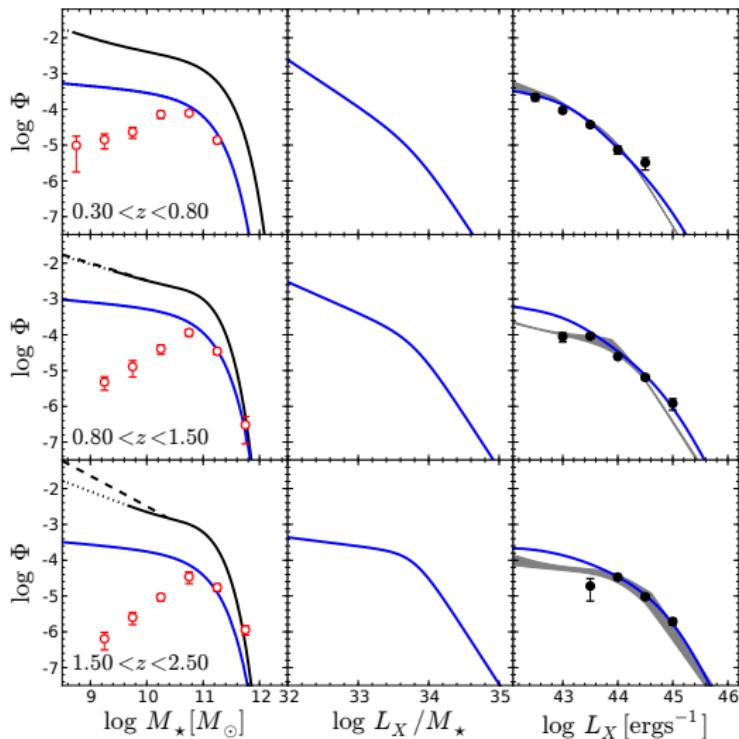
Sample: hard X-ray selected AGN from XMM-COSMOS

- ⇒ 915 AGN in redshift range
 $0.3 < z < 2.5$
- ⇒ M_\star from SED fitting
- ⇒ account for obscuration via N_H distribution
- ⇒ define AGN by cut in specific accretion rate $\log L_X/M_\star > 32$
- ⇒ AGN X-ray LF used as additional constraint



Bongiorno, AS et al. (in prep.)

Joint distribution function of M_\star and L_X/M_\star

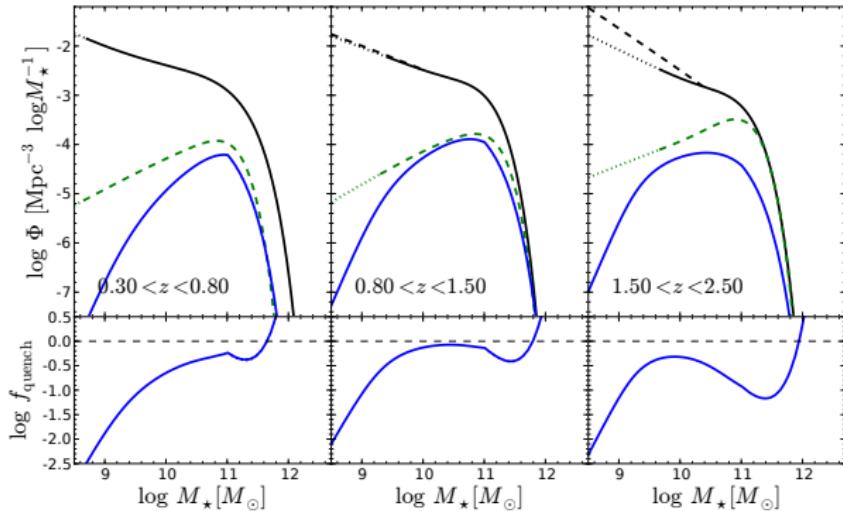


Bongiorno, AS et al. (in prep.)

AGN as driver for mass quenching of galaxies?

Compare:

- ⇒ mass function of galaxies in the process of being mass-quenched, based on Peng et al. (2010) model
- ⇒ AGN host galaxy mass function of luminous AGN ($\log L_X > 43$)



luminous AGN can accommodate quenched galaxy population at $\log M_* > 9.5$

Conclusions

- active BHMF and ERDF provide additional observational constraints on BH growth and galaxy evolution
- established at $z < 2$
 - ⇒ downsizing in AGN LF mainly driven by downsizing in the BHMF
 - ⇒ shutoff of black hole growth at the high mass end from $z = 2$ to $z = 0$
 - ⇒ new observational constraints for theoretical models of galaxy formation and BH growth
- determined AGN host galaxy mass function at $0.3 < z < 2.5$
 - ⇒ luminous AGN population consistent with mass quenching of massive galaxies